CIE4485
Wastewater Treatment

Prof.dr.ir. Jules van Lier

13. (Re)source Oriented Sanitation

TU Delft

CT4485 Wastewater Treatment

Lecture 6: (Re)source Oriented Sanitation

Prof.Dr.ir. Jules B. van Lier

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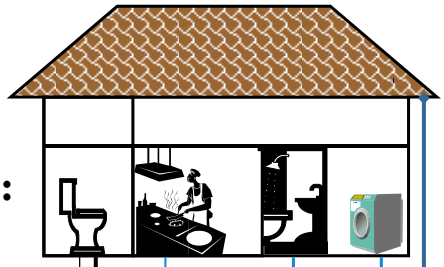
Learning Objectives

- To learn the composition of domestic wastewaters
- To understand the economics of our current system
- To understand the incentives for alternatives
- To learn how separate domestic streams can be dealt with?
- What are the treatment options
- Fantasy or a feasible alternative?

Prins opent sanitatieproject Waterschoon in Sneek tijdens succesvol symposium
Zijne Koninklijke Hoogheid de Prins van Oranje heeft **vrijdag 18 november 2011** de opening verricht van het duurzame en innovatieve sanitatiesysteem Waterschoon dat aangelegd is in de wijk de Noorderhoek in Sneek. Hij deed dit tijdens het Symposium Waterschoon 2011 in het bijzijn van zo'n 350 gasten.

Current sanitation:



Black water
2 L/p.day + flush 25-35 L/p.d

Grey water
100 L/p.day

Rain water
75 L/p.day
≈ 1.6% of total precipitation

up to 225 L /p.day

Connection costs:
4000-8000 euro

- **dilution of concentrated flows**
- **large scale collection**
- **centralised treatment**

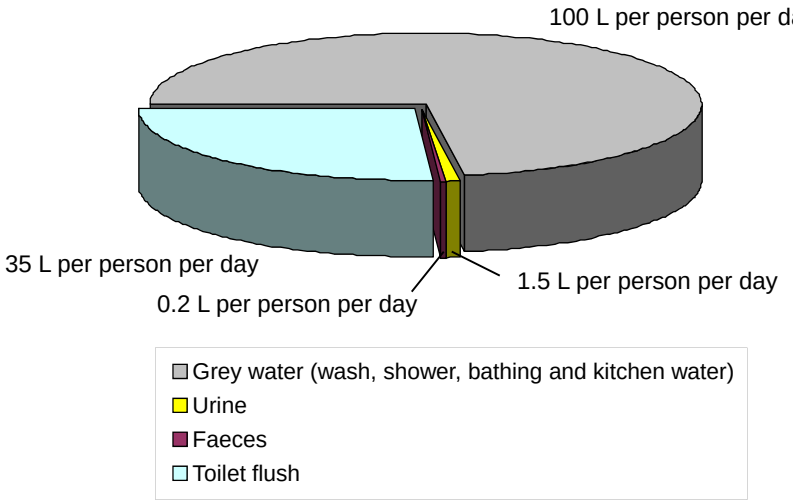
Centralized Wastewater-Treatment-Plants
End-of-Pipe-Technology

What are the constraints of centralised systems?

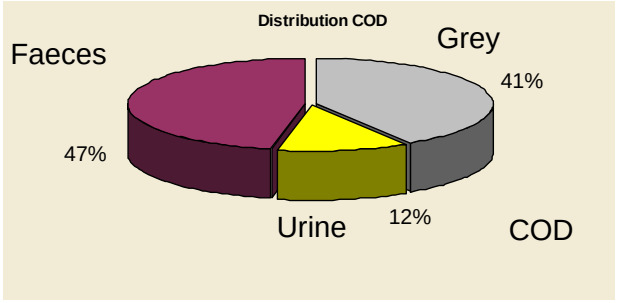
Centralized Wastewater-Treatment-Plants: **Constraints:**

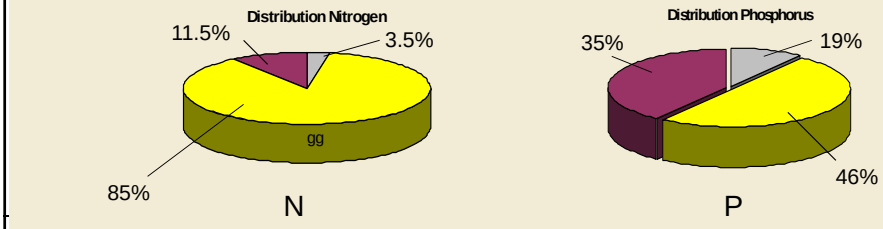
- High investment & maintenance costs – 65-70% for sewerage
- Long planning- and construction-times for the sewer system (not flexible)
- Difficult to expand with expanding population!
- Contamination of large volumes with small amounts of concentrated waste
- Risks for discharge of untreated sewage (rainfall, sewerage leakage)
- Risks of discharge hazardous compounds 'out of eye, out of concern'
- If not treated: discharge at single outfall
- Treated wastewater often still polluting receiving surface waters with nutrients, pathogens, hazardous compounds / hormones
- Large water requirement to prevent clogging
- Effective discharge of rainwater → city dryness
- High vulnerability (depend on central services)
- Nutrients in the waste water remain unused
- No direct reuse possible of clarified wastewater

Distribution of wastewater based on origin (NL)

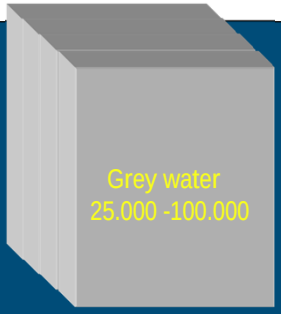


Distribution of COD, N and P over the various water fractions:





Composition and flow domestic wastewater



		Volume L/(PE.year)	Grey water 25.000 -100.000	Urine ~ 500	Faeces ~ 50
Loads kg/(PE.year)	N	~ 4-5	~ 3 %	~ 87 %	~ 10 %
	P	~ 0,75	~ 10 %	~ 50 %	~ 40 %
	K	~ 1,8	~ 34 %	~ 54 %	~ 12 %
	COD	~ 30	~ 41 %	~ 12 %	~ 47 %

Source: Otterpohl

Per capita emission

≈ 1.5 litres faeces plus urine plus kitchen waste with:

- 90% of the nitrogen;
- 80% of the phosphate;
- 80% of the potassium;
- 70% of the COD;
- main part of the pathogens;
- all medicine rest and hormones

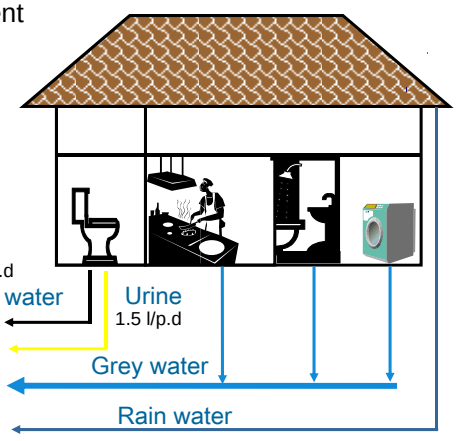
What is the alternative approach ????

- Collection
- Treatment
- Nutrients recovery
- Reuse

Decentralised Sanitation and Reuse (or EcoSan)

Separate collection and treatment of grey, black and 'yellow' wastewater

What are the perspectives??

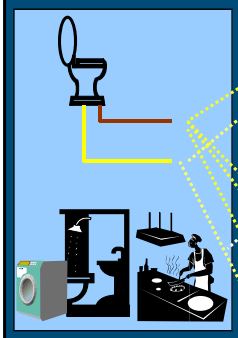


± 2 L/p.day + 25-35 L/p.day flush

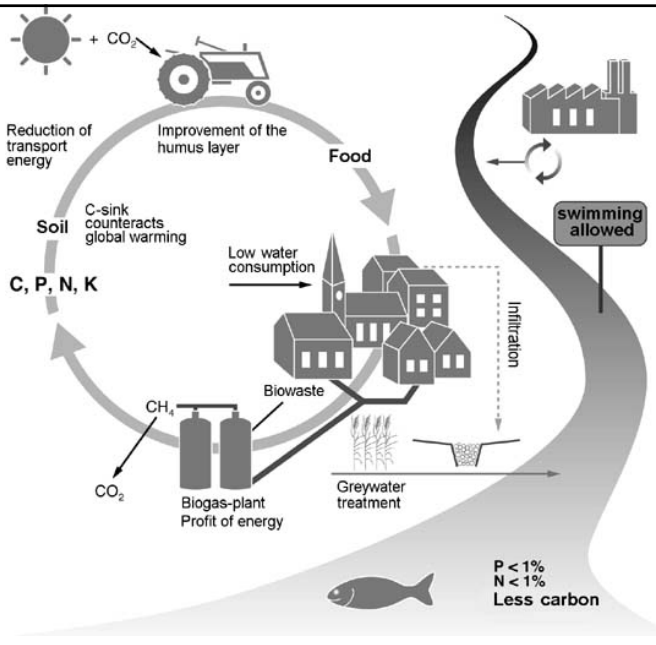
100 L/p.day

75-100 L/p.day

Perspectives of separation



- Black water: concentrated can be treated more efficiently at lower costs
- Grey water: relatively low pollution; can be treated with simple methods; potential source of water for local water system or irrigation
- Black water: pathogens are concentrated
- Black water: high organics concentration; can be used for energy generation (digestion)
- Black water: no pollution by heavy metals
- Urine: high nutrient content, high quality fertilizer; pathogen free, but possibly drug residuals



Otterpohl, 2000

Principles of DeSaR (decentralised sanitation and reuse)

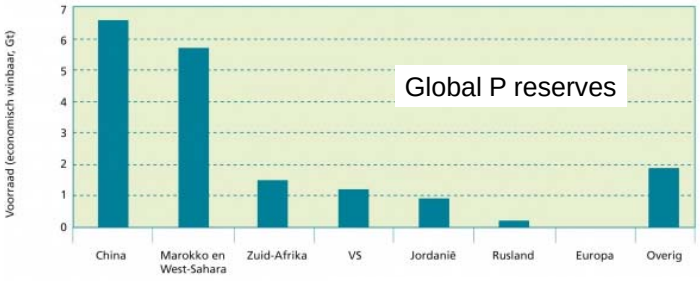
- Separate collection
- Local treatment and use
- Separate treatment of concentrated and diluted flows
- Recycling of nutrients, organic matter & water
- Minimization water use
- Minimization energy use
- Preventing emission into environment through leaking sewers and effluents

Nothing New!

Source oriented sanitation (or decentralised sanitation and reuse)
Already applied in 19th centuary:

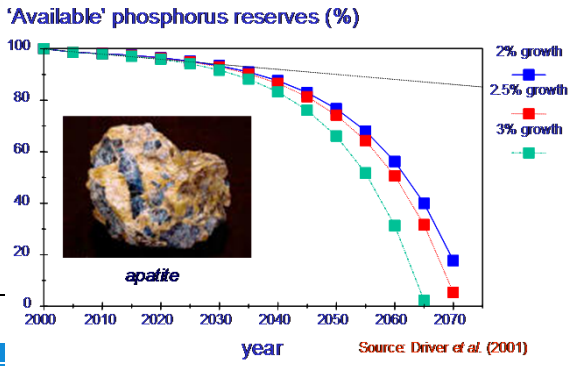
Need for large demands of fertilisers in agriculture!!

Nutrients availability again critical??



Global P reserves

Al-PO_4 / Fe-PO_4?



Nutrient recovery in black water treatment

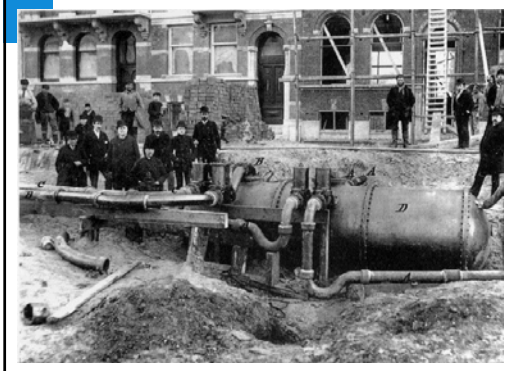
Potentials for the Netherlands (16,645,313 inh.)
Note: Dutch agriculture is export driven!!

	BW + KW (ton/y)	Synthetic fertiliser use (ton/y)	Potential coverage (%)
N	74,399	288,000	26
P	9,590	21,000	46
K	23,470	35,000	67

BW: black water (7.5 litre/p.e./d)
KW: kitchen waste

Zeeman, 2009,

1870's: Vacuum sewerage for collection of blackwater

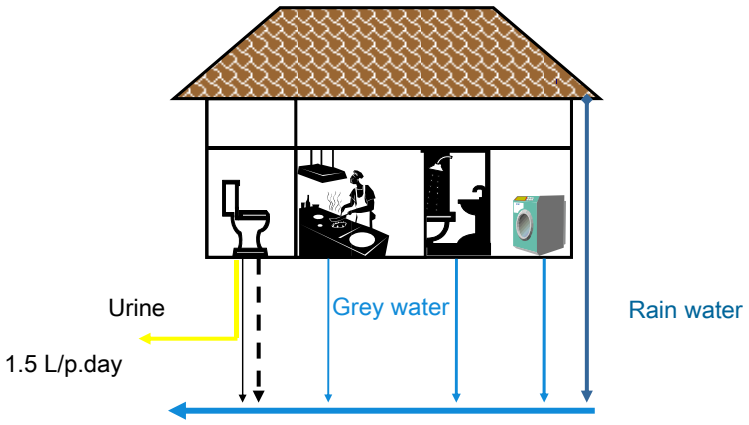


1. Developed by Charles Liernur in 1867 as alternative to waterborne sewerage
2. Basic idea: reuse of concentrated black water in agriculture
3. Collection via subsurface iron pipes by application of vacuum suction through 'locomobile': 400-500 pers./10 min., upto 15.000/night. Later: permanent pumps.
4. Human manure was directly used, dried or used for production of ammonium sulphate (Amsterdam)
5. Exploitation was in most cases cost effective (gains = costs)

Leiden (1200 pe, 1870-1915), Dordrecht (800 pe, 1872-1887), Amsterdam (1700 pe, 1872-1912), Prague (15.000 pe), St. Petersburg (20.000 pe), Luxembourg

Separate collection of urine:

What are the impacts on
- wastewater treatment system?
- recycling of nutrients?



Separate collection of urine: How to implement?

- Urine production: 1.5 L/p.d, **80% of N, 45% of P, 70% of K**
- Prevent dilution en keep nutrients concentrated: enhances recycling!
- Separate collection through special 'No Mix' toilets
- Direct use as a fertilizer is possible after 6 months of storage
- Nitrogen load to centralized WTPs can be reduced ➔ saves space and energy
- Other options: centralized urine treatment and recovery of minerals

Overview urine treatment methods:
e.g. Maurer et al., Water Research, 40: 3151-3166 (2006)

Demonstration toilets in Water museum, Arnhem

Transporting urine and wastewater

WasteW → Gravity sewers

(Faeces, grey water, rain water)

Urine → 1. Gravity sewers

2. Truck transport

(Water and minerals) 3. Sewers and trucks

Nitrogen load to centralized WTPs can be reduced
➔ saves space and energy

$$E_{net} = E_{aer} + E_{dew} + E_{inci} + E_{pump} + E_{mix} + E_{heat} - E_{CH4}$$

Urine separation	0	50	65	75	85	%
Digested sludge	2111	1917	1888	1881	1760	kg/d
Urine influent	0	45000	58500	67500	76500	kg/d
$[N_{tot}]$effluent	7	12	6	2	1	mg/l
Total Energy	15239	-6204	-5671	-5467	-4907	MJ/d
	6.2	-1.6	-1.5	-1.4	-1.3	W/pers

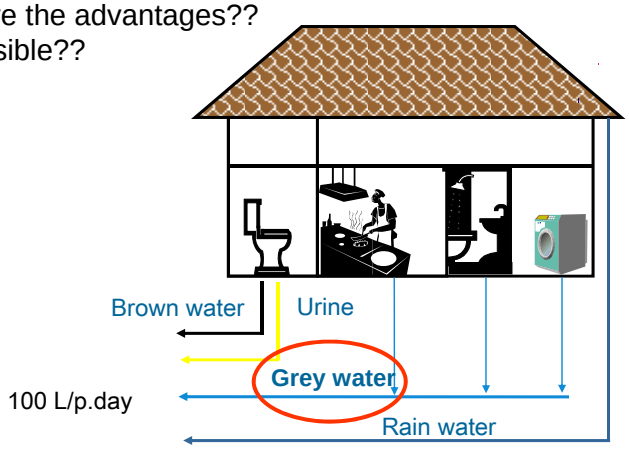
Palsternackan Stockholm (1995):

51 apartments en, 160 inhabitants (urine separation)

Urine is stored for 6 months (to remove remaining pathogens)
and is directly used in agriculture

Separate collection and treatment of grey water

What are the advantages??
Is it feasible??



Grey water treatment

- Grey water (2/3 of total wastewater) is relatively clean and can be treated locally
- Treated water can be used for ground water recharge, local water systems (attractive urban environment) or irrigation
- Several treatment options: e.g. constructed wetlands, biorotors, membrane bioreactors, high loaded activated sludge
- Application of constructed wetlands in urban residential areas in The Netherlands is accepted.

Constructed wetlands - examples

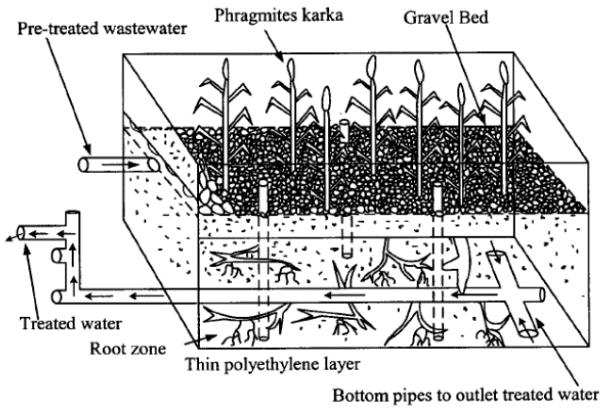
Rural environment (Sweden)

Urban environment (Oslo)

Landscape architects on constructed wetlands:

"Constructed wetlands are very interesting for urban design"
"By integrating constructed wetlands in urban design there are de facto hardly any extra costs"

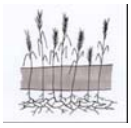
Vertical flow constructed wetland



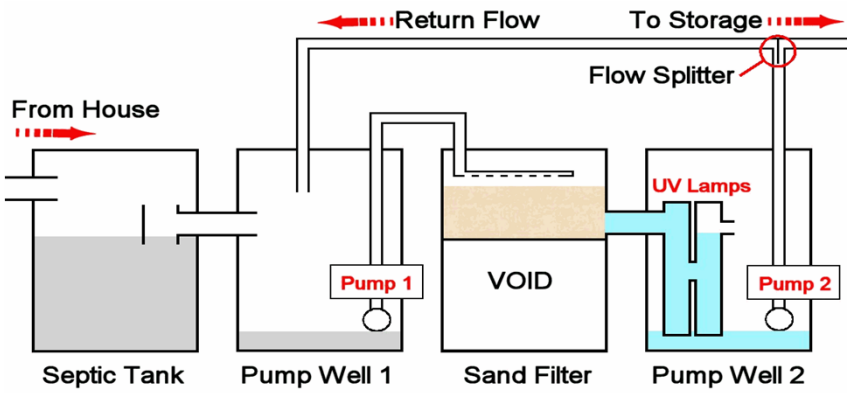
Example of a sub surface constructed wetland, planted with *Phragmites karka* (source: Billore et al, 1999)

Grey water treatment in constructed wetlands

	De Drielanden – Groningen (horizontal flow helophyte systeem)		Flintenbreite - Luebeck, Duitsland (vertical flow helophyte system)	
	Influent	Effluent 1999	Influent	Effluent
COD (mg O_2/l)	550	45	502	59
BOD_5 (mg O_2/l)	298	2	194	14
N-tot (mg N/l)	12,6	1,6	12	2,7
NH_4-N (mg N/l)	3,8	0,22	4.5	0,9
NO_3-N (mg N/l)	< 0,03	0,11	--	--
P-tot (mg P/l)	1,8	0,31	8	5,7
PO_4-P	0,94	0,23	7,6	4,8

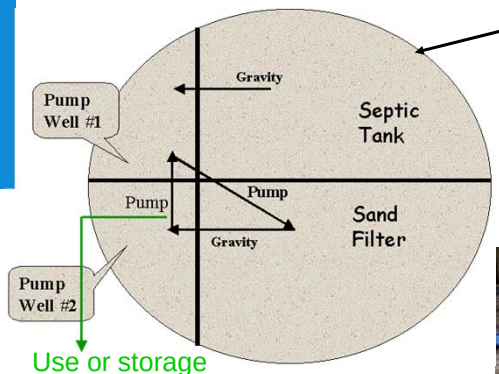


The Greywater System, Australia



House

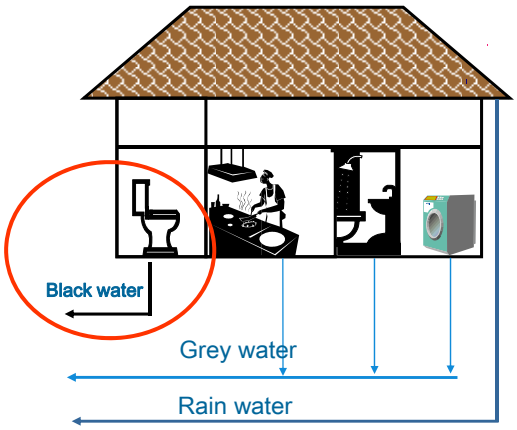
Grey water system, Australia



Septic tank compartment

Sand filter (full)

Separate collection and treatment of black water:



2 L/p.day + flush

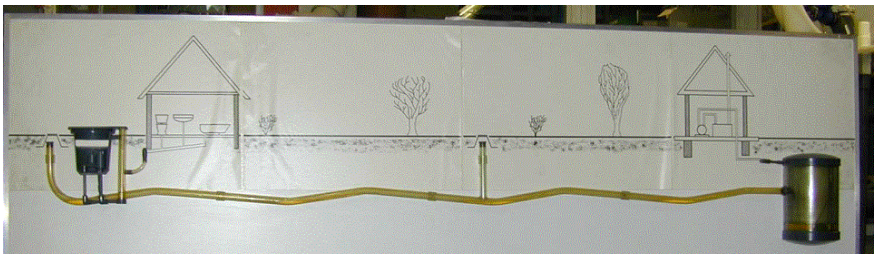
Black water treatment

- Vacuum collection and transport to keep black water concentrated
- Digestion for energy recovery at local scale
- Use of remaining product as fertilizer (e.g. after composting)

Vacuum-Toilet 0.7 litres/flush (saves approximately 25 l pp per day

Source: Otterpohl

Roediger, Hanau



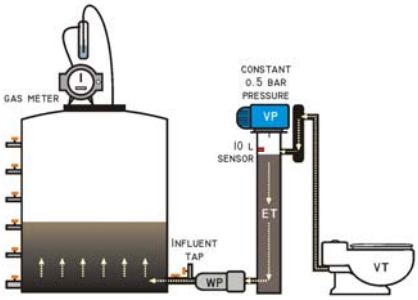
Prof.Dr.ir. Grietje Zeeman,
Wageningen University

Digestion of concentrated black water and kitchen wastes, pilot reactor at Sub-department of Environmental Technology:

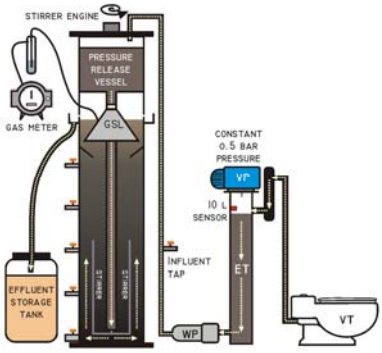
- temperatures: 15, 20, 25 °C
- influent $COD_{blackwater}$: 9-13 g/l
- influent $COD_{blackwater + kitchen}$: 13-23 g/l

Pilot-Plant Set Up

Accumulation tank reactor



Upflow septic tank system



V_{gas} = 11 m^3/person/year (black water + kitchen)

> 50 % methanisation

Evaluation pilot research

Advantages of anaerobic digestion for concentrated domestic wastewater

- Biogas production
- Reduction of organics
- Nutrient preservation
- Small sludge production
- Stable composition of the product

Advantages of long retention time:

- Stable, robust, shock-load less sensitive process
- Storage secured
- Good reduction of organics
- Pathogens reduction

Quality of product: heavy metals

Expected average concentrations of heavy metals in a mixture of faeces and urine N = 2 g/L, N_{demand} = 150 kg/ha, Volume : 75 m^3 human manure comparison with standards for WWTP sludge

Metal	mg/L digested product	g/ha/y	g/ha/y meadow standard	g/ha/y farmland standard
Cu	0.16	**12**	75	150
Cr	0.016	**1.2**	75	150
Ni	0.011	**0.825**	30	60
Zn	1.45	**108**	300	600
Pb	0.003	**0.225**	100	200
Cd	0.0015	**0.112**	1.25	2.5
Hg	0.0013	**0.0975**	0.75	1.5

Quality of product: pathogens

Blackwater (faeces + urine) + kitchen waste; COD = 13-23 g/l:

T = 20°C	influent	Storage 84 d No feed	Storage 120 d No feed
E.coli/100 mL	**5.8×10^6**	**0.2×10^4**	**4.1×10^3**
Reduction (%)		**99.96**	**99.999**

Brown water (faeces) + kitchen waste; COD = 32-66 g/l:

T = 20°C	influent	Storage 84 d No feed	Storage 120 d No feed
E.coli/100 mL	**6.8×10^7**	**7.4×10^5**	**0.8×10^3**
Reduction (%)		**98.9**	**99.9988**

Evaluation/conclusions

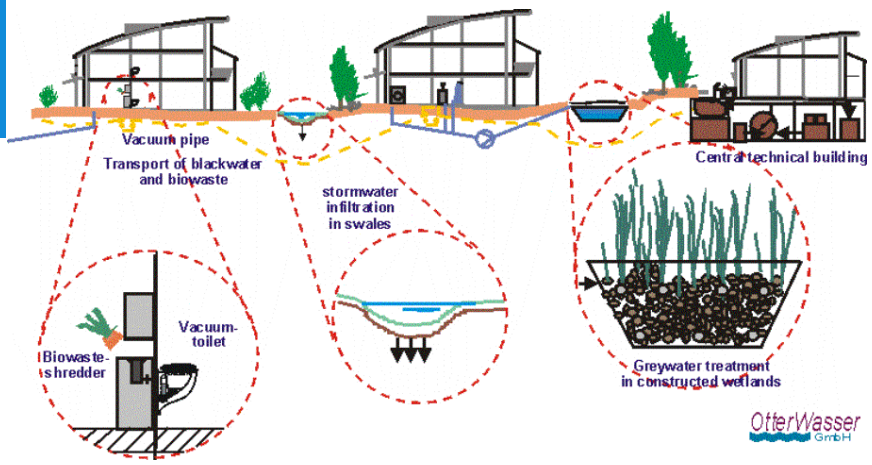
Advantages of anaerobic digestion for concentrated domestic wastewater

- Biogas production
- Reduction of organics
- Nutrient preservation
- Small sludge production
- Stable composition of the product

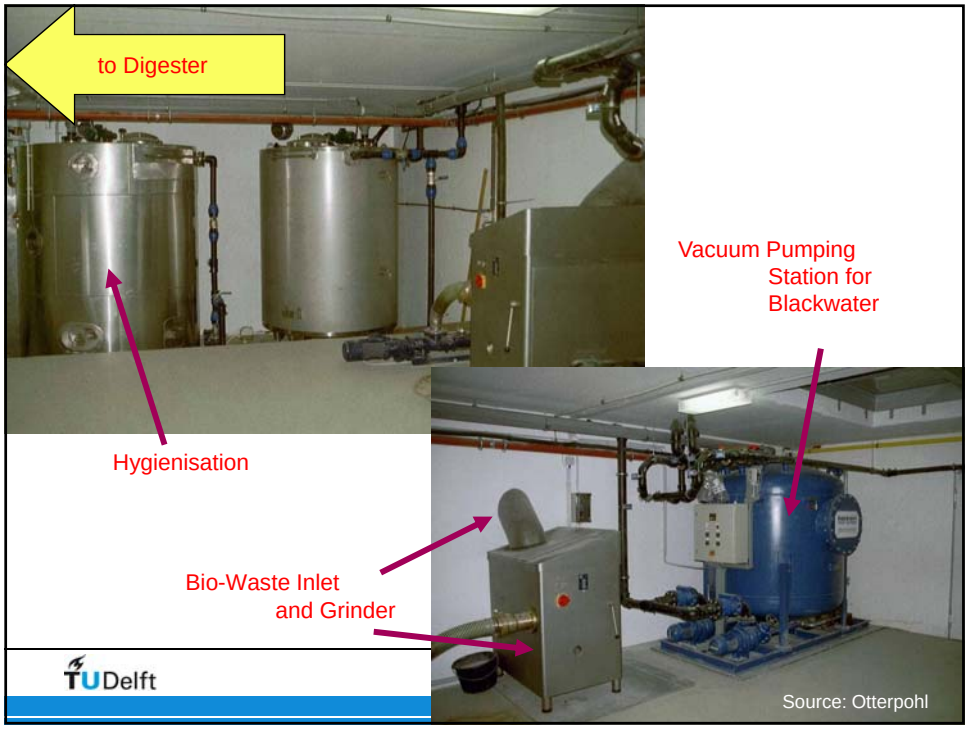
Advantages of long retention time:

- Stable, robust, shock-load less sensitive process
- Storage secured
- Good reduction of organics
- Pathogens reduction

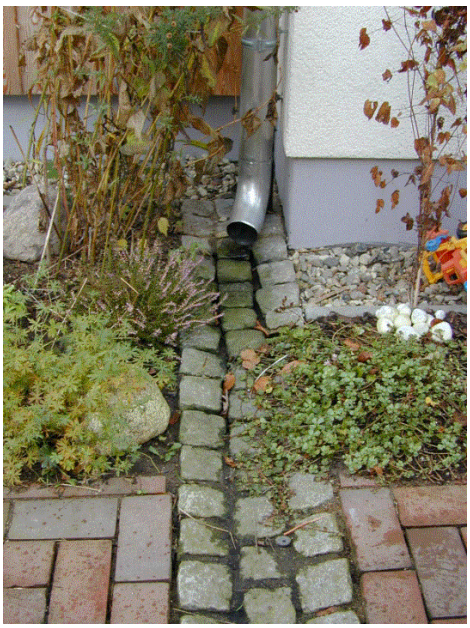
Case study: Lübeck-Flintenbreite ‘sewerless city’:

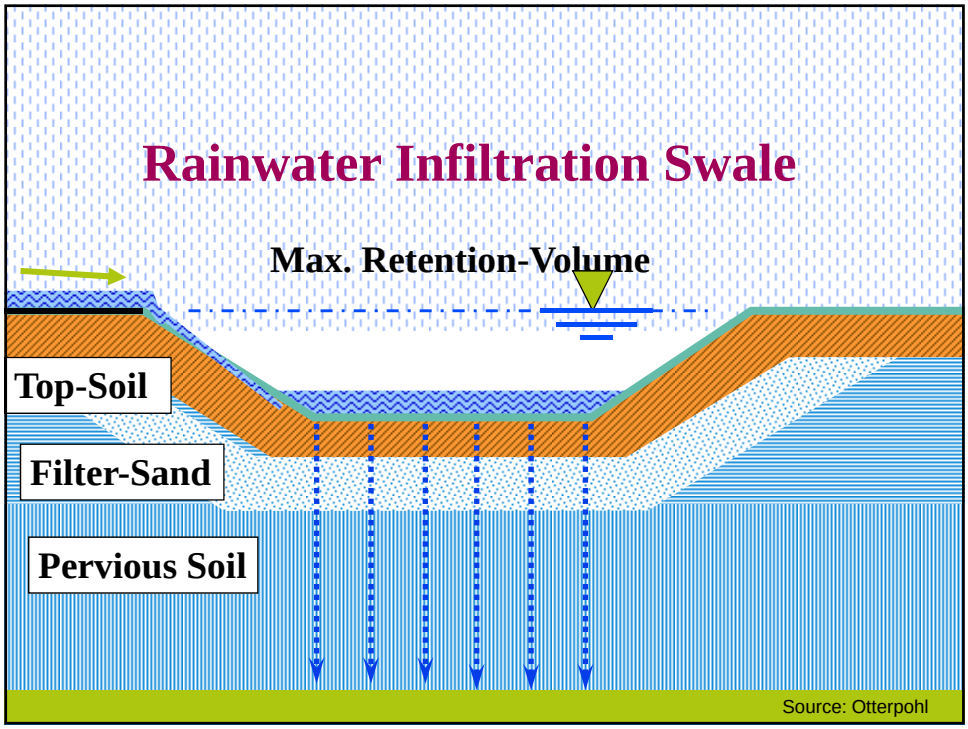


Peri-Urban Settlement Lübeck-Flintenbreite (400 inhabitants)
Vacuum-Biogas-System for Blackwater plus Biowaste
Otterwasser GmbH, Lübeck www.otterwasser.de


to Digester
Vacuum Pumping Station for Blackwater
Hygienisation
Bio-Waste Inlet and Grinder
TUDelft
Source: Otterpohl

Rainwater infiltration





Constructed wetland for the grey water

TU Delft

Separation at the source (full scale): Sneek

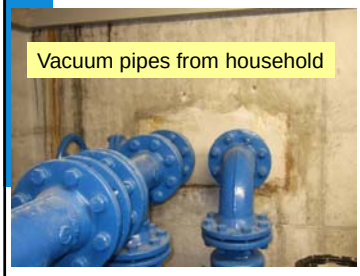
Black water:
- Decentralised digestion
- Energy returns to household
- Nutrients as fertilisers
- Digested matter: soil conditioner

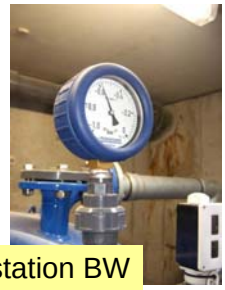
Vacuum toilet

Digester

Zeeman,
Wageningen UR

Decentralised sanitation: impact on sewerage conveyance / **Piping system**

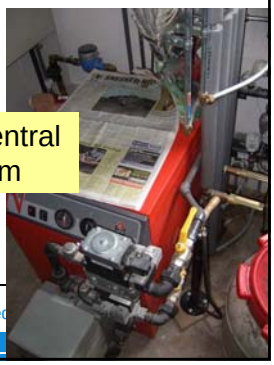




Vacuum station BW

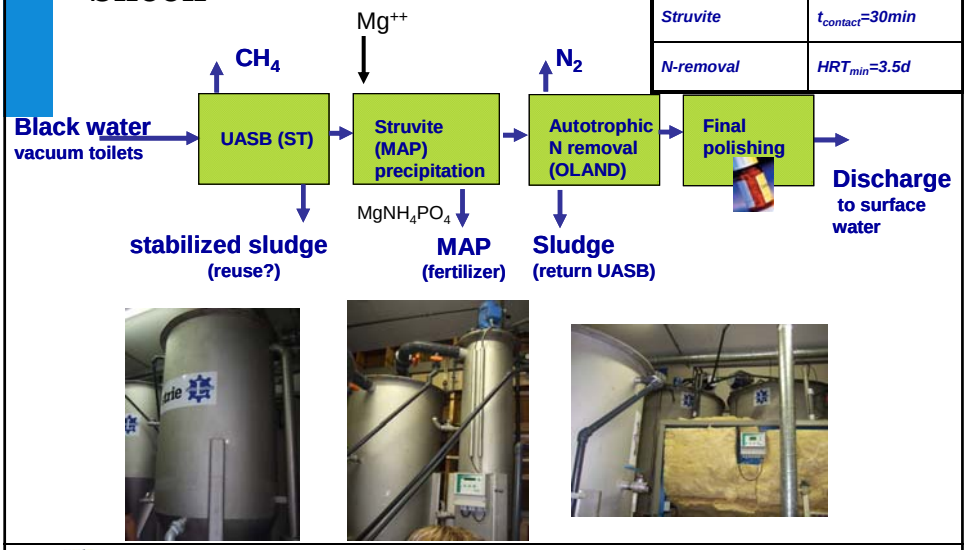
Sneek Desar project

Biogas-fed central heating system



Black water treatment: Sneek

UASB (ST)	*HRT_{min}=7d; T_{max} = 30°C*
Struvite	*$t_{contact}$=30min*
N-removal	*HRT_{min}=3.5d*



Separation at the source: Sneek


Urine + faeces + kitchen waste (Sneek):
- 1.5 *l* in volume (Zeeman et al., 2007)
- 91 % N
- 69 % P
- 70 % COD
- Pathogens
- salts
- micro pollutants

Drop in drinking water consumption from 50 to 30 $m^3.pers^{-1}.year^{-1}$…!!

Stroom uit poep en pies van de hele buurt

Volgende week betrekken zestien gezinnen hun nieuwe woning in Sneek. Dat is geen nieuws, maar wel dat het kleinste kamertje in de huizen is uitgerust met een vacuümtoilet. Dit toilet, bekend van vliegtuigen en scheepen, verbruikt maar liefst 85 procent minder water dan een gangbare wc.

De zeer geconcentreerde smurrie van uitwerpselen en urine maakt het bovendien mogelijk menselijke meststoffen als stikstof en fosfaat te hergebruiken en energie terug te winnen. Op termijn zouden zelfs auto's in Sneek en omgeving kunnen rijden op biogas dat alkomstig is van pies en poep.

Vanaf juni gaan nog eens zestien Sneekse families voortaan op de vacuümpot. 'Kernpunt is dat

Volkskrant, Saturday, April 29, 2006:

Past dat allemaal? 'De garage is groot genoeg', zegt Zeeman, 'bovendien is de betreffende huurder werknemer van het Friese waterbedrijf Landustrie dat de installaties bouwde. De man is aanspreekpunt voor andere bewoners.'

Het demonstratieproject in Sneek is een door de overheid gesubsidieerd Economie, Ecologie en Technologie (EET)-project. Een bonte stoet deelnemers werkt samen in het Friese project. Installatiebedrijf Landustrie, toilettenproducent Roediger, gemeente, waterschap, twee woningcorporaties en kennisinstituut Wetsus in Leeuwarden. 'Friesland profileert zich steeds meer op water', zegt Wetsus-directeur prof. Cees Buisman vergenoegd. 'Wetsus wil commerciële relevantie en wetenschappelijke excellentie bij elkaar brengen. Wij hebben de ambitie om de kern te vormen van het nationale topinstituut water.'

Het project in Sneek moet aantonen dat de decentrale zuivering werkt. Behalve waterbesparing, energieproductie en terugwinning van nutriënten, ziet Buisman het als voordeel dat de gangbare rioolwaterzuiveringsinstallaties worden ontlast. 'Daar wordt met veel energie, zuurstof en chemie sterk verdund afvalwa-

ningen Universiteit.

Aansluiting op het riool is daardoor overbodig. De onverdunde uitwerpselen, die bestempeld 'zwart afvalwater' worden genoemd, komen samen in een vacuümstation bij de garage van een van de 32 bewoners. Daar wordt de boel onder normale druk gebracht en in een vergistingsinstallatie gepompt. 'Daarbij ontstaat biogas – het energierijke mengsel van methaan en koolzuurgas', legt Zeeman uit. Dat gas kan in een gasmotor verstookt om elektriciteit op te wekken.

Dat is nog niet alles. In de garage wordt aan het vergistingsresultant magnesium toegevoegd, waarmee de meststoffen stikstof en fosfaat worden gebonden. 'Daardoor ontstaat zogeheten struviet, dat een uitstekende vervanger is voor kunstmest', zegt Zeeman. 'In Nederland is er nog geen markt voor, maar in Japan vindt deze meststof gretig aftrek.' Pikant is dat er in Sneek ook een proef is waarbij groente- en fruitafval van huishoudens wordt vermalen met een verboden grinder en daarna gemengd met het zwarte afvalwater.

ning, gehouden is medicijnresten, hormoonresiduen en bestrijdingsmiddelen uit het afvalwater te halen. Buisman: 'Als je het afvalwater niet verdunt, maar geconcenteerd houdt, is het economisch aantrekkelijk om geavanceerde oxidatieve technieken in te zetten.'

Hij doelt op technieken die met ozon of uv-licht de organische micro-verontreinigingen afbreken. Bij een schaal van vijfhonderd woningen wordt dit alles economisch aantrekkelijk.

Sneek heeft grootse plannen. Op stapel staat namelijk de bouw van de grote nieuwbouwwijk Harinxmaland met 1200 tot 1500 woningen. 'De gemeenteraad streeft ernaar ook deze huizen met zo'n vliegtuigtoilet uit te rusten', zegt Bargboer.

Ook het ziekenhuis en andere openbare gebouwen zouden kunnen worden afgekoppeld van het riool om deze vergaande energie-, water- en nutriëntenbesparing te bewerkstelligen.

René Didde

Energy from sanitary waste?

Energy conversion factors:
1 kcal ≈ 4.2 kJ
1 kWh ≈ 3.6 MJ = 3600 kJ
1 MJ ≈ 0.278 kWh
1 m^3 CH_4 = 0.0011286 t.o.e. (ton oil equiv.)
or 0.714 liters of gasoline/diesel

Methane gas:
9410 **kcal/Nm3**
39.37 **MJ/Nm3**
10.95 **kWh/Nm3**

Discharge: wastewater + kitchen waste: ≈ 150 g COD/(p.d)
Conversion to CH_4: 55% = 82.5 g/d = 28.9 / CH_4, or 10.5 Nm^3 CH_4/y
Or: 10.5 * 10.95 = 115 kWh/y ≅ 40 kWh-e/y

Average energy consumption:
4400 kWh/year for 4-persons household.

Sanitary waste contributes to about 160/4400 =
3.6% of energy demand

Energy balance of the Sneek concept:

	Utility	Energy	Energy in $MJ_{electric}.p^{-1}.year^{-1}$
Biogas production (black/grey water, kitchen waste)	Waste(water) treatment	10,5 m^3 $CH4.p^{-1}.y^{-1}$ = 374 $MJ.p^{-1}.y^{-1}$	131
Energy consumption	Vacuum transport	25 $kWh.p^{-1}.y^{-1}$	-90
	Kitchen waste grinders	-5 $kWh.p^{-1}.y^{-1}$	-18,0
	Post- treatment		-43
Energy saving	STP	24 $kWh.p^{-1}.y^{-1}$	86
	Conventional sewer	30 $kWh.p^{-1}.y^{-1}$	108
	Drinking water	0.5 $kWh.m^3_{produced}$	26
Total			200

Domestic wastewater as a resource:

Total energy savings in Sneek: 200 MJ.person^{-1}.year^{-1}
Extrapolating to the Netherlands: 915 million kWh-e/year
≙ 100 MW-e
≙ 200.000 4-persons households

Potentially reusable grey water: 90 *l*.person^{-1}.day^{-1}
540 million m^3.year^{-1} in NL
(8-11 million ha irrigated agr. land…)

Nutrient recovery in black water treatment

Potentials for the Netherlands (16,645,313 inh.)
Note: Dutch agriculture is export driven!!

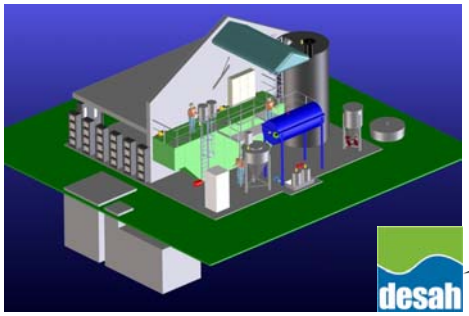
Sneek results
(32 houses, 6 litre BW/p.e./d; no KW)

	BW + KW (ton/y)	Synthetic fertiliser use (ton/y)	Potential coverage (%)		N, P (ton/y)	NH_4^+, PO_4^{3-} (ton/y)
N	74,399	288,000	26		46,174	37,668
P	9,590	21,000	46		3,828	2,686
K	23,470	35,000	67			
CH_4					$98*10^6$ m^3/y	

BW: black water (7.5 litre/p.e./d)
KW: kitchen waste

Zeeman, 2009,
Elsinga, 2009

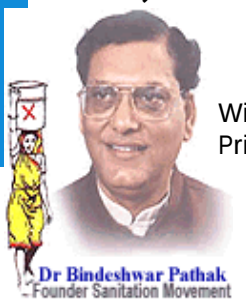
New Sanitation: full scale project Sneek: 250 houses



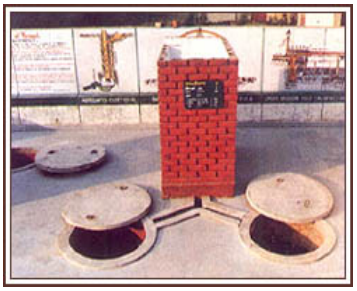
Prins opent sanitatieproject Waterschoon in Sneek tijdens succesvol symposium
Zijne Koninklijke Hoogheid de Prins van Oranje heeft **vrijdag 18 november 2011** de opening verricht van het duurzame en innovatieve sanitatiesysteem Waterschoon dat aangelegd is in de wijk de Noorderhoek in Sneek. Hij deed dit tijdens het Symposium Waterschoon 2011 in het bijzijn van zo'n 350 gasten.

www.waterschoon.nl

India; Sulabh toilet system:



Winner 2009 Water Prize Sweden!



Community on-site sanitation: "block units"

India; Sulabh toilet system: resource recovery!!

Biogas

Dried human manure
(granular form)

Electricity

Current best practice in slum areas: bio-latrines for community use

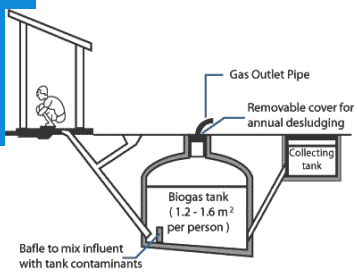
Existing systems:

- Nairobi: Kibera slum
- Kisumu: Nyalenda, Obunga, Manyatta and Bandani slums

Multifunctional facility. Biolatrines comprise:

- ground floor; toilets & showers;
- 1st floor; meeting room, office, kitchen and resource centre;
- Top floor: open sides & simple roof for large group meetings
- Design: HRT 120 d, 300-600p.e./d
- possibilities for water vending

Bio-latrine: sanitation coupled to waste valorisation?!



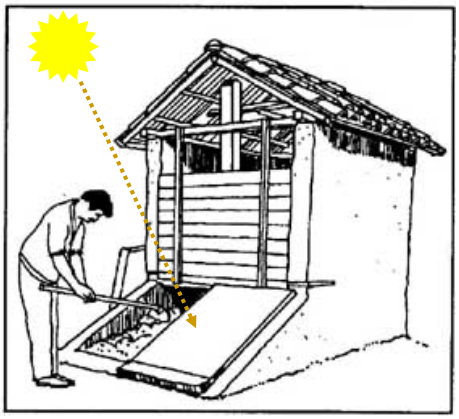
- prevent diseases
- prevent water pollution
- protect drinking water source
- produce nutrients
- produce soil conditioner
- produce energy

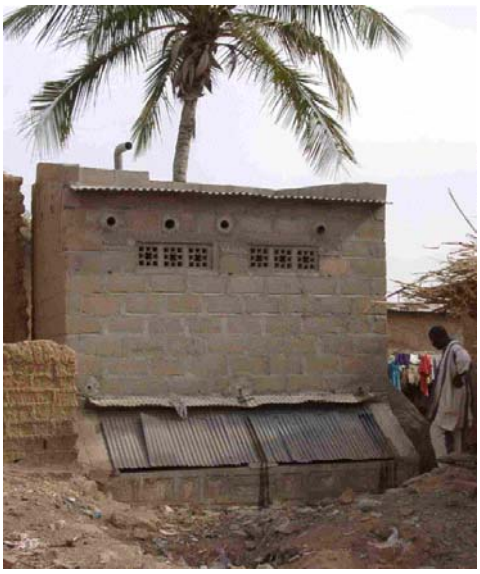
Bio-energy!

≈ 200 Wh.cap^{-1}.day^{-1}

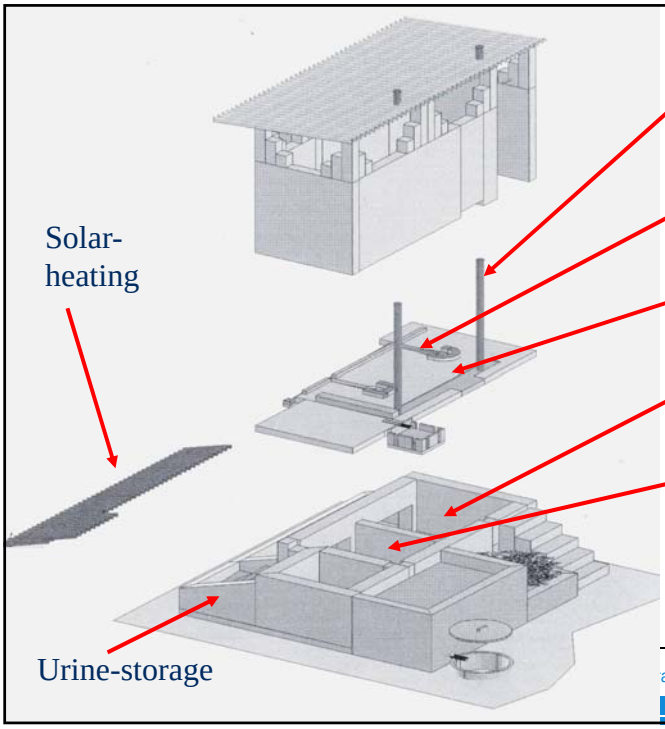
Application of water-less toilets in developing countries:

Solar Desiccation-Toilet
Low-Tech, very cheap, little maintainance required
(from Esrey et al., Ecological Sanitation, SIDA 1998)





Desiccation Toilet
Mali, West Africa
GTZ / Otterwasser GmbH

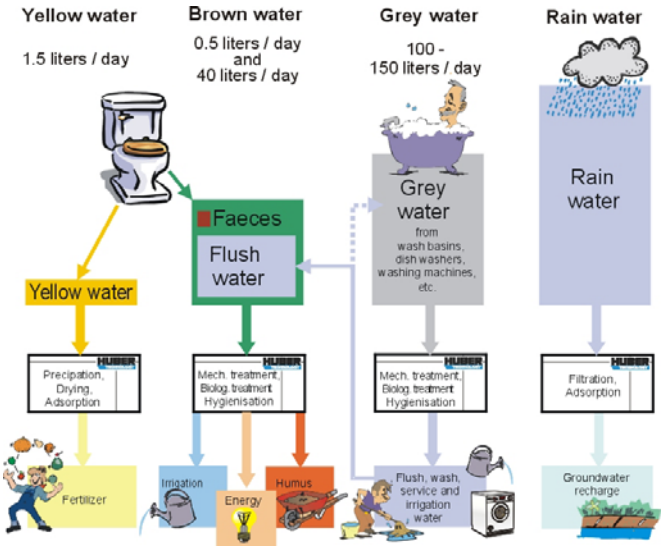


Conclusion

„No single measure would do more to reduce disease and save lives in the developing world than bringing safe water and adequate sanitation to all.“

UN Secretary-General Kofi Annan

Decentralized Sanitation and Reuse



Source: Huber Technology