28th Alaska Health Summit, January 10-13, 2011

Wastewater treatment in cold/arctic climate with a focus on small scale and onsite systems

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Department of Plant- and Environmental Sciences
Norwegian University of Life Sciences (UMB)

Extremely cold climate

Large areas - extremely low population density

island

one

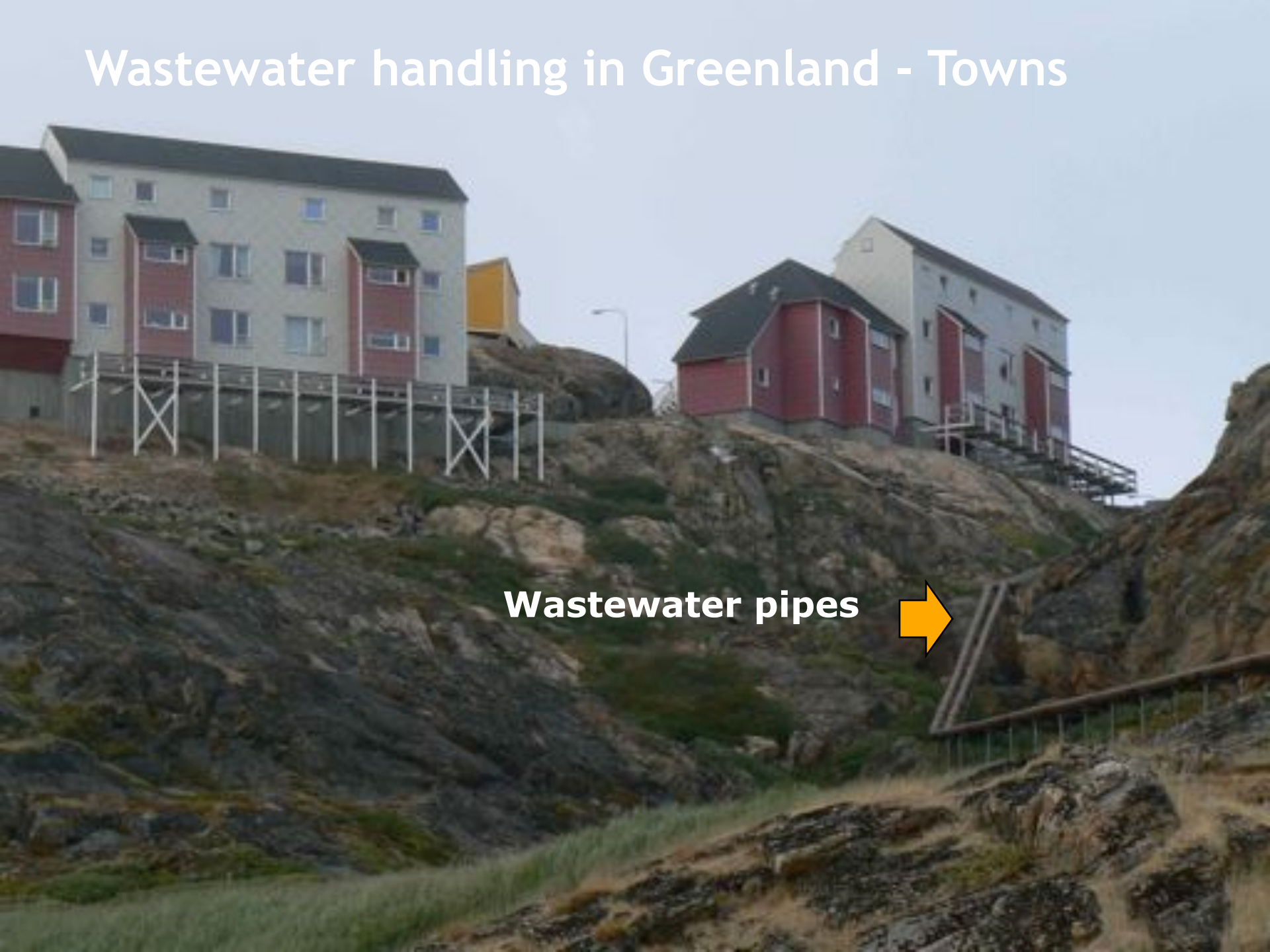
Sisimiut Greenland, 5000 people (2500 dogs)

Low income - poor communities


Social stress


Water pipe

Wastewater handling in Greenland - Towns




Sewer outlet

Wastewater handling in Greenland - towns and smaller settlements

Wastewater handling in Greenland - towns and smaller settlements

” Honey buckets”

Smell !
Dignity !
Health risk !

Sewage outlet


Greywater outlet


Frozen greywater


Greywater discharge pipe

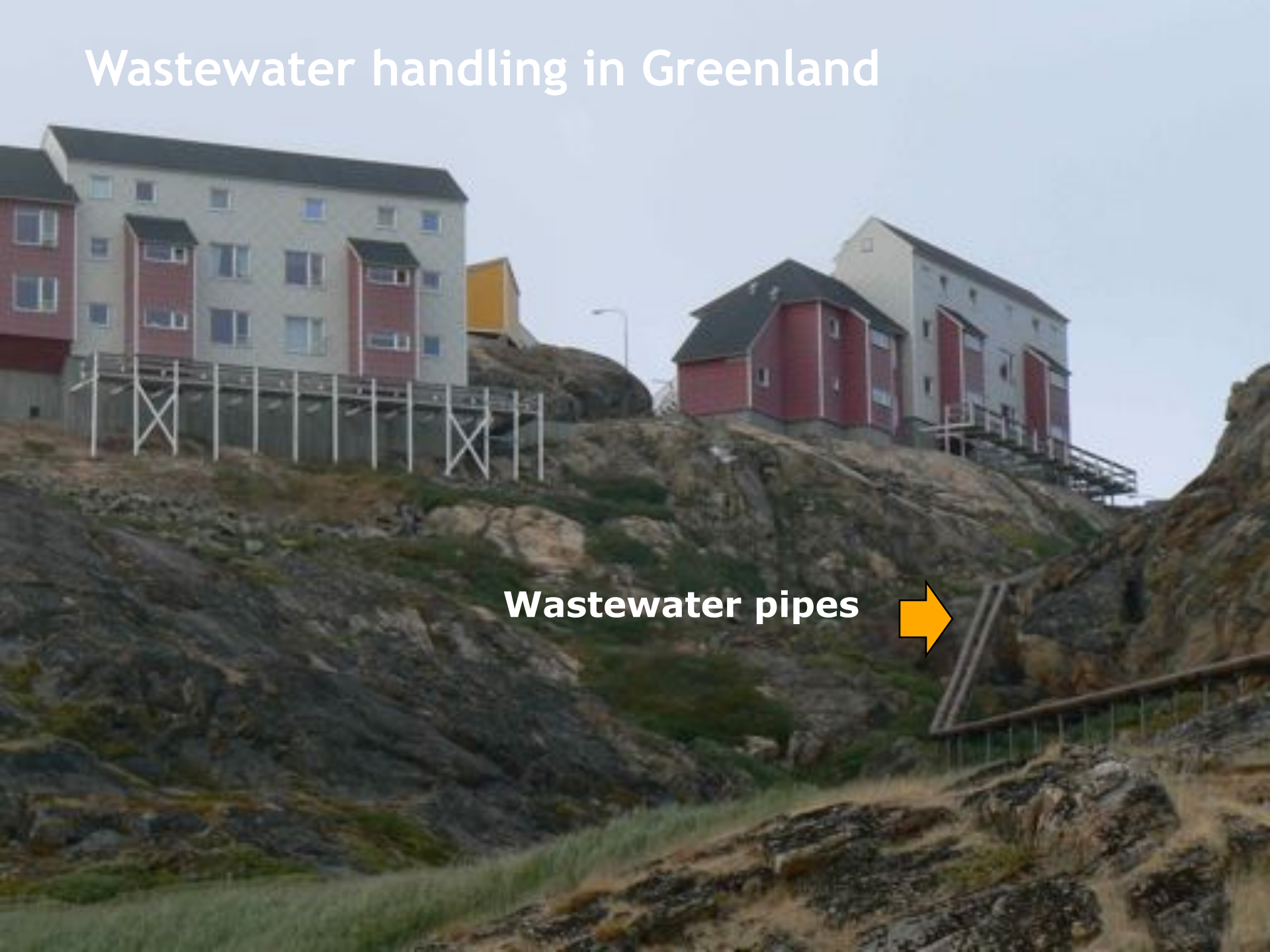
Handling of wastewater in the Arctic

- Wastewater is led untreated to the recipients everywhere in Greenland
- WHY IS WASTEWATER HANDLING POORLY DEVELOPED
- WHAT ARE THE CONSEQUENCES FOR THE WATER ENVIRONMENT?

Wastewater transport in the arctic is challenging
Piping systems

Photos: Frøydis M. Reinhart

Wastewater handling in Greenland



Wastewater handling in the Arctic

- Piping systems are extremely expensive

Wastewater handling in the Arctic

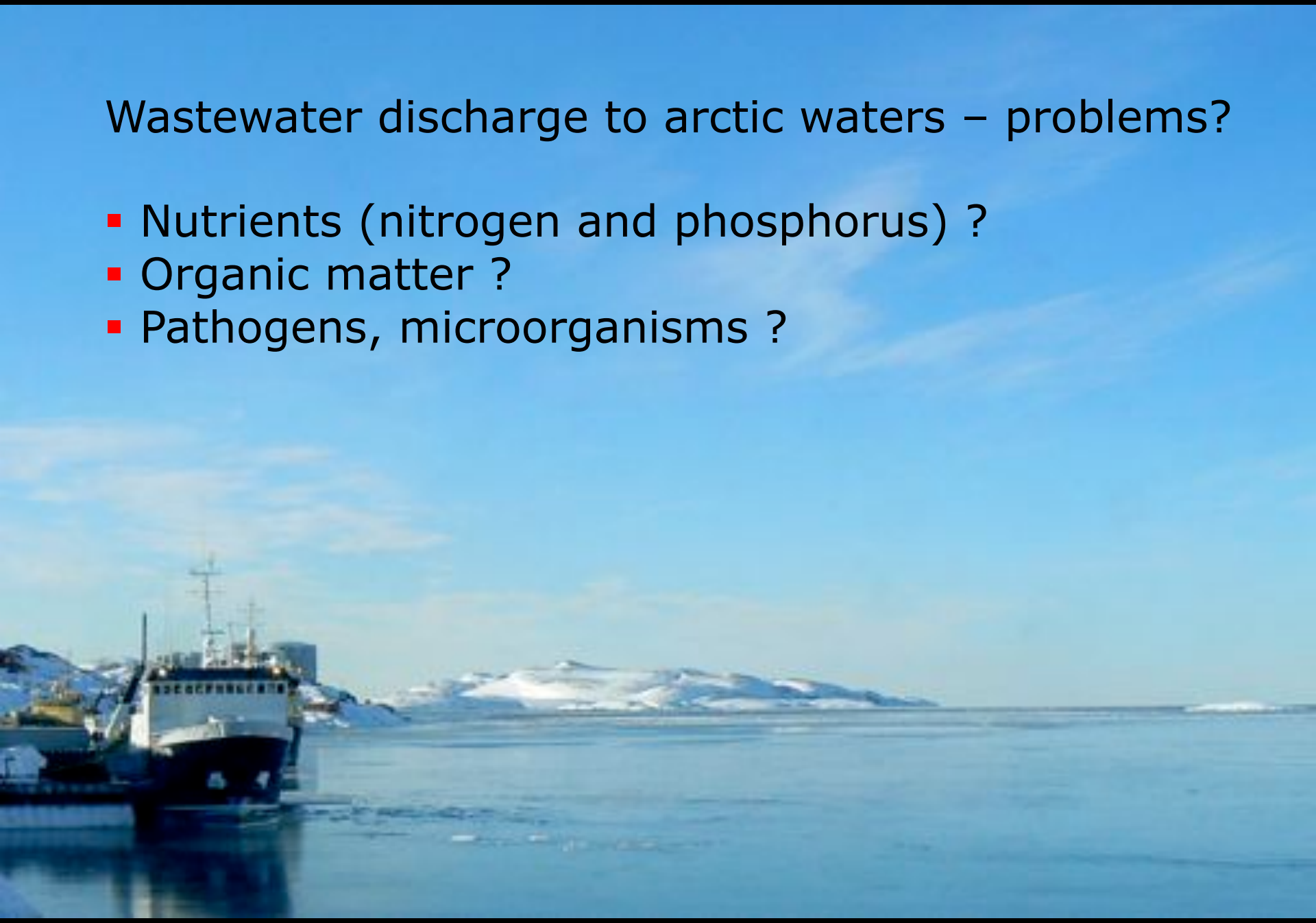
- Piping systems are extremely expensive
- Treatment processes are challenging/ expensive to operate

Handling of wastewater in the Arctic

- Wastewater is led untreated to the recipients everywhere in Greenland
- WHY IS WASTEWATER HANDLING POORLY DEVELOPED?
- WHAT ARE THE CONSEQUENCES FOR THE WATER ENVIRONMENT AND HEALTH?

Wastewater discharge to arctic waters – problems?

- Nutrients (nitrogen and phosphorus) ?
- Organic matter ?
- Pathogens, microorganisms ?



Wastewater discharge to arctic waters – problems?

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Wastewater discharge to arctic waters – problems?

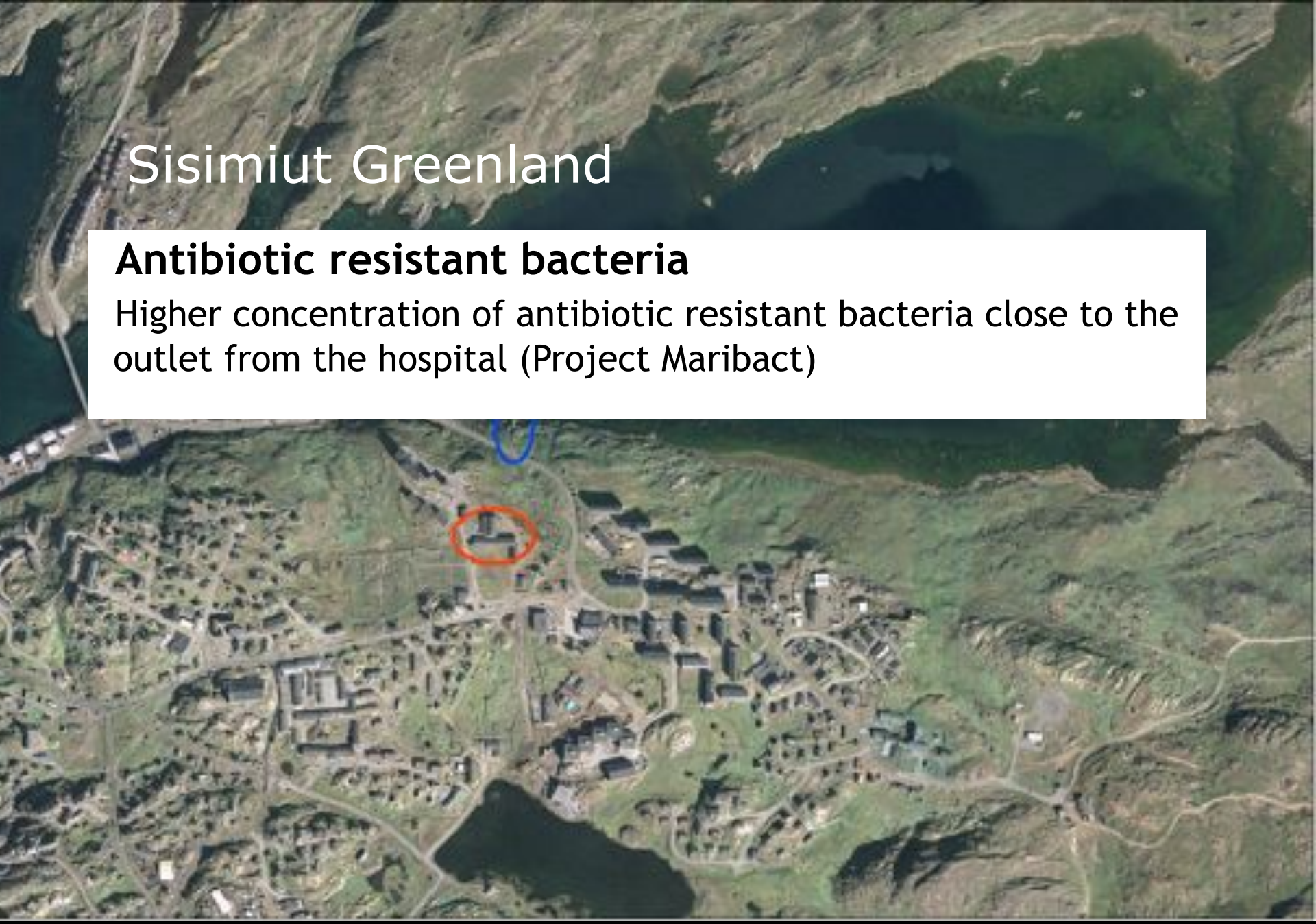
- Nutrients (nitrogen and phosphorus) ?
- Organic matter a local problem
- Pathogens, microorganisms?


Sisimiut Greenland
Sewage outlet
Hospital

Sisimiut Greenland

Antibiotic resistant bacteria

Higher concentration of antibiotic resistant bacteria close to the outlet from the hospital (Project Maribact)



Sisimiut Greenland

Antibiotic resistant bacteria

Higher concentration of antibiotic resistant bacteria close to the outlet from the hospital (Project Maribact)

Pharmaceutical residues

It has been shown that hormones for instance affect fish at remarkably low concentration (1,0 ng/L) (Routledge *et al*., 1998, Purdom *et al*., 1994*)*

Accumulation of unwanted substances in the food chain

Wastewater discharge to arctic waters – problems?

- Nutrients - no problem
- Organic matter a local problem
- Antibiotic resistant bacteria
- **Organic micropollutants**
  - * Medicine residues
  - * POP´s

Solutions to the sanitary challenges

- Centralized systems
- Onsite systems (decentralized)
- Systems with source separation (decentralized)
  - Low flush, dry or incineration toilets
  - Urine divertion
  - Greywater treatment

Solutions to the sanitary challenges

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Wastewater handling in the Arctic

- Piping systems are extremely expensive
- Treatment processes are challenging/ expensive to operate

Cost aspects of of centralized sewer systems

- Collection system **70 - 90 %**
- Treatment **10 - 30 %**

(Otis 1996, Mork et al. 2000)

Cost aspects of of centralized sewer systems

- Collection system **70 - 90 %**
- Treatment **10 - 30 %**

(Otis 1996, Mork et al. 2000)

ENERGY:

- The water sector is the forth most energy intensive sector in the UK

(The Parliamentary Office of Science and Technology, 2007)

Centralized vs. decentralized

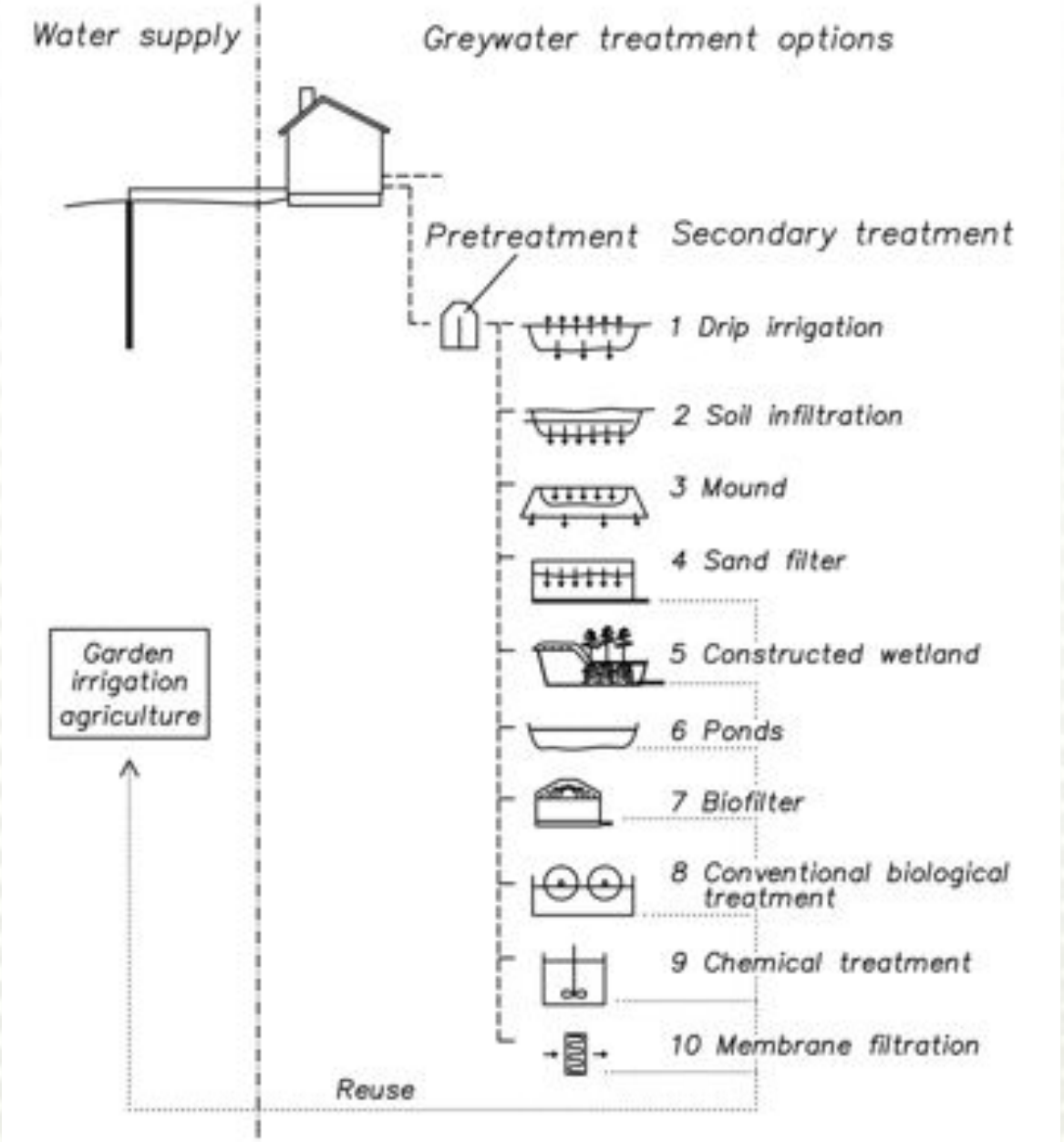
Photo: F. Reinhardt

- **Centralized systems are expensive both to construct and to operate. If adequate decentralized systems (from a technical, economical and social aspect) are available these should be preferred**

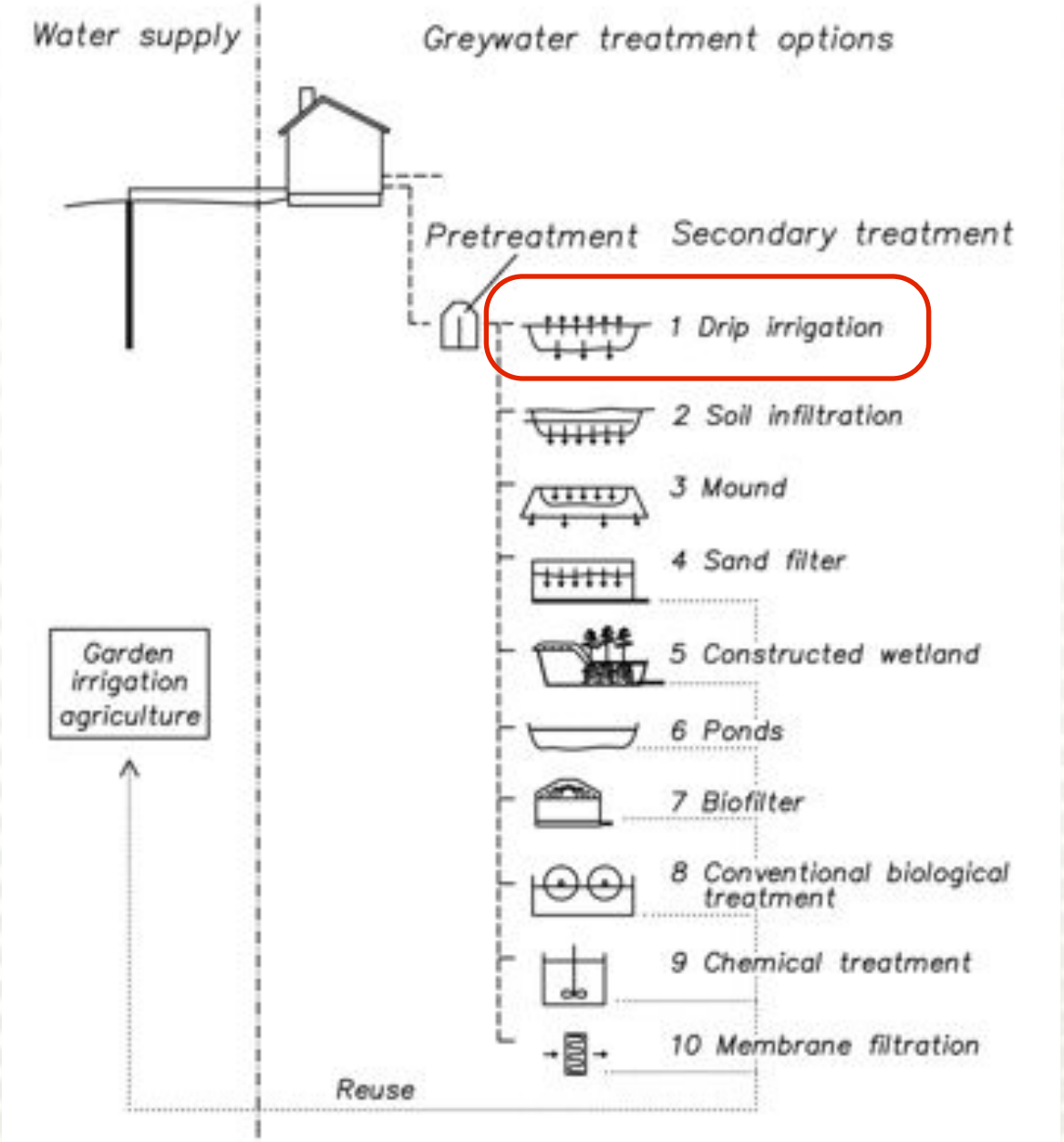
Solutions to the sanitary challenges

- Centralized systems
- **Onsite systems (decentralized)**
- Systems with source separation (decentralized)
  - Low flush, dry or incineration toilets
  - Urine divertion
  - Greywater treatment

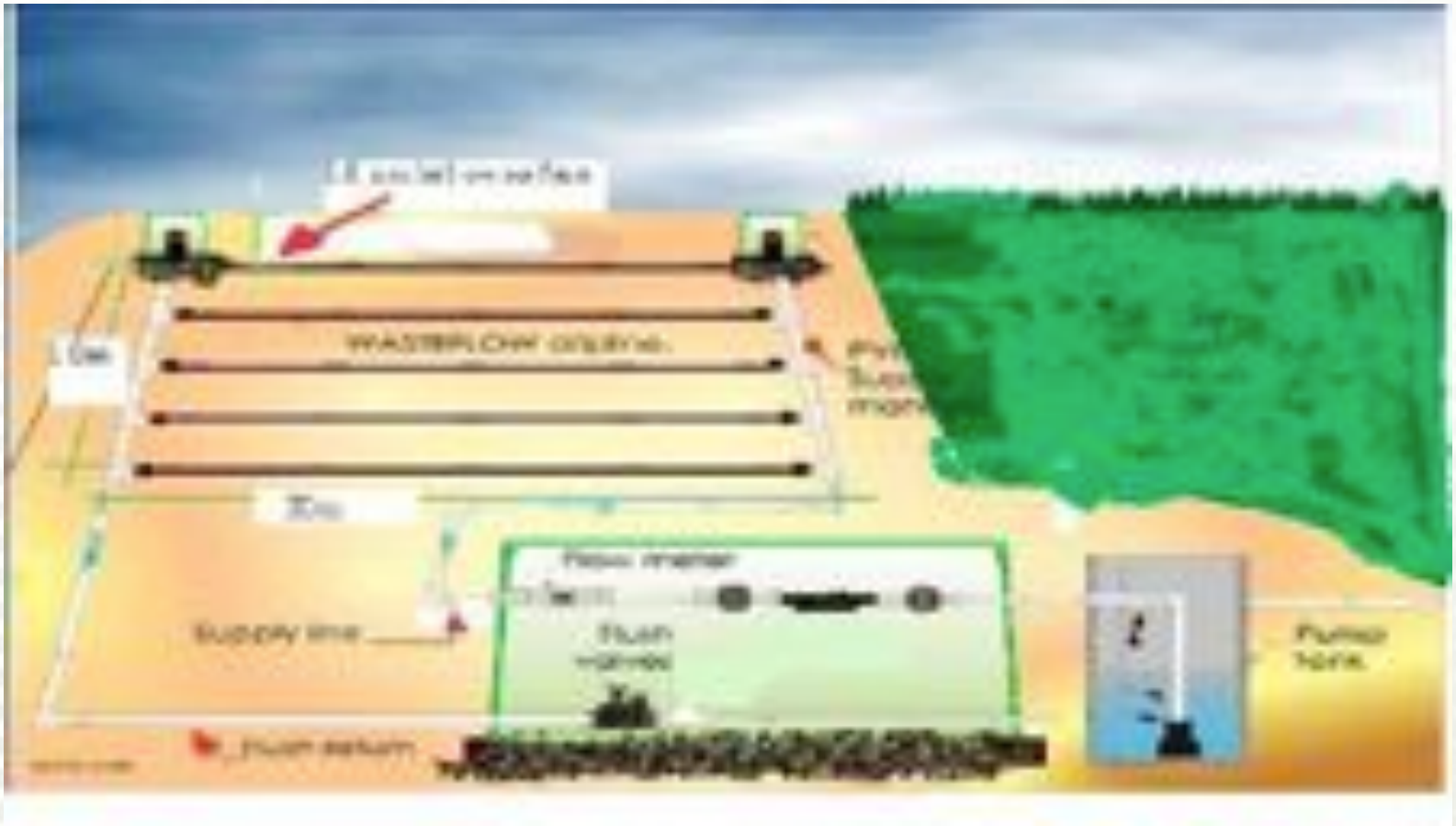
Onsite systems - technology options



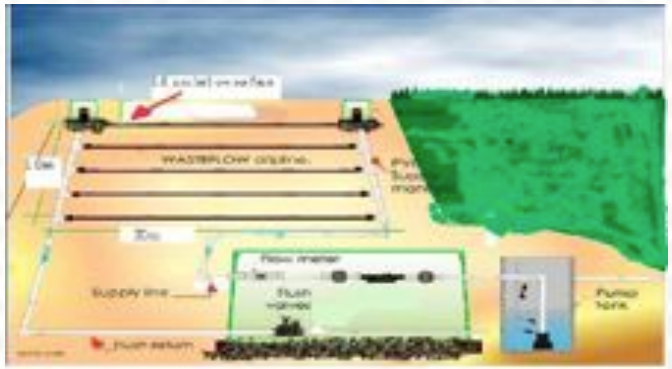
Onsite systems



Drip irrigation

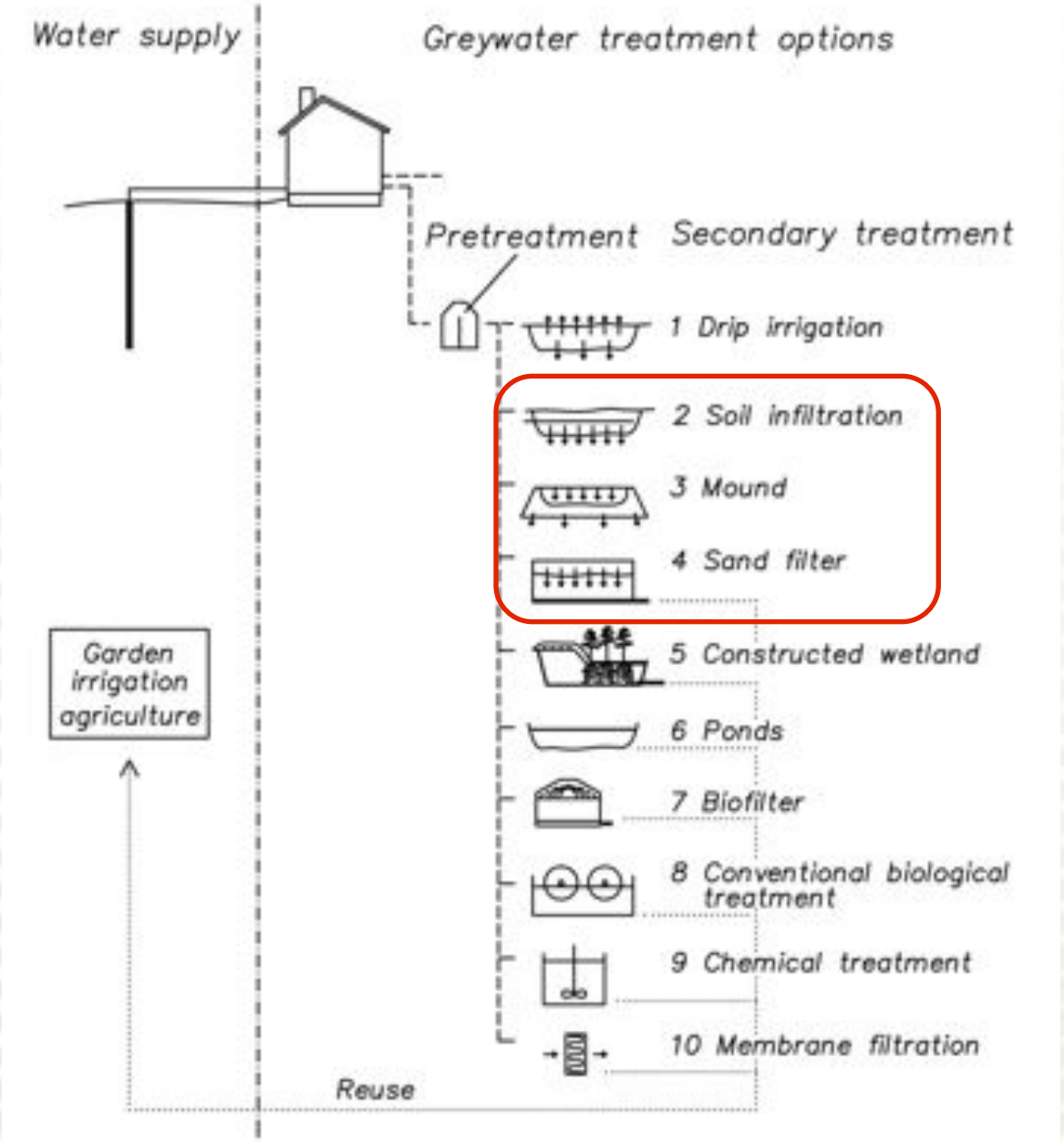


Drip irrigation



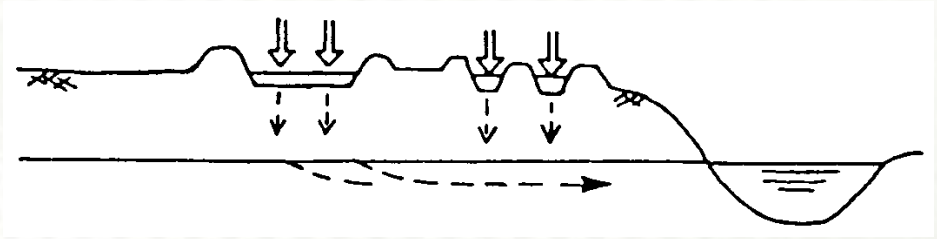
Treatment performance Overall	High
Treatment performance Hygiene	High
Investment cost	Medium/ high
O&M	Medium
Technical complexity	Low/ medium
Suitability arctic conditions	Low/ medium

Onsite systems

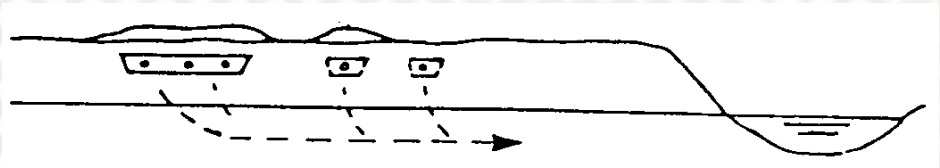


Soil infiltration systems - system types

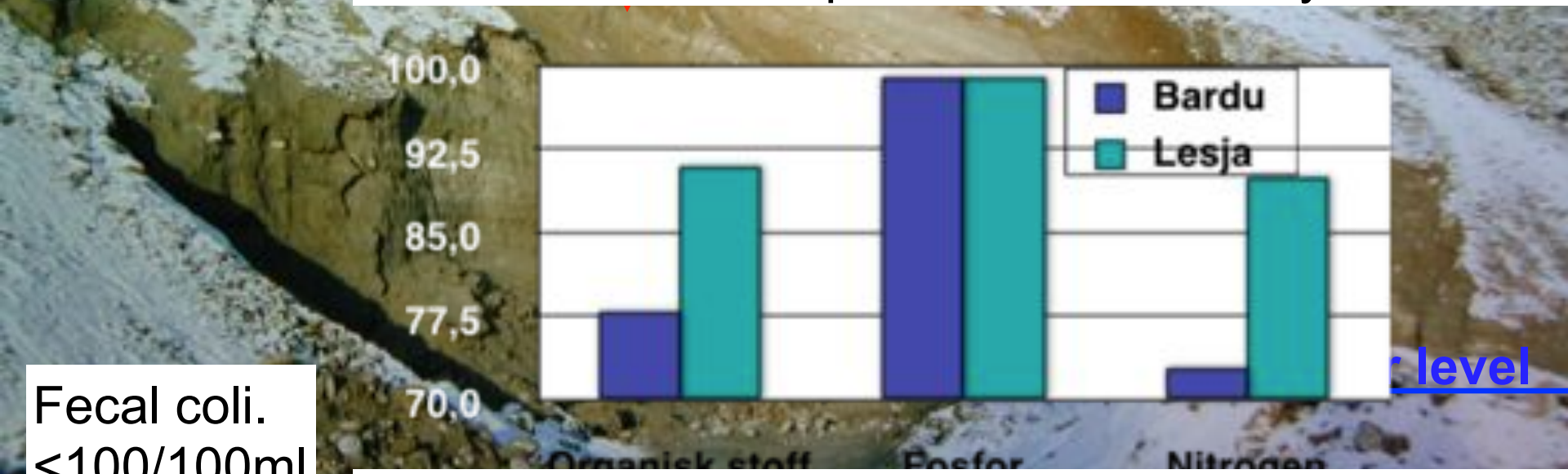
Open systems - infiltration in ponds



Subsurface (buried) systems - infiltration trenches



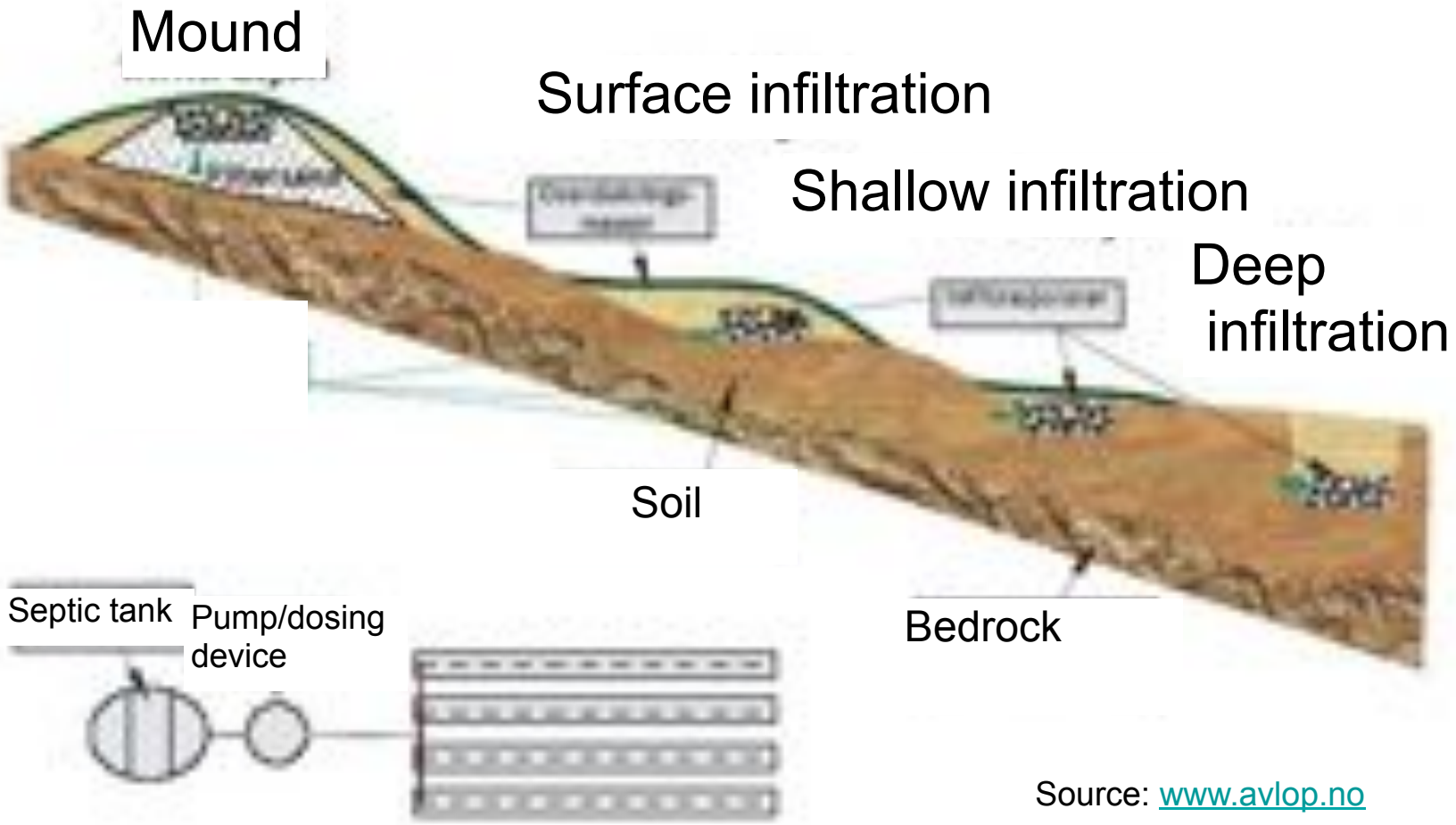
Treatment results rapid infiltration Norway



Fecal coli.
<100/100ml

COD Phosphorus Nitrogen (Kraft 1998)

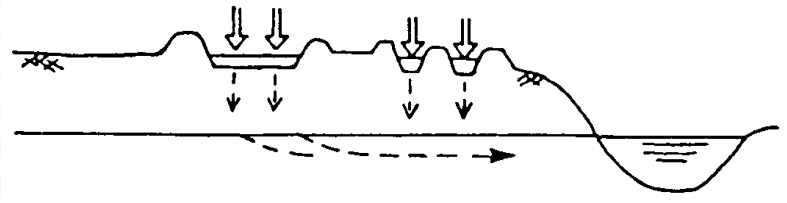
Buried soil infiltration systems - design types



Source: www.avlop.no

Soil infiltration systems

Open systems - infiltration in ponds



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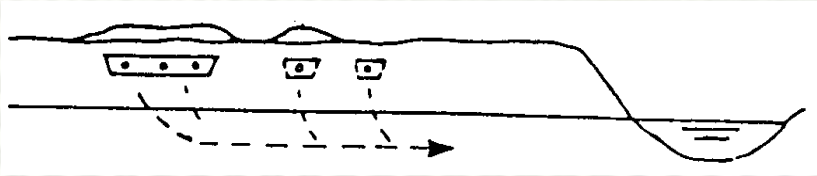
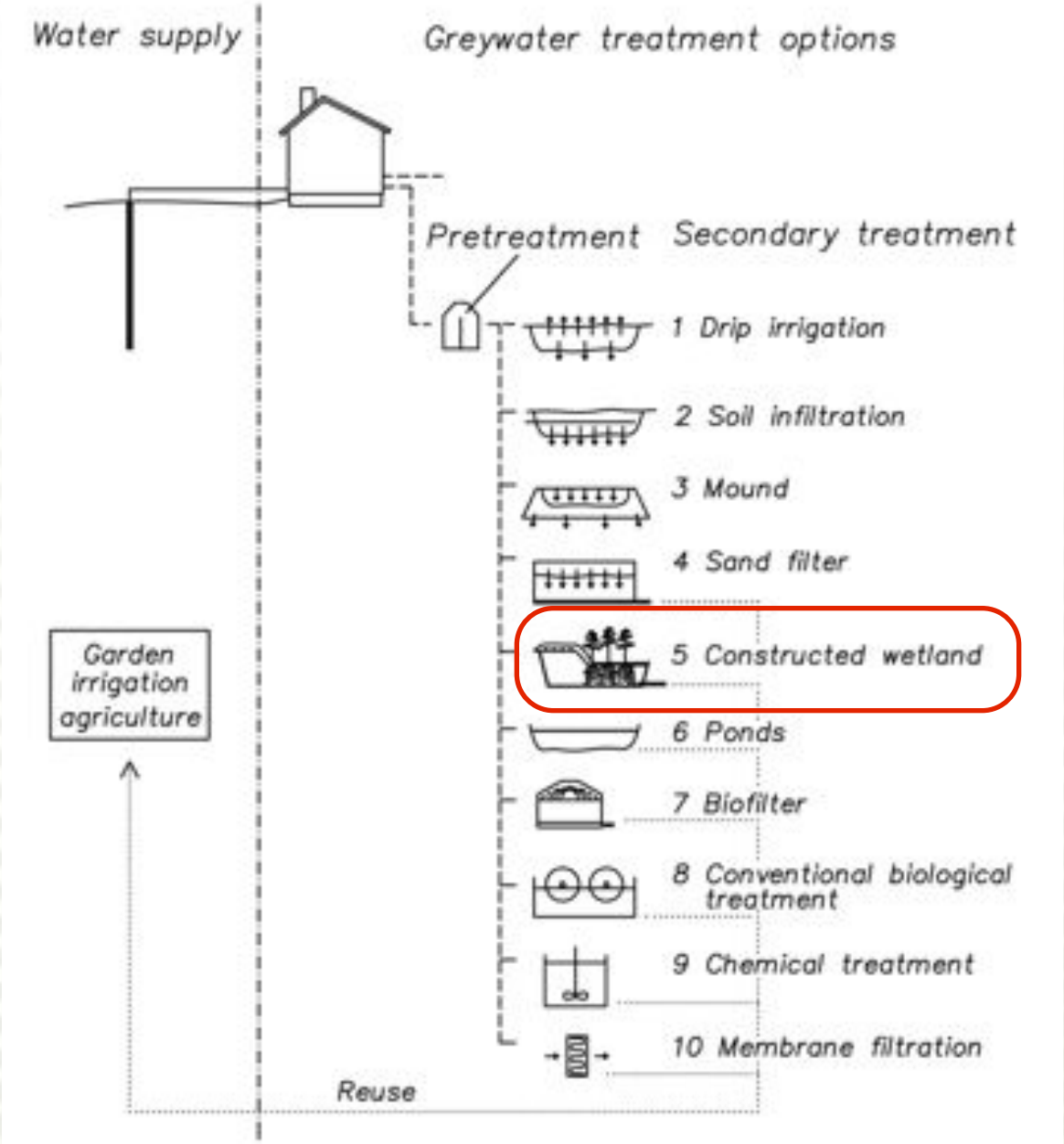


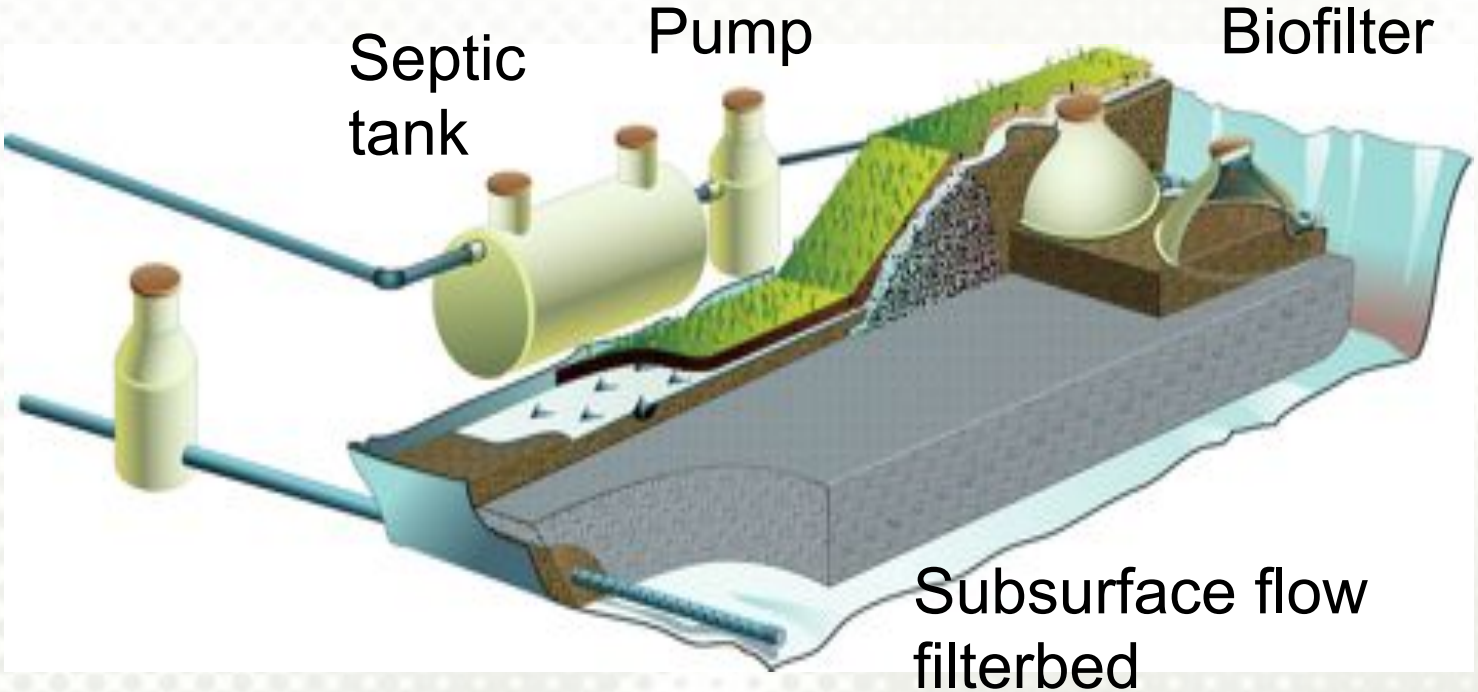
Treatment performance Overall	High
Treatment performance Hygiene	High
Investment cost	Low
O&M	Low
Technical complexity	Low/ medium
Suitability arctic conditions	Low/ medium

Onsite systems

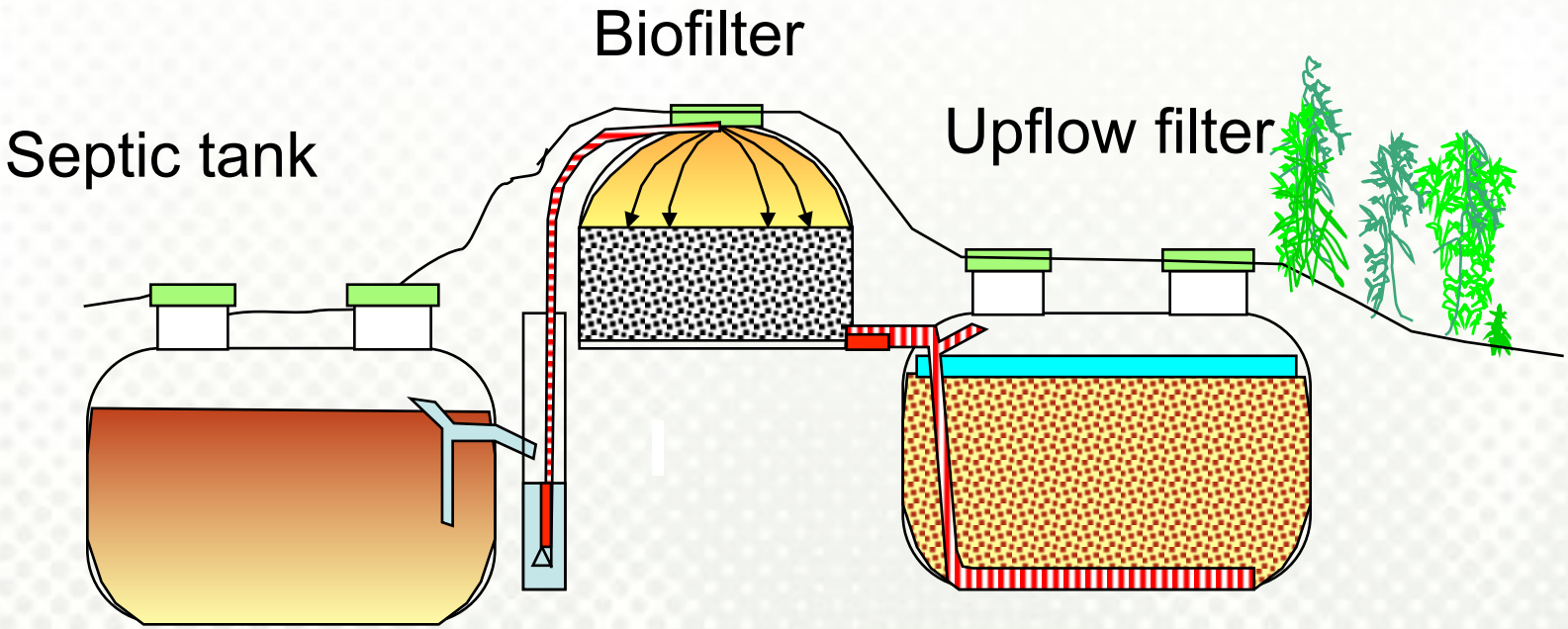


Constructed wetlands / filterbeds

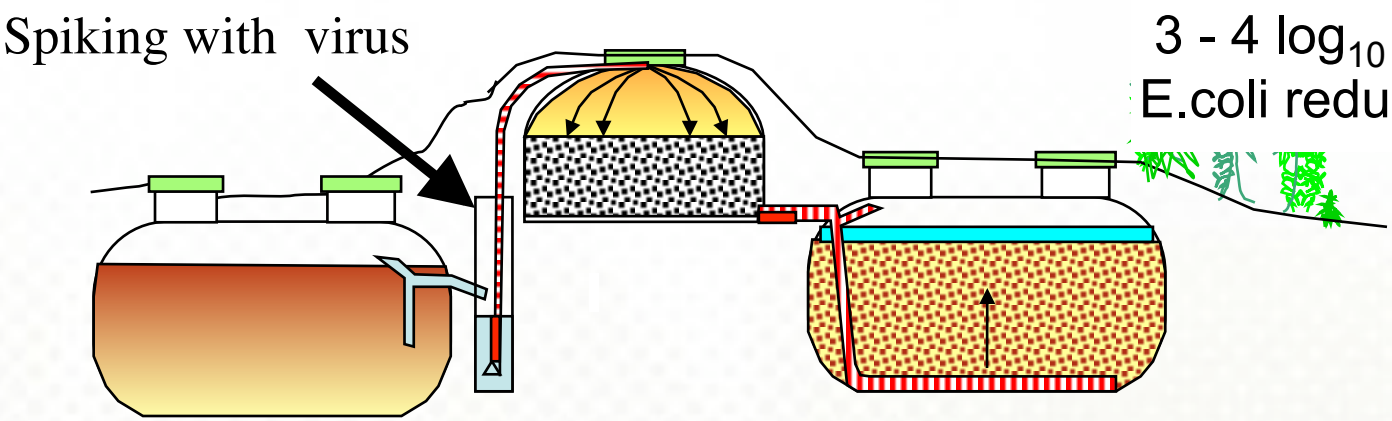
Constructed wetland/Filterbed



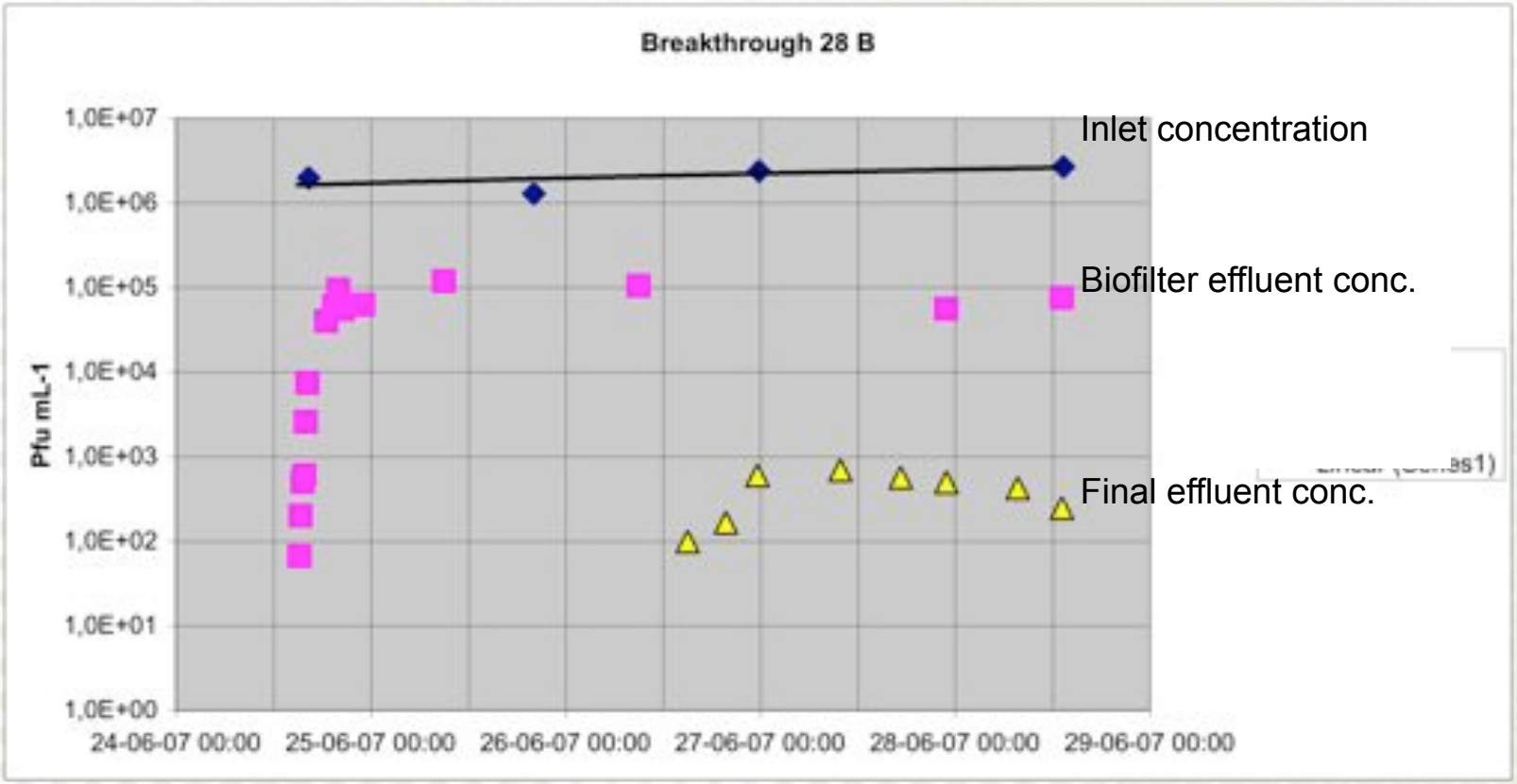
Compact filterbed



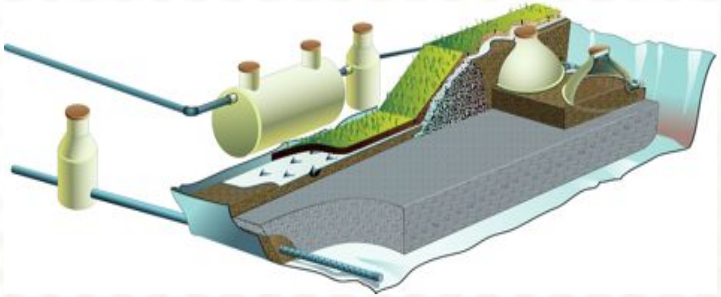
COMPACT FILTER

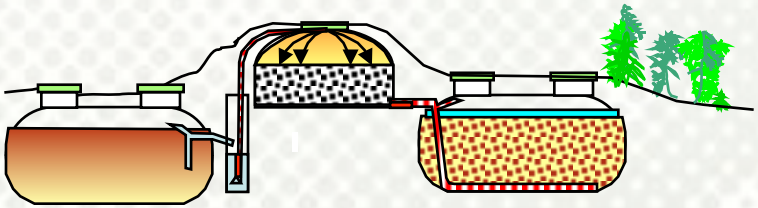


3 - 4 $\log_{10}$ virus and E.coli reduction



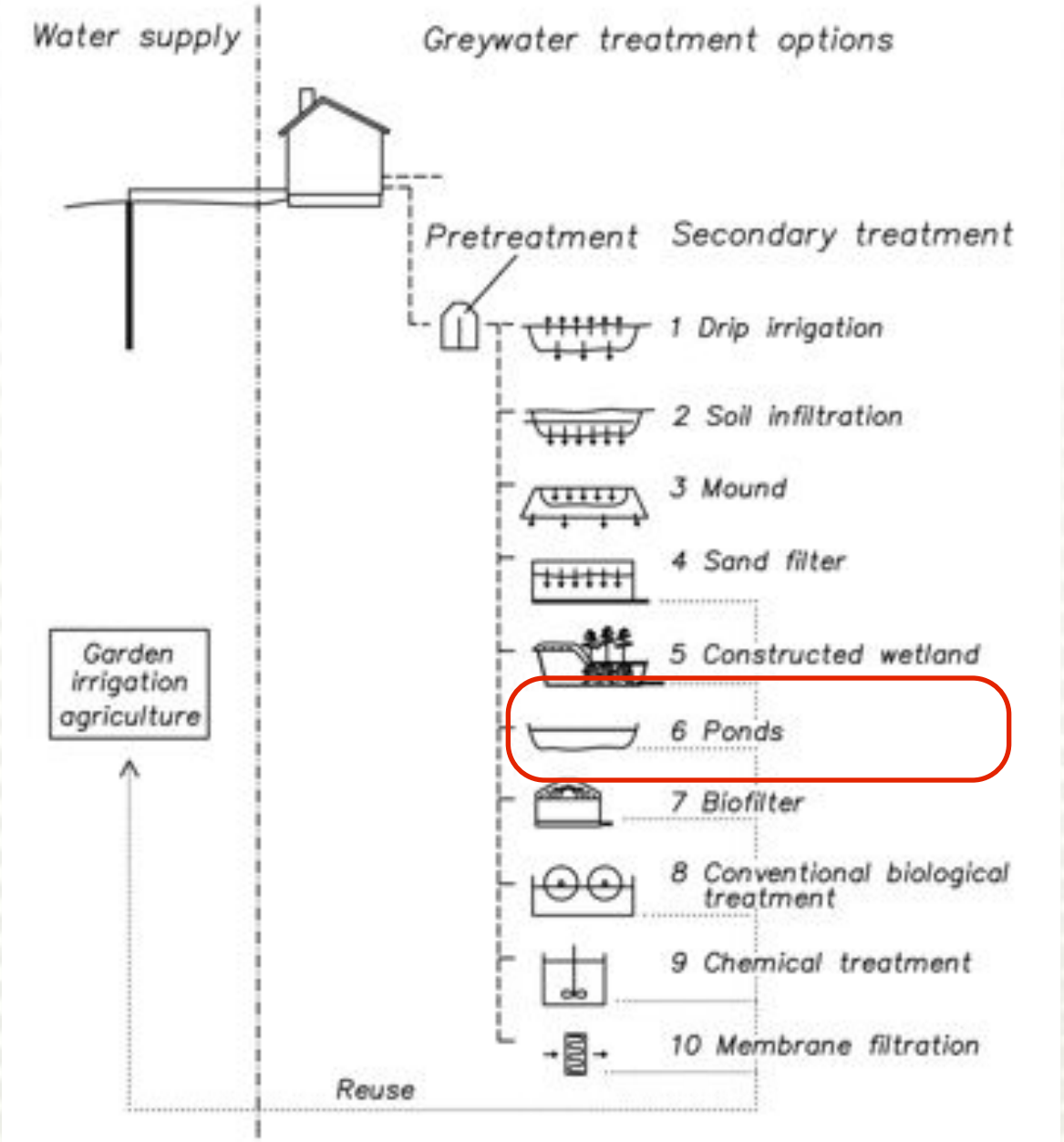
Constructed wetland/Filterbed - verdict





Treatment performance Overall	**High**
Treatment performance Hygiene	**High**
Investment cost	**High / medium**
O&M	**Medium**
Technical complexity	**Medium**
Suitability arctic conditions	**Medium/ high**

Onsite systems



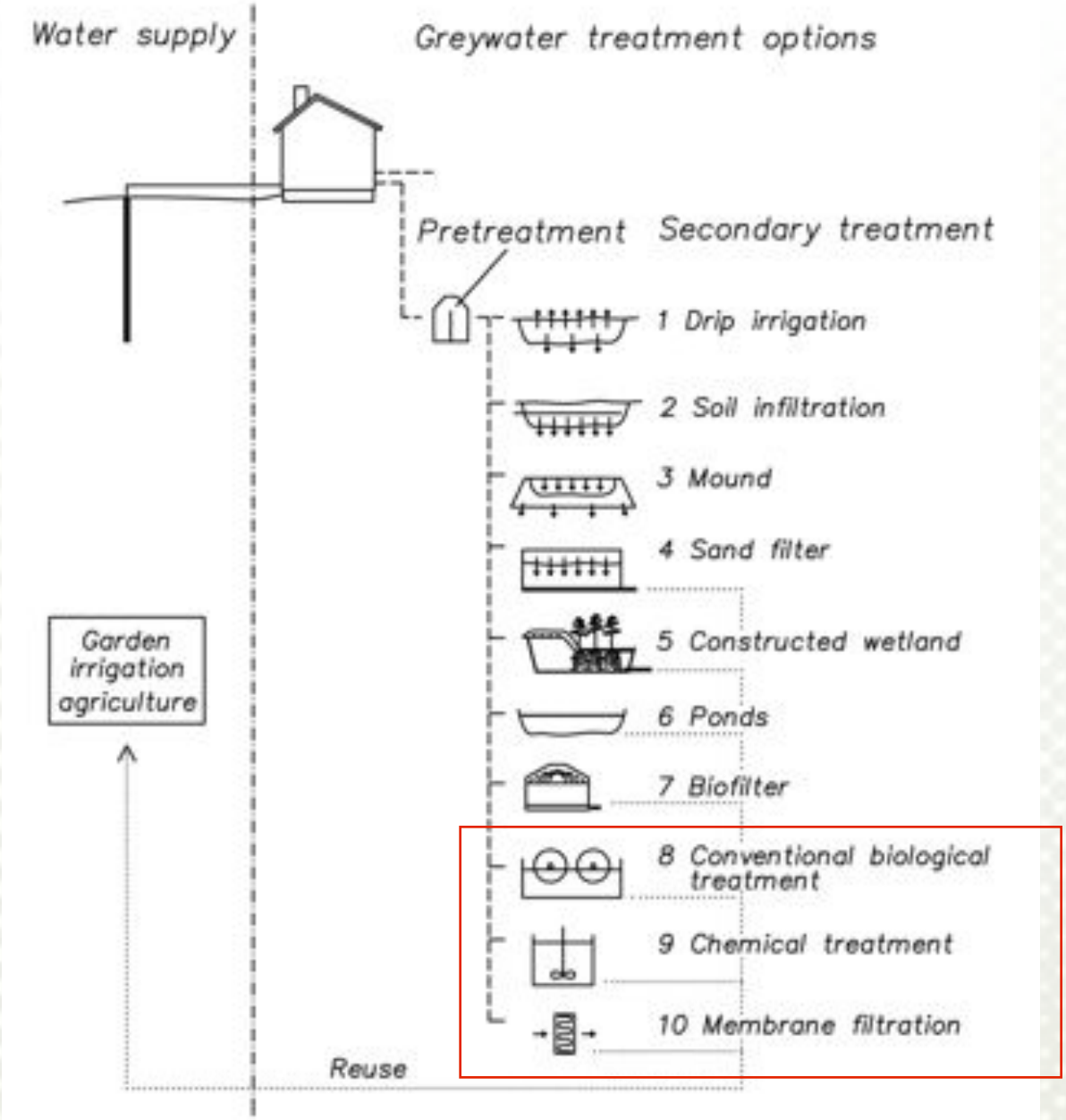
Sewage lagoons/ponds

Sewage lagoons - pond systems

Photo: F. Reinhardt

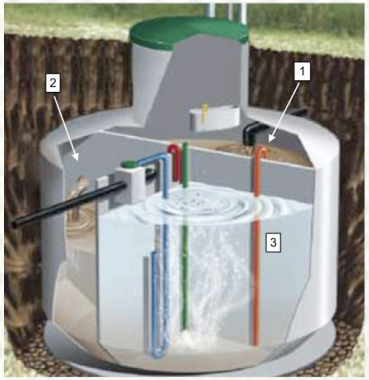
Treatment performance Overall	**Low/ medium**
Treatment performance Hygiene	**Low/ medium**
Investment cost	**Low/ medium**
O&M	**Low/ medium**
Technical complexity	**Low/ medium**
Suitability arctic conditions	**Low/ medium**

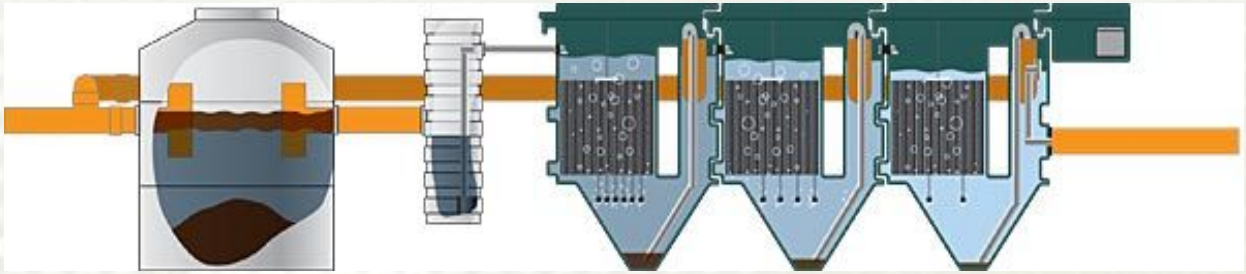
Onsite systems



Package treatment plants - downsized conventional systems

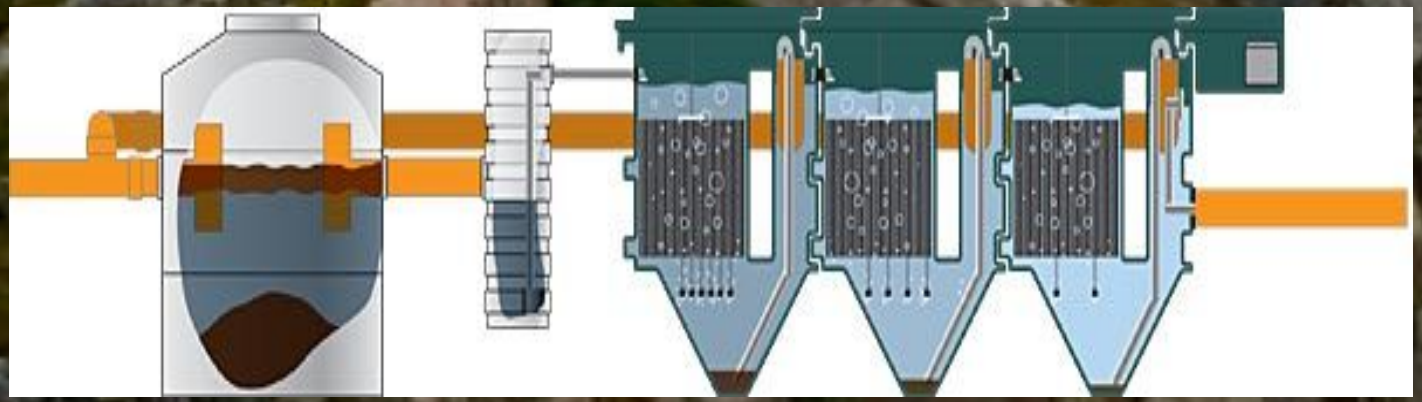
- Different designs





Package treatment plant - Sisimiut

Package treatment plant - Sisimiut



Package treatment plant - Sisimiut

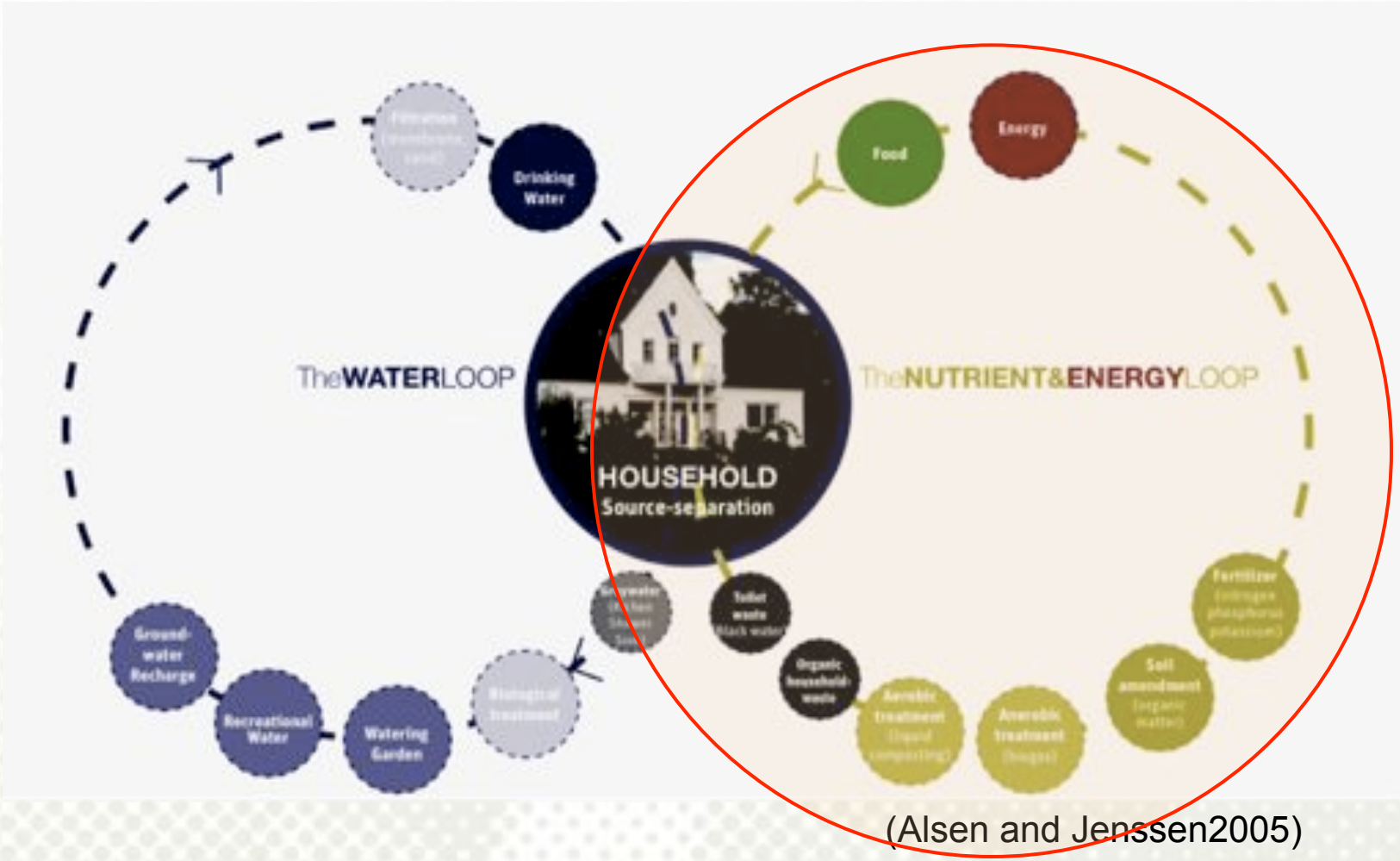
Package treatment systems

Treatment performance Overall	Medium
Treatment performance Hygiene	Low/ medium
Investment cost	High / medium
O&M	High
Technical complexity	High
Suitability arctic conditions	Low

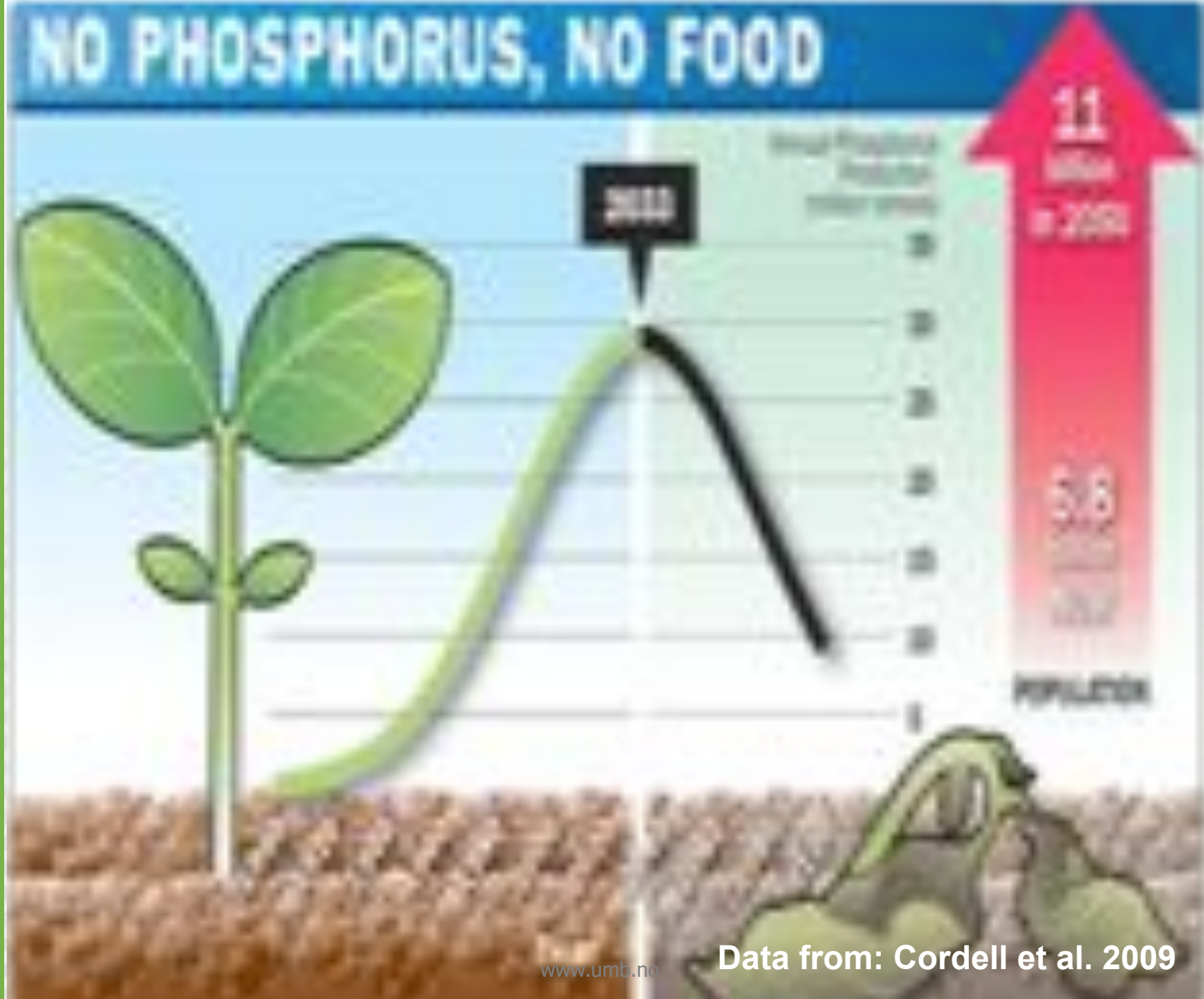
Solutions to the sanitary challenges

- Centralized systems
- Onsite systems (decentralized)
- **Systems with source separation (decentralized)**
  - Low flush, dry or incineration toilets
  - Urine divertion
  - Greywater treatment

Source separation of wastewater

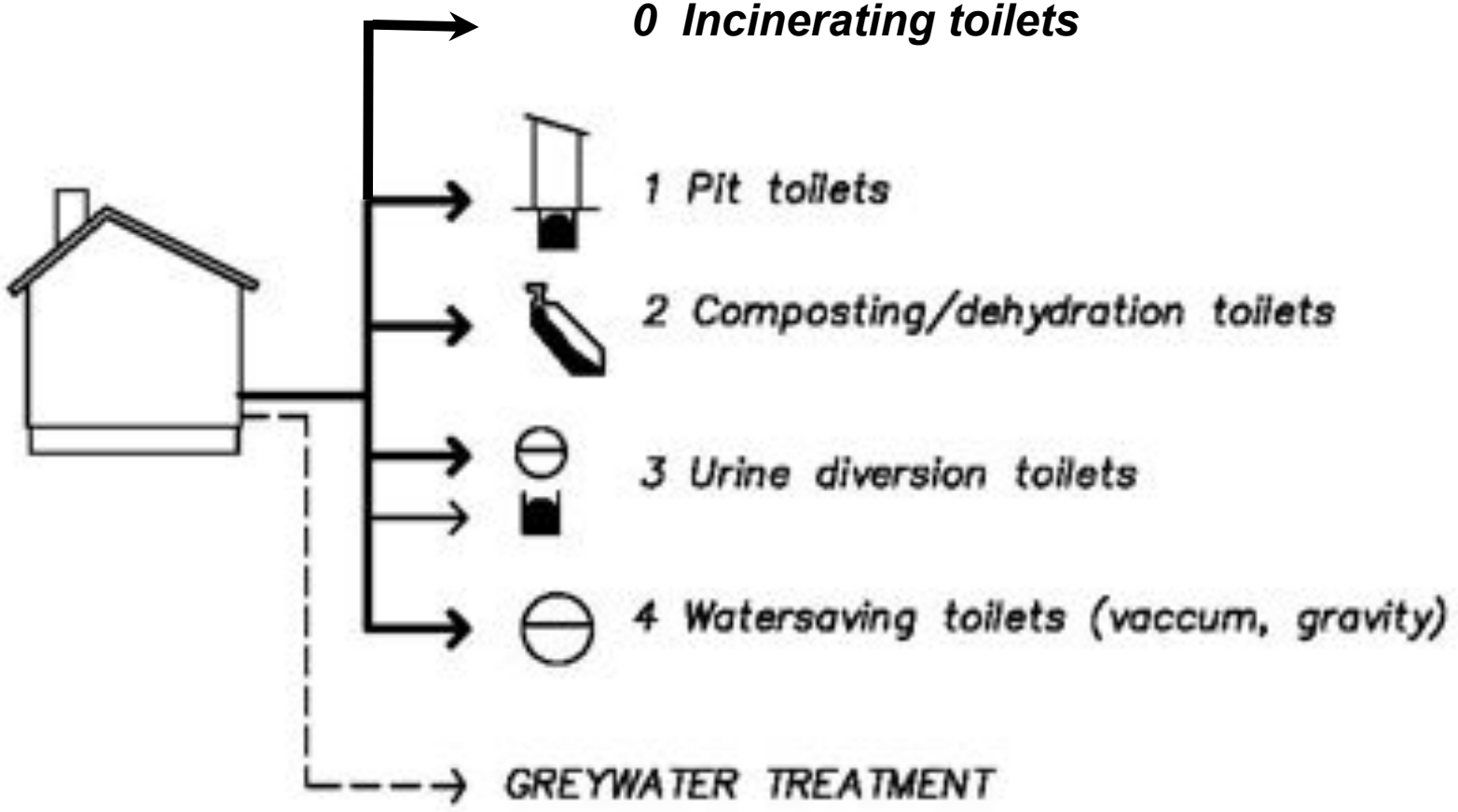


(Alsen and Jenssen2005)

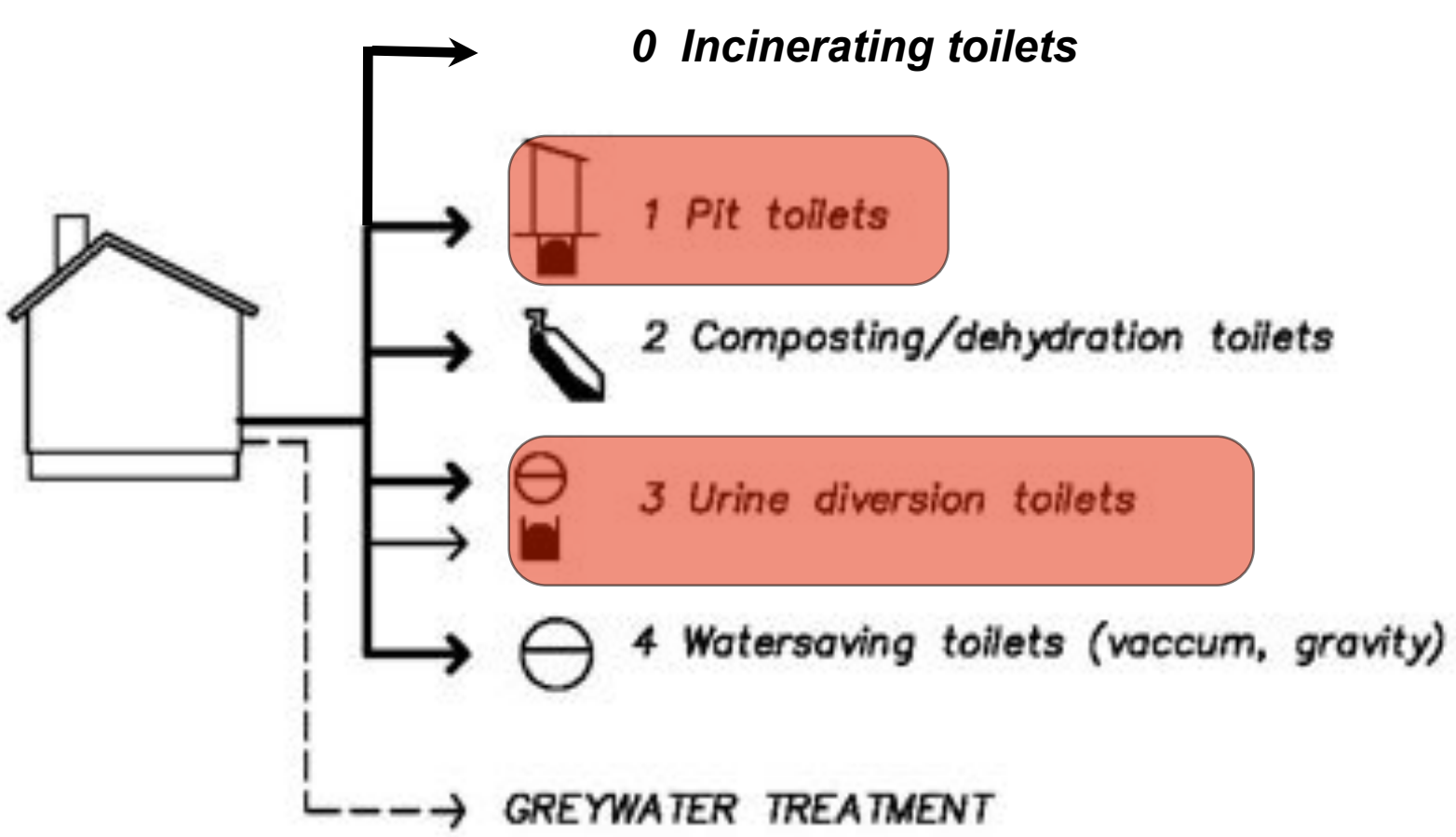


Data from: Cordell et al. 2009

Source separation - toilet options



Source separation - toilet options



Contribution from the toilet

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

Contribution from the toilet

6 - 20 liters per flush !

20 - 40% of the total water use !

Future toilet types (commercially available today)

	Water use
• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving (vacuum&gravity)	0.5 - 1.0 liter/visit
• Incinerating	0 liter/visit

Future toilet types (commercially available today)

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Incinerating toilets

Incinerating toilets

1 → 2 → 3

Troll - the Norwegian research station in Antartica

Incinerating toilets

User friendliness	Medium/ low
Hygiene	High
Investment cost	High
O&M	High
Technical complexity	High
Suitability arctic conditions	Low/ medium

Future toilet types (commercially available today)

	Water use
• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
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Composting toilet at roadside facility - Sweden

Elected the best roadside facility in Sweden 2003 - 2008

Composting toilet system - removable compartments

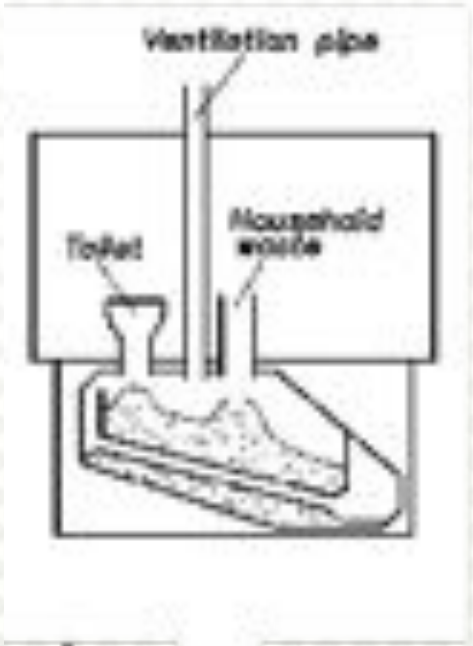
Composting toilet at roadside facility - Sweden

Clean odourless toilets

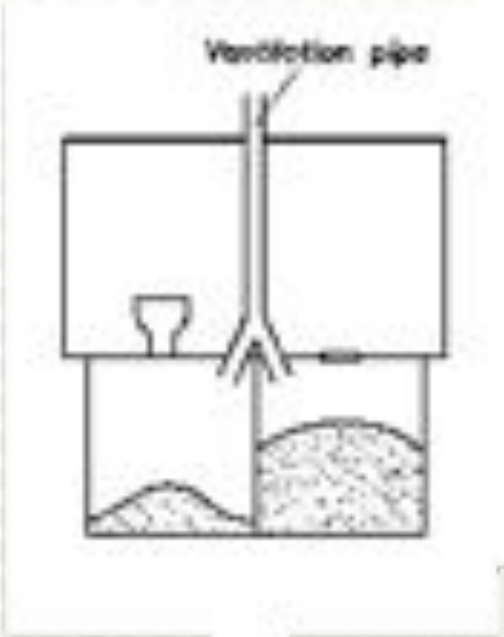
Composting toilet - bathroom design

- High standard and comfort possible

Composting toilets - design



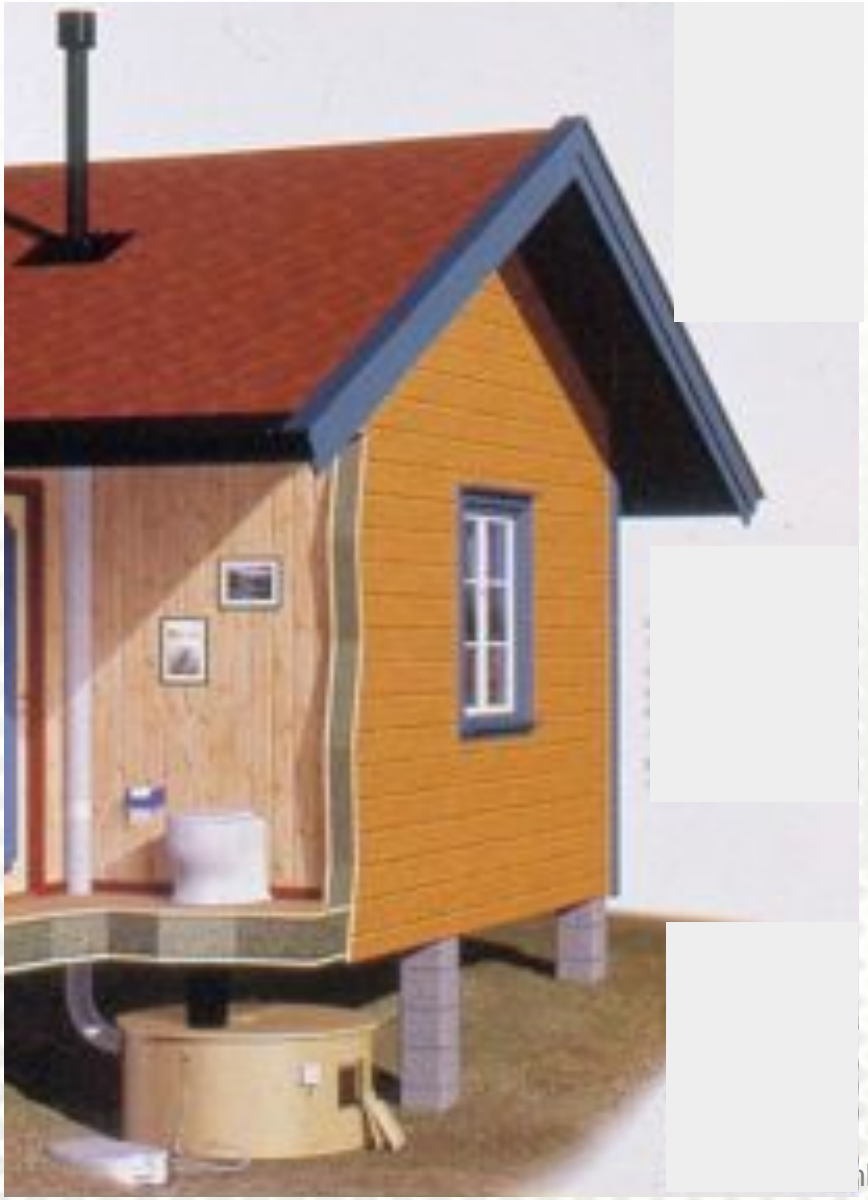
Single compartment



Dual compartments

Removable compartments

Composting toilets - advantages

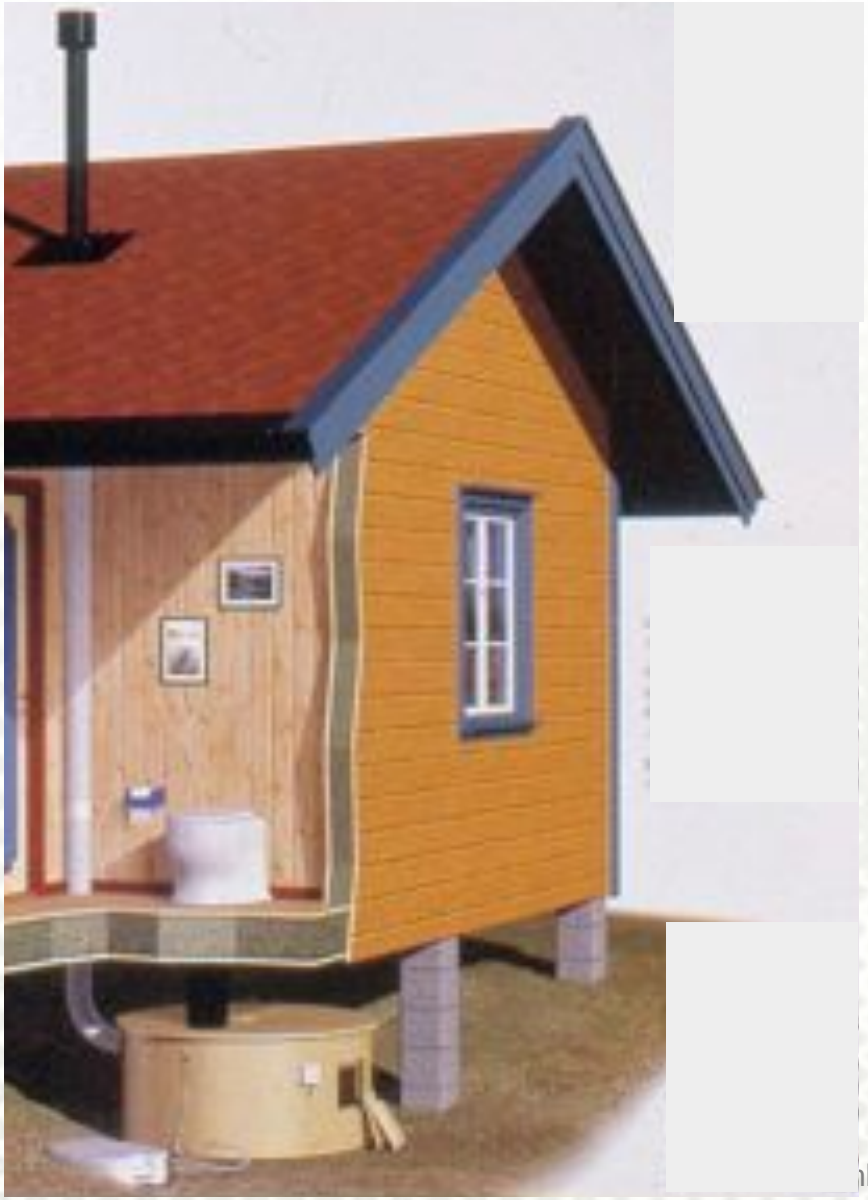


Volume reduction:

- 70 - 90%
- 550 down to 55 liters
- Uses no water
- Simple and robust

(Del Porto and Steinfeld 1999)

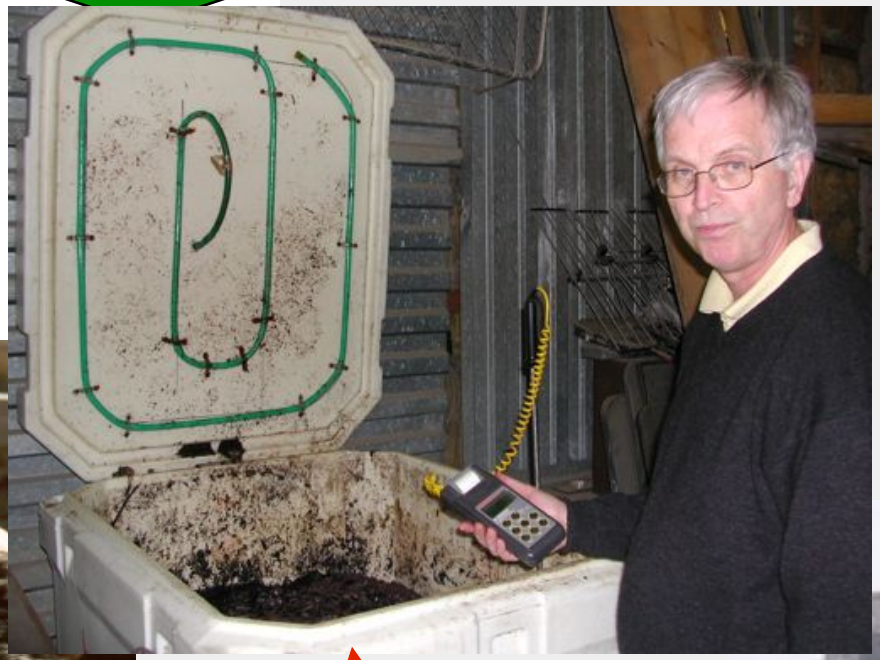
Composting toilet - challenges



- Public acceptance
- Maintenance
- Excess liquid
- Insulation
- Hygiene
  - no system above 43°C
  - risk of handling

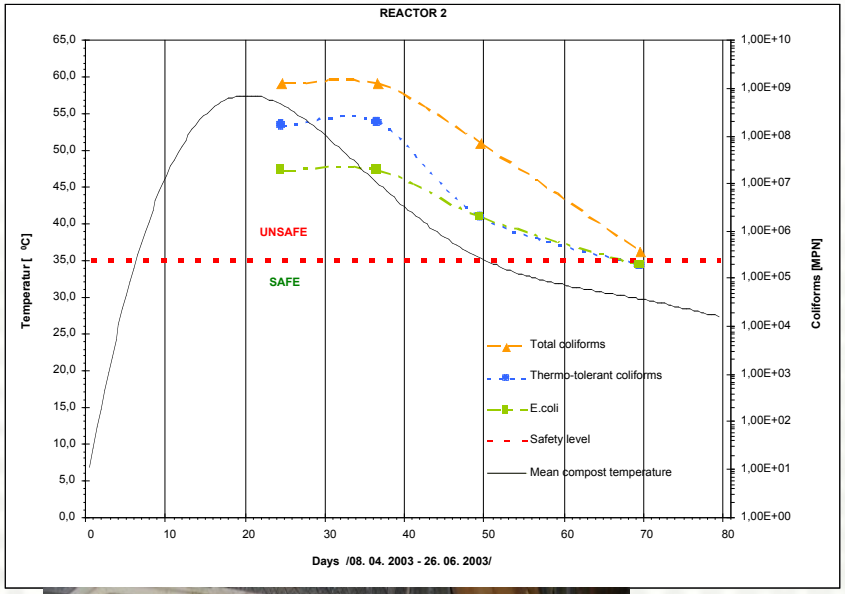
Secondary composting

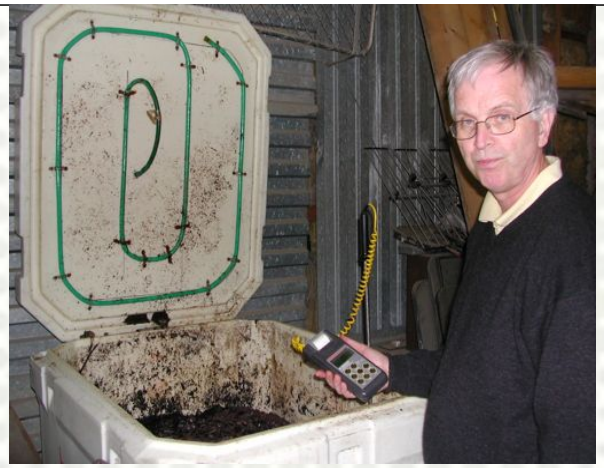
Final product



Temperature:
Outside -54C
Inside +12C

Composting toilets – an option for the Arctic ?





- International research show that dry sanitation may give an equal or higher reduction of pathogens and a high reduction in risk of exposure.

(Stenström 2001)

Composting toilet - handling

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

Composting toilet - handling

User friendliness	Medium/ high
Hygiene	High
Investment cost	High/low
O&M	Medium/ low
Technical complexity	Low
Suitability arctic conditions	High*

Future toilet types (commercially available today)

	Water use
• Composting /dry sanitation	0 - 0.1 liter/visit
• Urine diverting	0.1 - 4.0 liter/visit
• Water saving (vacuum&gravity)	0.5 - 1.0 liter/visit
• Incinerating	0 liter/visit

Low flush toilets – an option for the Arctic ?

Vacuum
0.5 - 1.5 liters/flush

Gravity
1 liter/flush

Low flush toilets – an option for the Arctic ?

Contemporary Scandinavian bathroom design using vacuum toilets

Photos: P.D. Jenssen

Low flush toilets – adaption to the Arctic

Low flush toilets – adaption to the Arctic

Low flush gravity toilet

Insulated underground holding tank with heating cable

Quick coupling for easy pumping

Low flush toilets – adaption to the Arctic

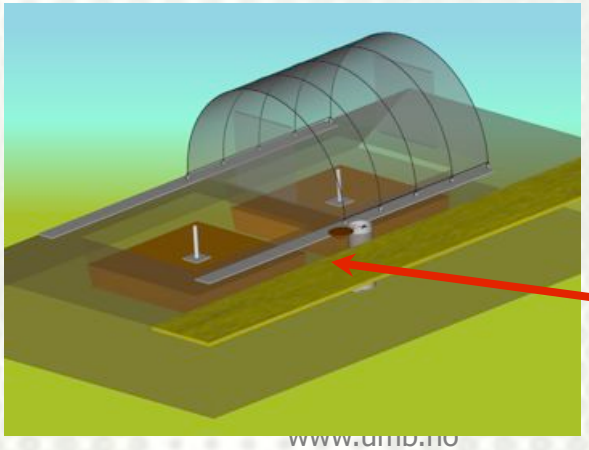
Low flush
gravity toilet

?

Low flush toilets – adaption to the Arctic

Low flush gravity toilet

Low flush toilets – adaption to the Arctic



Blackwater dewatering unit

Low flush toilets – adaption to the Arctic?

Low flush toilets – adaption to the Arctic?

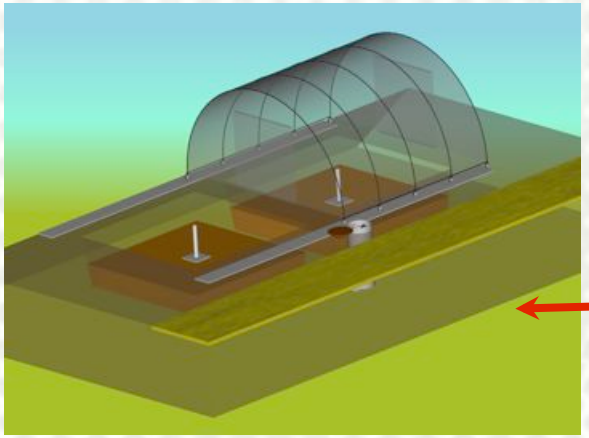
Sisimiut Greenland

” Honey buckets”

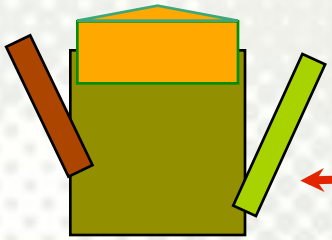
Modern low flush toilet

Sisimiut Greenland

Low flush toilets – adaption to the Arctic



Biogas digester



Low flush toilets – adaption to the Arctic

Sisimiut Greenland

Sisimiut – New possibilities

Thermophilic anaerobic treatment - BIOGAS

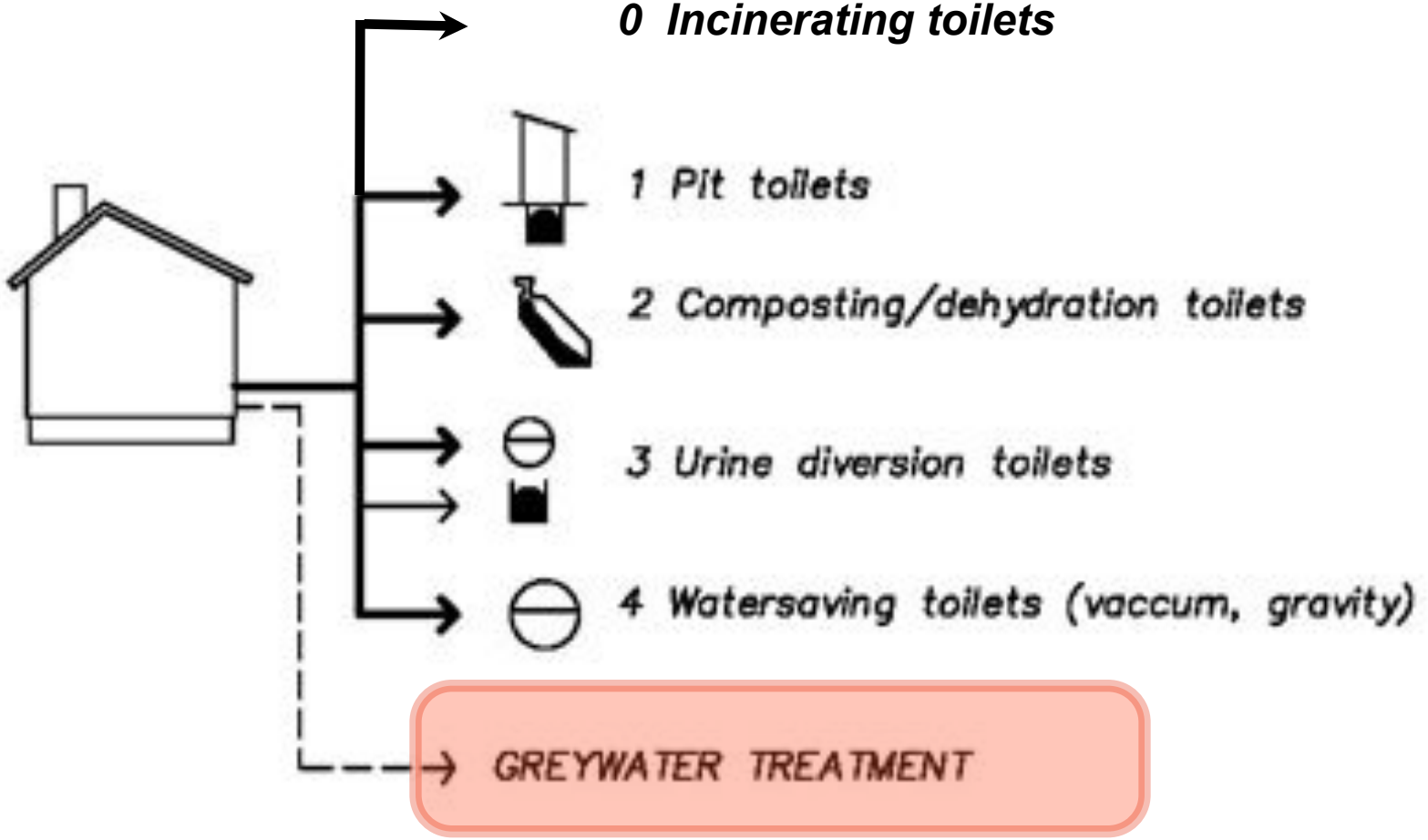
Waste incinerator

Energy

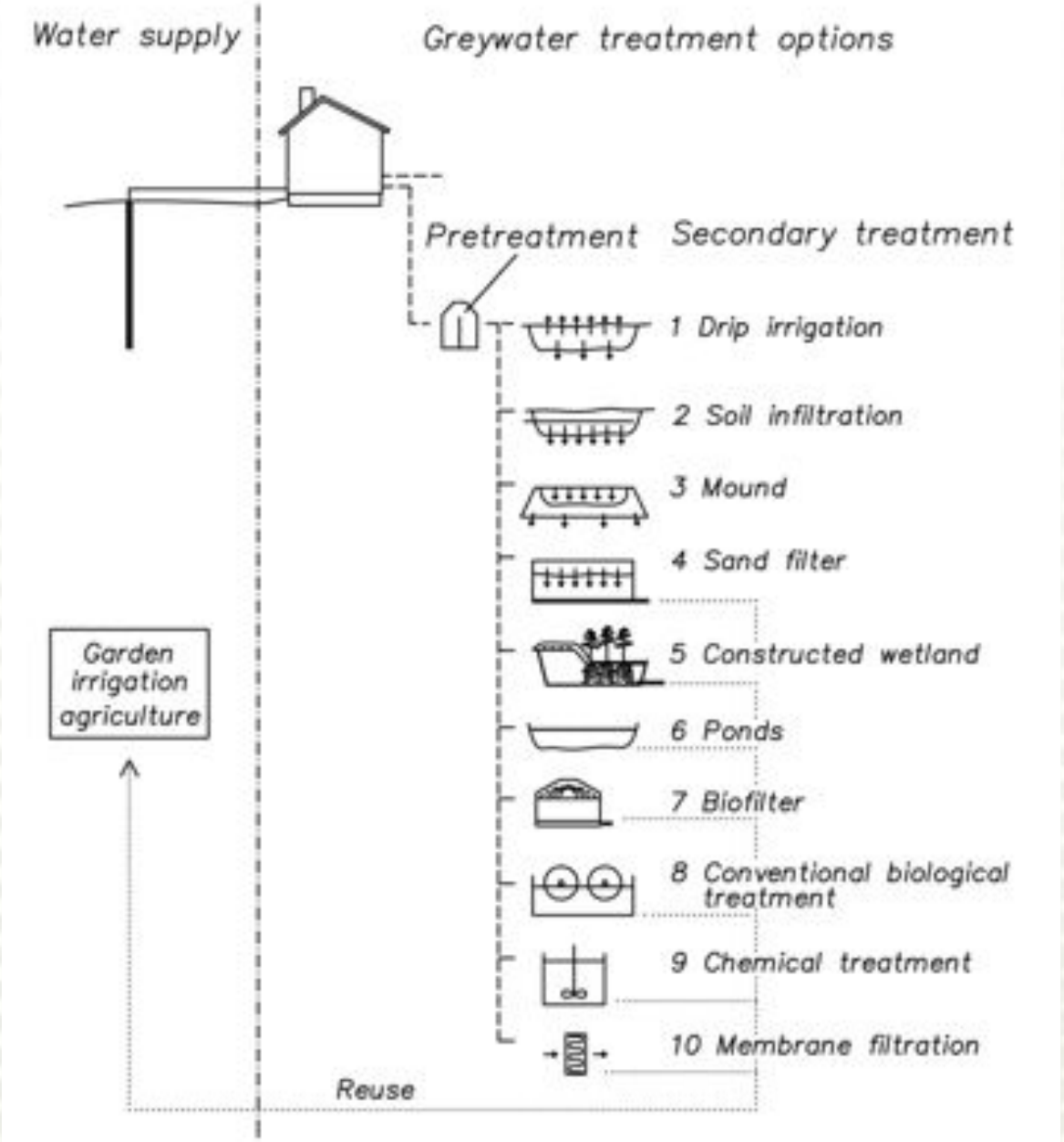
Nutrients

Growth medium

Source separation - greywater



Onsite systems suitable for GREYWATER treatment



Compact greywater treatment system

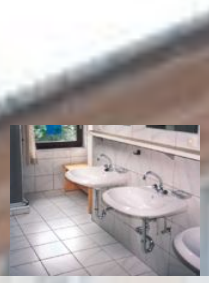
Producing efluent that meets European bathing water standards

(Ecomotive Inc.)


Greywater discharge pipe

SANBOX – a solar powered treatment system for remote locations such as mountain lodges

The vision SANBOX



Washing facilities

Vacuum toilet system

Dewater and decompose blackwater solid fraction

treat greywater to swimming water quality

high systems reliability with redundant core components

Evaporate blackwater liquid fraction

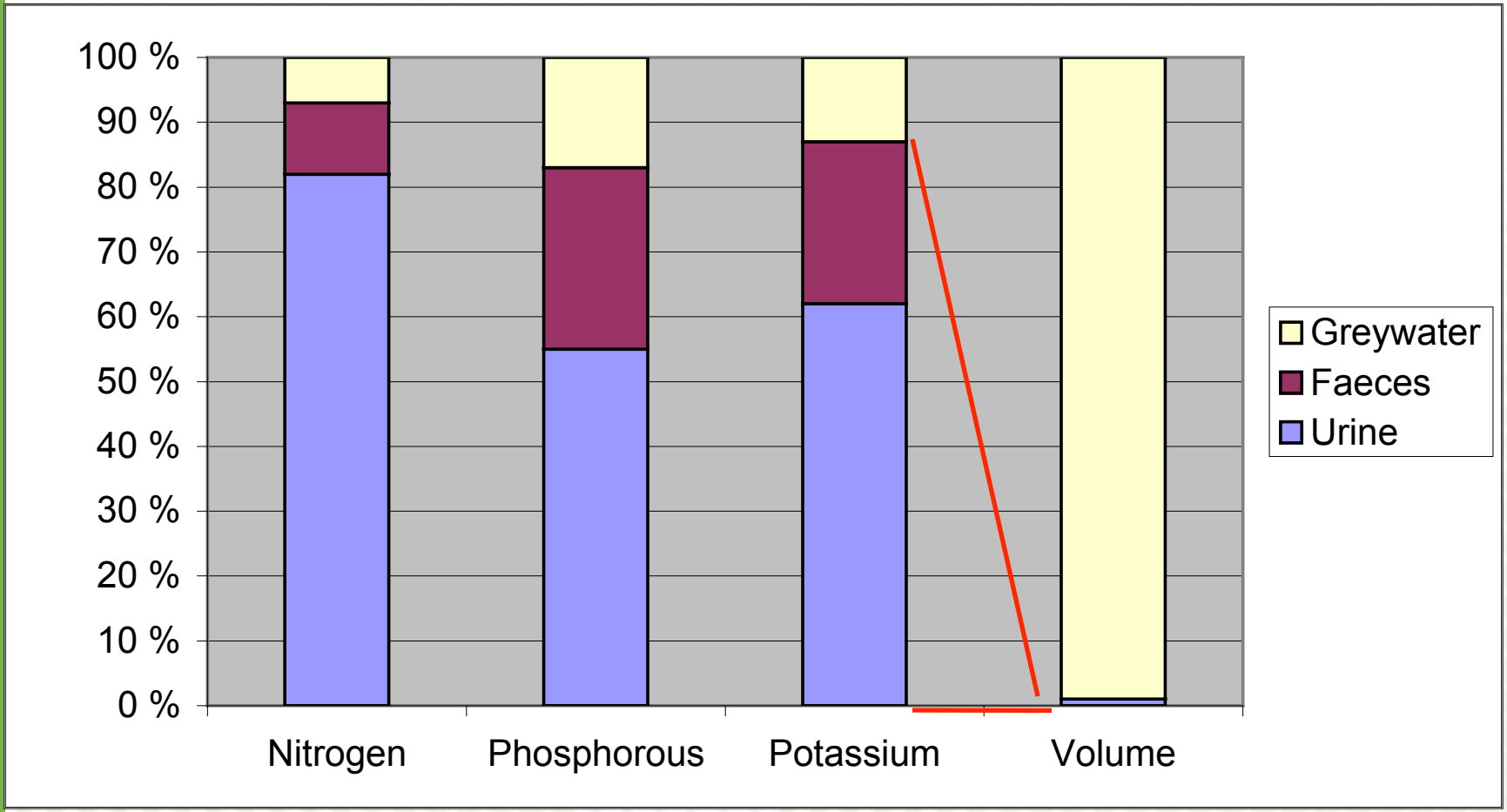
Use greenhouse technology to provide processes energy from solar hea

Main conclusions

- **Organic micropollutants,** including **medicine recidues**, and **hygiene components** may pose the highest environmental and health risk of wastewater discharge to arctic waters
- Conventional centralized sewer systems are expensive to construct an operate and probably not sustainable.
- There are options that can be used immediately or after some R&D
- Decentralized/onsite systems and source separating systems especially have potential to solve the sanitation problems in a sustainable way


Thank you !

Nutrients and volume of domestic wastewater fractions

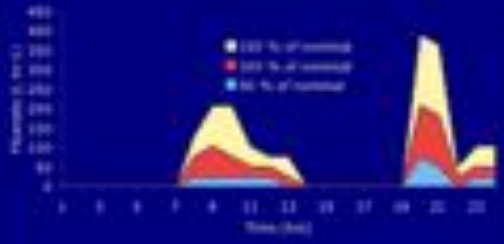


(Jönsson et al., 2000).

Info box 1. Greywater treatment system (Ecomotive AS)

The knowledge about greywater, different filter materials and their performance at different wastewater loading regimes have been utilized in the design of a new greywater treatment system for single households. The aim has been to improve the treatment efficiency and to reduce the size and costs. In addition, the operation and maintenance should be easy and rational. The flow-chart in the figure below shows the design.

Easy access to all parts of the system has been important during the design. The septic tank and the dosing pump is an integrated part of the treatment unit, as well as the control unit. All parts included nozzles and filter materials are accessible from the manholes. Another important factor is the pump control, which has been constructed to give optimal hydraulic loading to the



The greywater treatment unit with a design flow rate of 600 L d^{-1} (nominal), has been tested with application of greywater from student dormitories at loading rates of 300, 600 and 900 L d^{-1} following a daily flow variation similar to the water consumption pattern in a household. There was a resting period of 25 days in the middle of the test. This is of special interest for application at recreational homes, huts and cottages, where there will be resting periods of varying duration. Large variations in loading rates have been a major challenge in biological treatment.

The test results are shown in the table below.

	Total P			BOD$_5$			SS		
Load	Mean	Stdev	n	Mean	Stdev	n	Mean	Stdev	n
Inlet	1.10	0.27	35	131.22	36.73	35	87.13	29.97	32
Out 300 L/d	0.18	0.01	3	2.67	0.58	3	7.00	1.41	2
Out 600 L/d	0.22	0.14	35	3.61	2.73	18	4.93	1.27	17
Out 900 L/d	0.16	0.05	5	4.71	2.43	7	4.67	1.47	4

The BOD$_5$ removal increased to 90 % after seven days of operation. The inlet concentration of *E.coli* has been monitored regularly by 24 hrs composite sampling. Inlet concentration varied between 10^6-10^7. The *E.coli* removal has varied between 2-3 log.