Sanitation systems and technologies for developing countries

Kai Udert and Elizabeth Tilley

Eawag: Swiss Federal Institute of Aquatic Science and Technology

The problem

There is no urban wastewater management

or

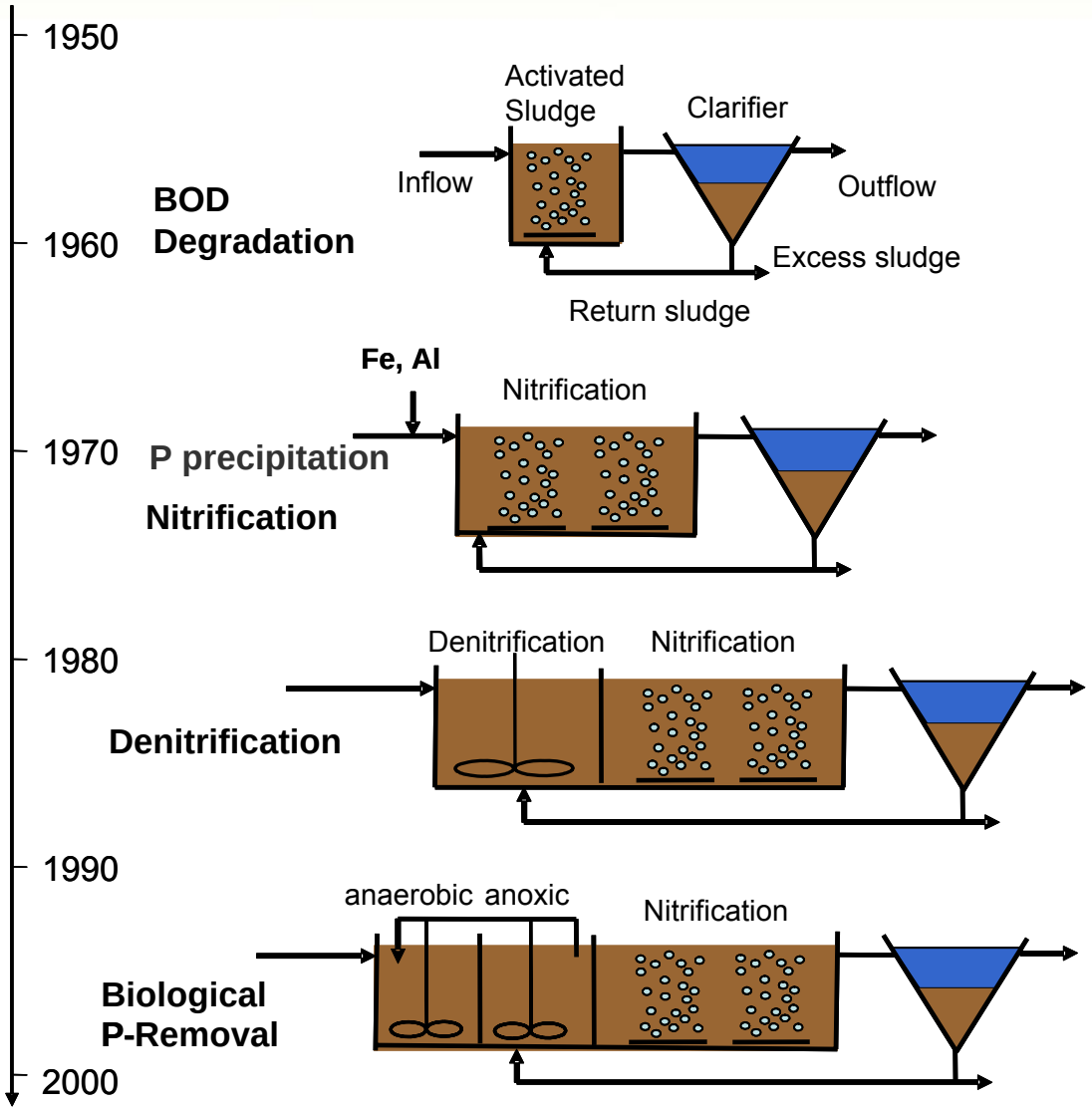
Technological solutions are not appropriate or not working

by courtesy of Christoph Lüthi

Wastewater treatment in Switzerland

Today's solution: large centralized wastewater treatment plants.

Development of Wastewater Treatment



	Sludge Age (days)	Volume (L pers[1])
BOD Degradation	2 – 4	20 - 40
P precipitation / Nitrification	8 - 12	80 - 140
Denitrification	10 - 15	100 - 160
Biological P-Removal	14 - 20	140 - 200

by courtesy of H.Siegrist

Centralized systems are effective but costly

97% of population connected to central WWTP

Estimated nutrient removal: 70% P 25% N

40’000 km public sewers and
about 40‘000 km private drains

Value of system: ~ 100 billion CHF
(about 14‘000 CHF/capita)

About 90% of the capital costs in the sewers

Operational costs: 3.5 billion CHF

by courtesy of Max Maurer
BUWAL (1996), BAFU (2008), Siegrist & Boller (1997)

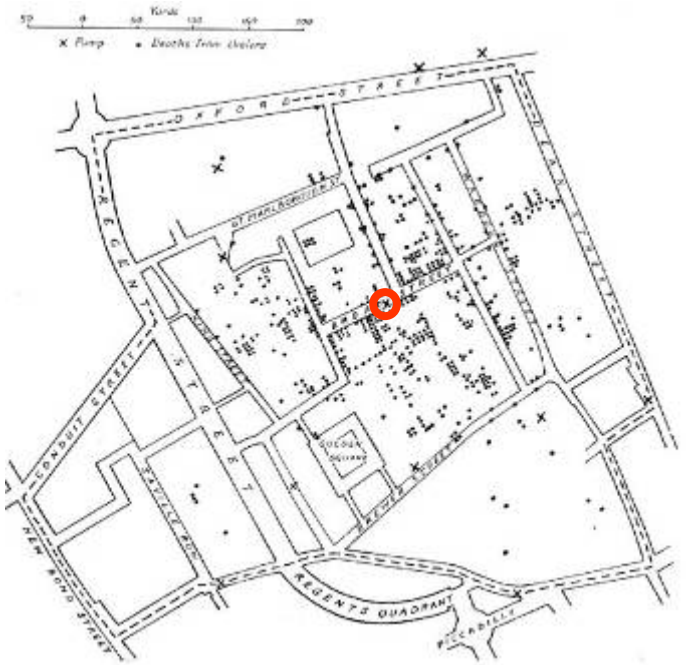
Wastewater Management in CH

What is the purpose?

?

What does the technology require?

?

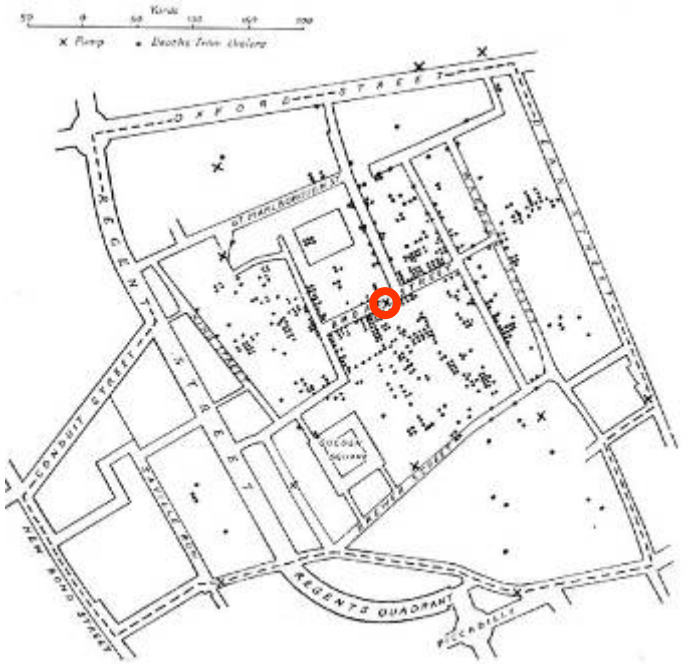


John Snow, London 1854

Wastewater Management in CH

What is the purpose?

- Hygiene
- Convenience
- Protection of nature and water resources



John Snow, London 1854

What does the technology require?

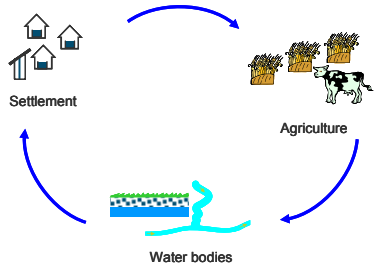
- Experienced staff
- Efficient administration
- Energy and resources (e.g. chemicals for precipitation)
- Water
- Money

Cities without sewers

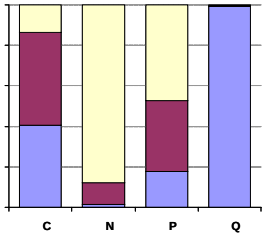
- Represent more than 90% of cities in developing countries
- Are very heterogeneous in urban infrastructure
- Often lack financial and human resources for sanitation development and upgrading

The wider view

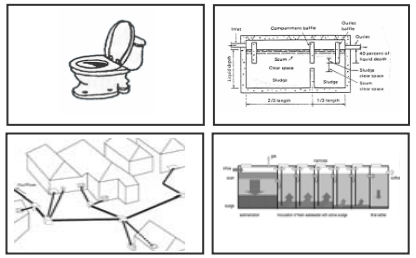
Cycles of water and nutrients



Wastewater is a mixture of very different streams

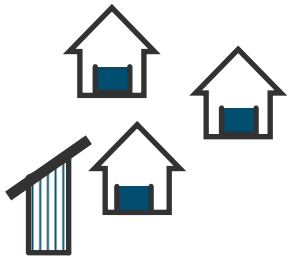


Necessary elements of sanitation systems



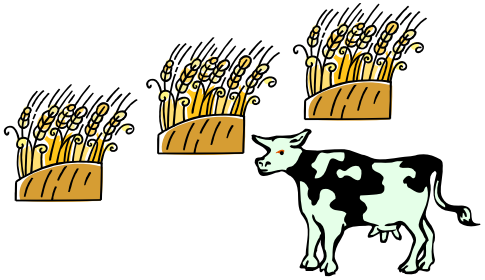
Organizational possibilities

Cycles

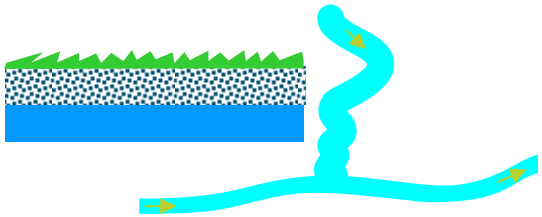


Settlement

?

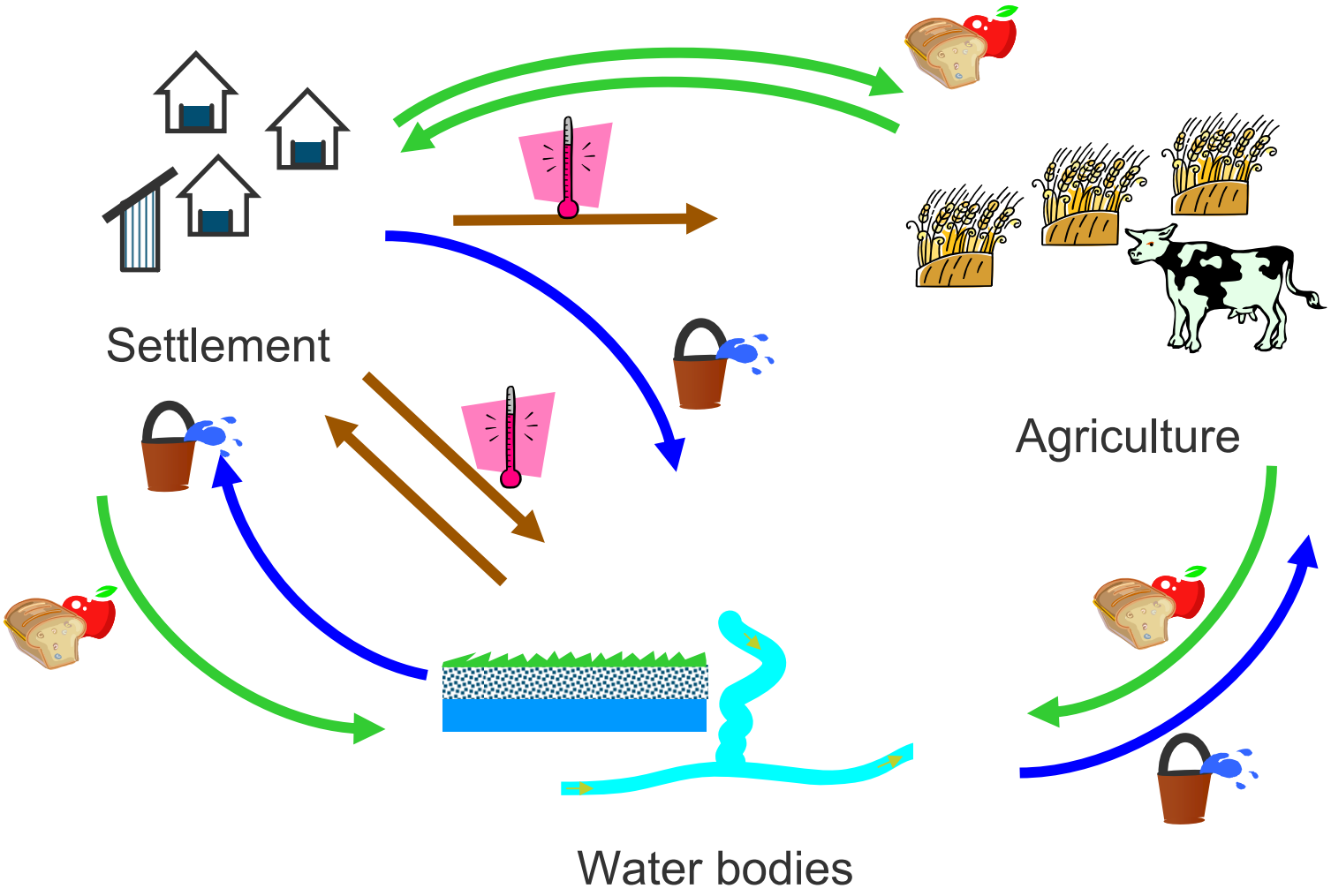


Agriculture



Water bodies

Cycles



Primary wastewater streams

	Total	Greywater***	Urine	Faeces
Volume [l/cap·yr]	25'000-100'000	**25'000-100'000**	500	50
Nutrients Nitrogen	2 - 4 kg/cap·yr	5%	**85%**	10%
Phosphorus	0.3 - 0.8 kg/cap·yr	10%**	**60%**	30%
Potassium	1.4 - 2.0 kg/cap·yr	34%	**54%**	12%
COD	30kg/cap·yr	**41%**	12%	**47%**
Faecal coliforms	-	**10^4-10^6 /100ml**	0*	**10^7-10^9 /100ml**

* healthy people
** can be as high as 50%, depending on washing and dish-washing powder used
*** values representative for industrialized countries

Additional inputs to the system

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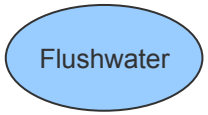
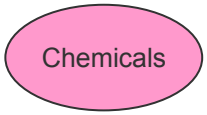


Flushwater

the water that is used to move excreta, urine or faeces and create a water-seal



Chemicals

cleaning detergents, pharmaceuticals

Organics

bulky, carbonaceous material required for its chemical and structural properties in some technologies

Dry Cleansing Material

material used to wipe oneself after urinating or defecating, e.g. paper, leaves, corncobs, rocks, etc.

Anal Cleansing Water

the water used to wash oneself after urinating or defecating

What goes OUT of a sanitation system?

Blackwater- mixture of urine, faeces, flushing water, anal cleansing water, dry cleansing material

Faecal Sludge- undigested, or partially digested slurry or solid that results from the storage or treatment of blackwater or excreta

Compost/Humus is the earth-like, brown/black material that is the result of decomposed organic matter

- Usually only blackwater is considered in sanitation planning
- Sanitation systems must be designed by keeping all inputs and products in mind
- Faecal sludge is commonly ignored/forgotten

Faecal Sludge- Nobody‘s friend

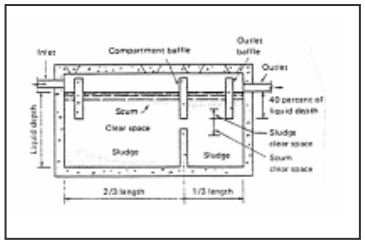
Thick and yellow- from unsewered family toilets emptied every few weeks: unstable sludge

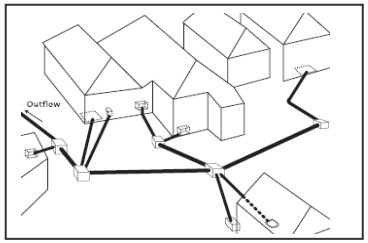
Thin and black - sludge that is ,‘septic‘ and is emptied after years of storage: partially stable

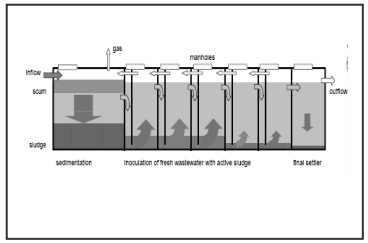
What are the parts of a sanitation system?

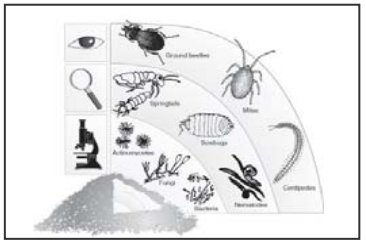
What are the parts of a sanitation system?

User Interface	Collection and Storage	Conveyance	(Semi-) Centralised Treatment	Reuse and Disposal

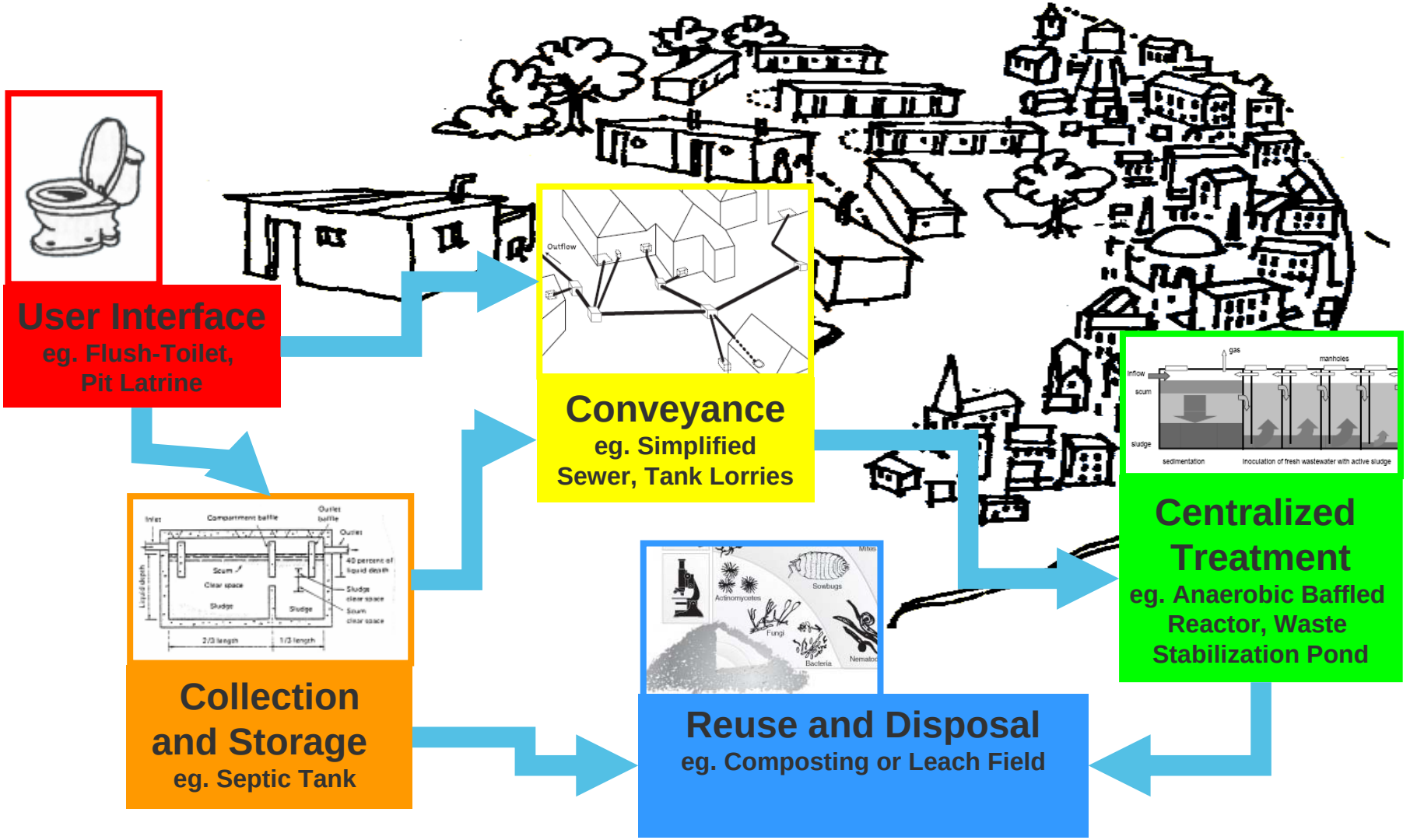




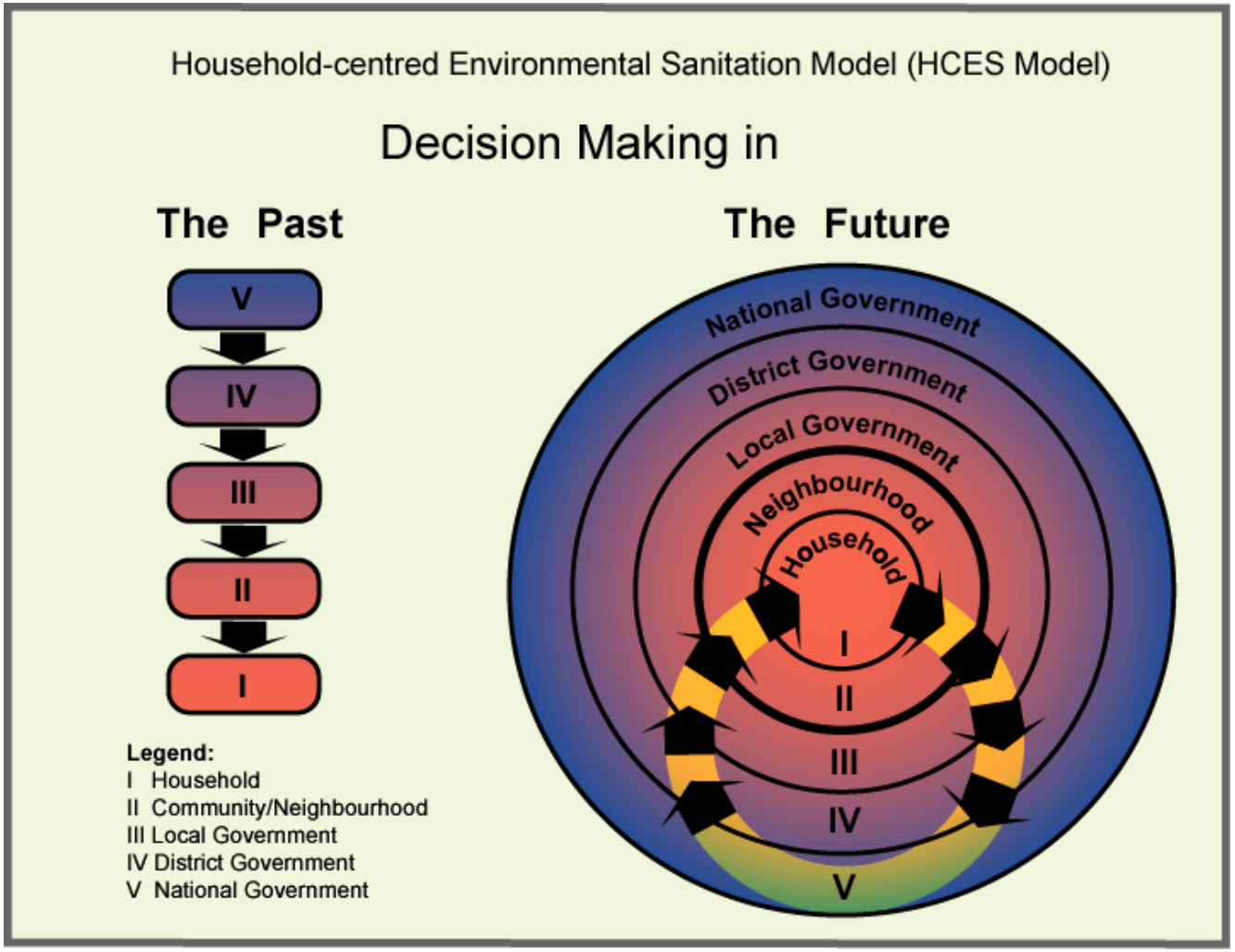




Processes of sanitation systems

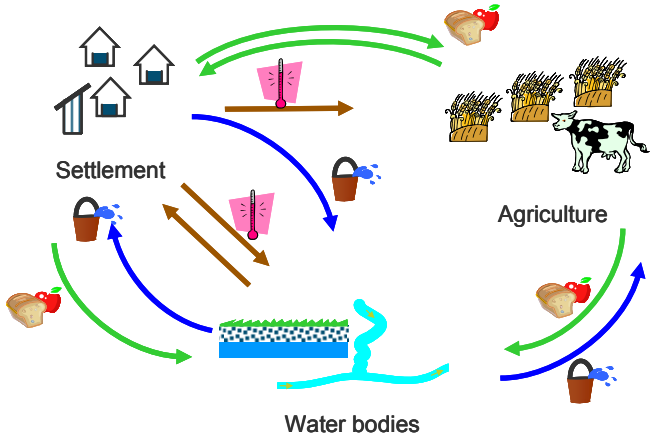


HCES: Iterative process of decision making

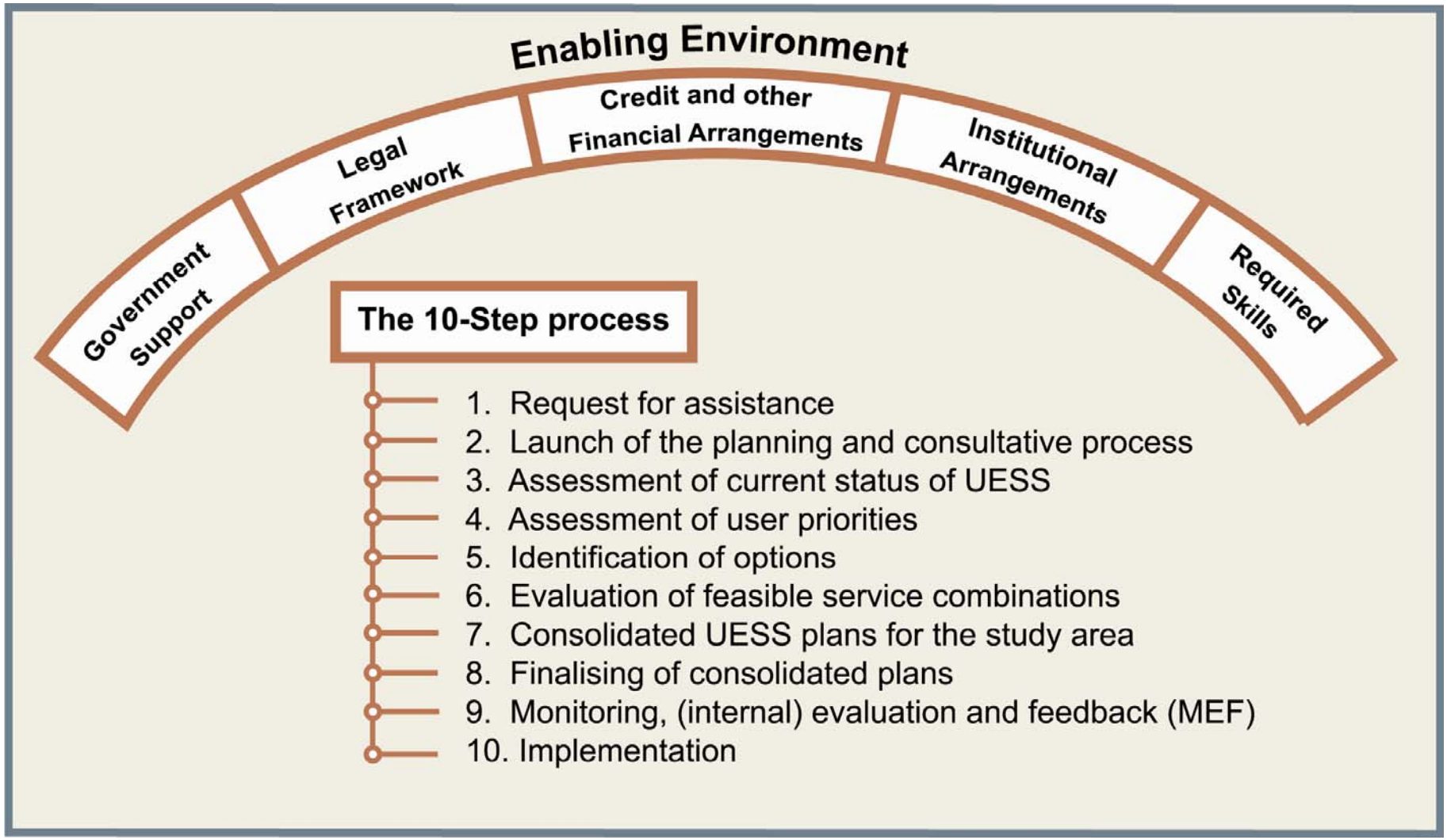


Household-Centered Environmental Sanitation

- the household and the neighbourhood are at the core of the planning process
- solving problems within the ‘zone’ nearest to where the problems arise
- bottom-up and top-down approaches within an integrated framework
- circular model, emphasising resource conservation and reuse

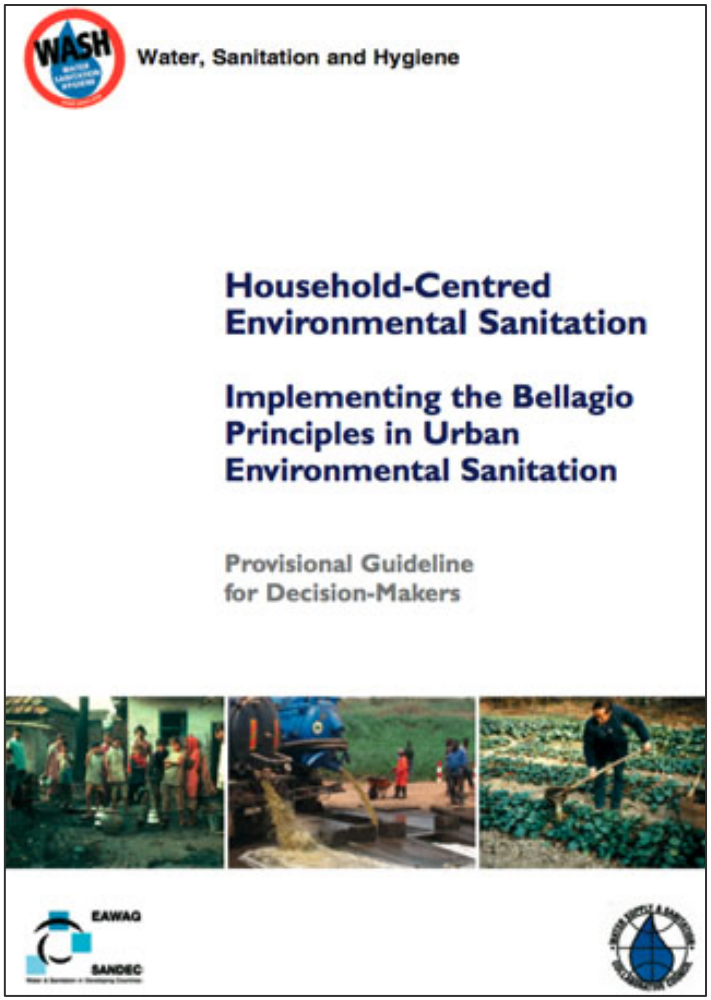


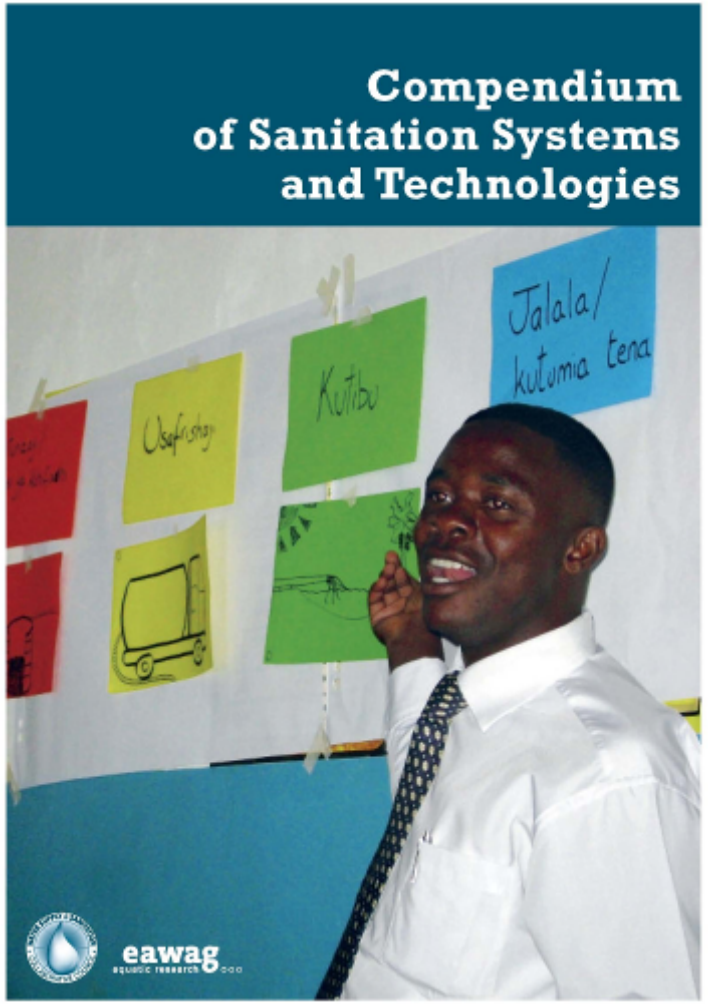
10-steps of HCES



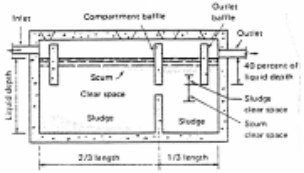
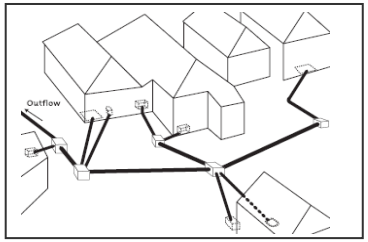
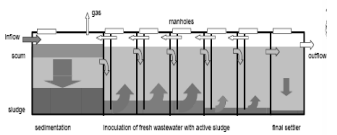
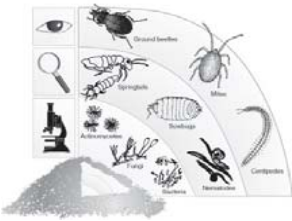
Current guidelines from Eawag / Sandec

HCES and the Compendium of Sanitation Systems and Technologies





Technologies for the user-interface

User Interface	Collection and Storage	Conveyance	(Semi-) Centralised Treatment	Reuse and Disposal
				
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No flushing

Inputs

User Interfaces

Products fed into the Sanitation System

Urine

Faeces

Cleansing material/water

Dry Toilet

(1)

(2)

Excreta

Urine

Faeces

Urine Diverting Dry Toilet

(3)

Urine

Faeces

With flushing

Products

User Interfaces

Products fed into the Sanitation System

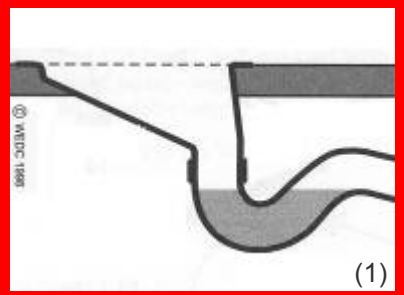
Urine

Faeces

Flushwater

Cleansing material/water

Pour-Flush Toilet



(1)


(2)

Blackwater

Urine

Faeces

Flushwater

Cleansing material/water

Cistern-Flush Toilet

(4)


(3)

Blackwater

Technologies for the collection and storage

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	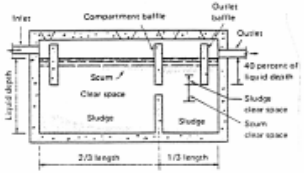	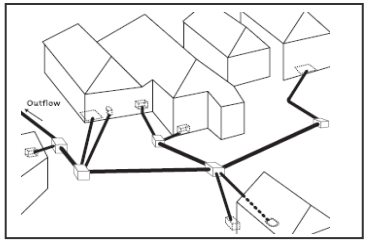	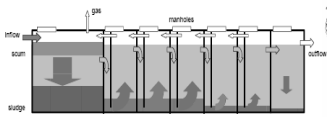	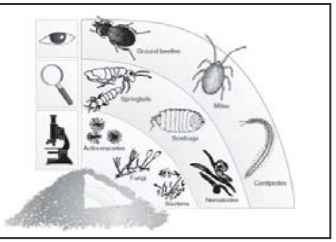
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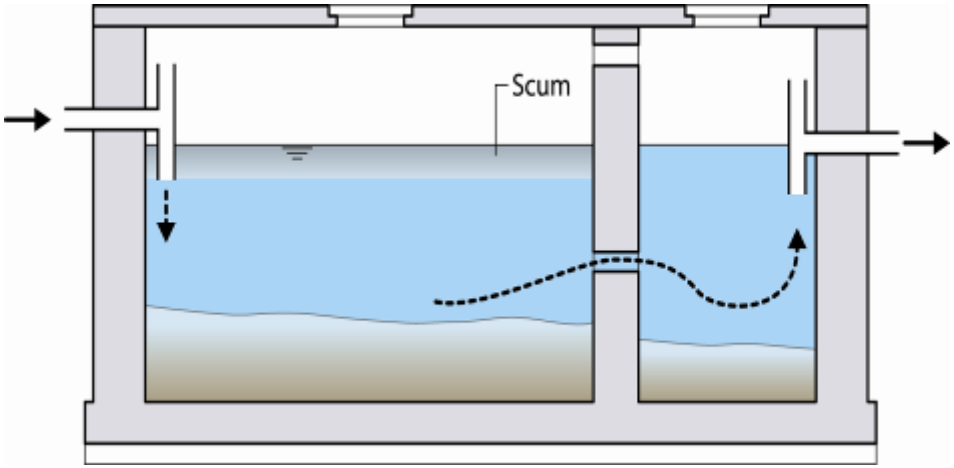
Septic tank

sedimentation

partial stabilization by anaerobic digestion



- most frequent onsite treatment unit worldwide
- 2 to 3 compartments

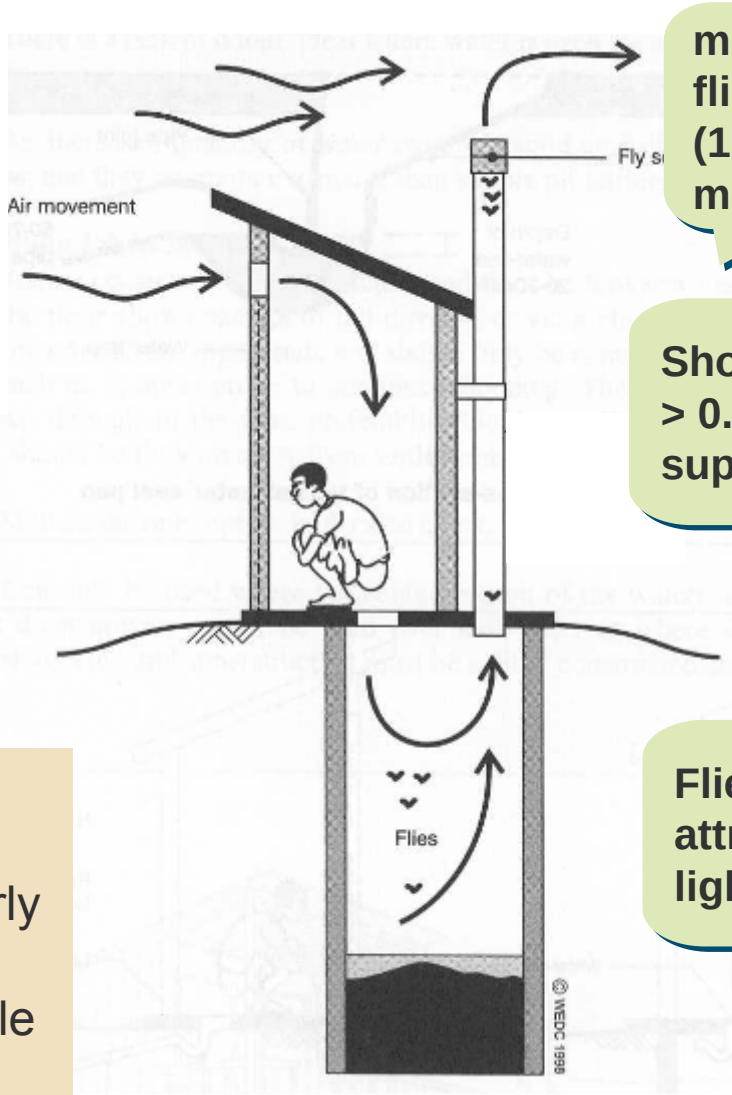
\+ simple, little space required because of being underground
\+ low O&M costs

\- little removal of dissolved and suspended matter (COD removal approx. 50%)
\- high investment costs

VIP latrine (ventilated improved pit latrine)

Naturally induced ventilation with screened ventilation pipe

→ removes odor and prevents escape of flies



mesh traps flies (1.2-1.5 mm mesh) size

Should extent > 0.5 m above superstructure

Flies are attracted by light from pipe

\+ odors and flies reduced

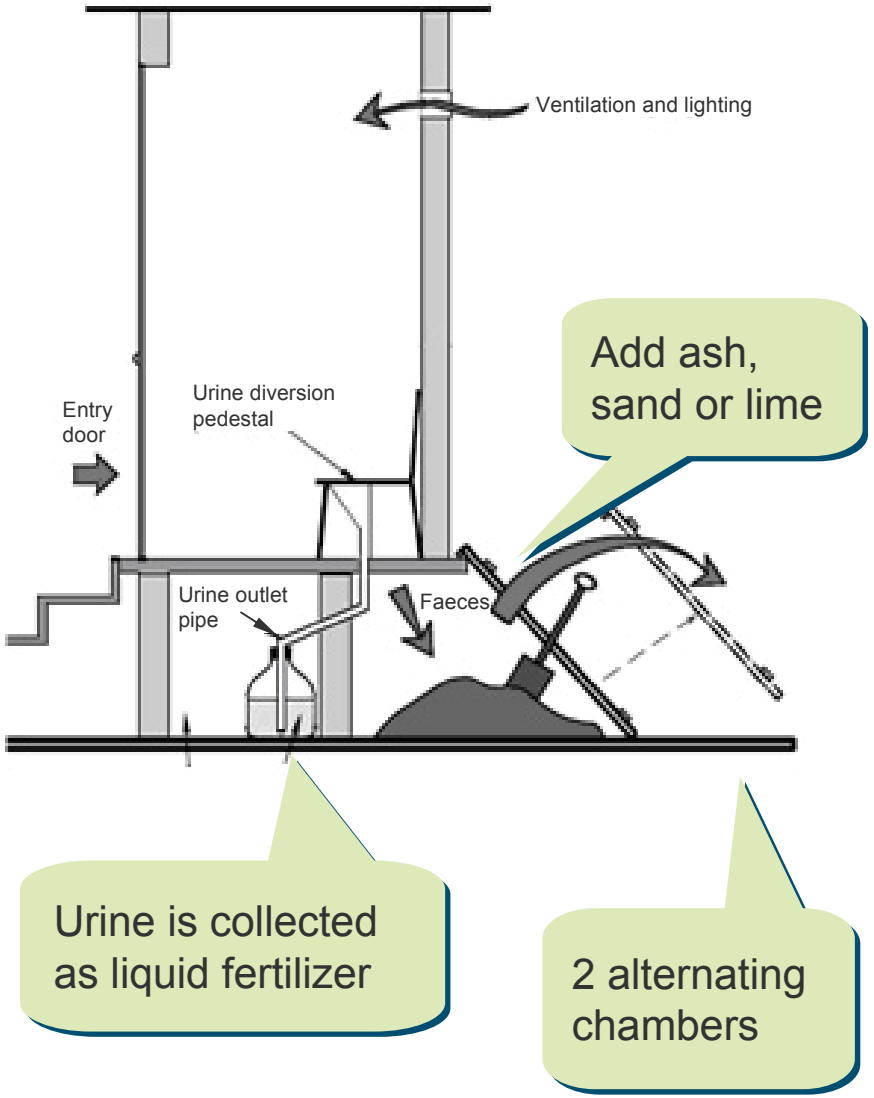
\- difficult to construct properly

\- more expensive than simple pit latrine

Deyhdration vaults

Requirements
- special squatting pan/seat
- education and acceptance
- constant source of ash, sand etc.
- a use or discharge point for urine

+ no waste, but fertilizer
+ simple to design
+ little flies or odours if used correctly
+ easy and safe handling of dried material



Conveyance technologies

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	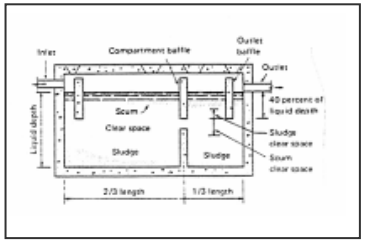	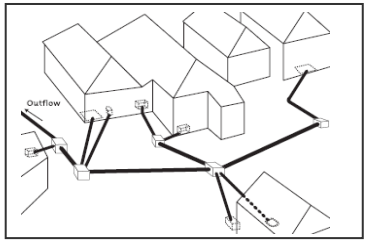	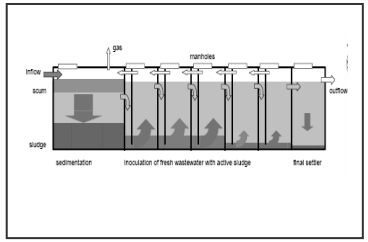	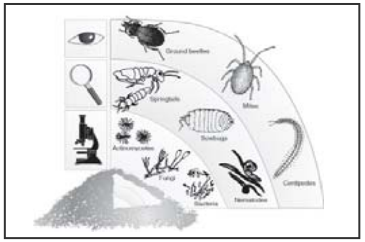
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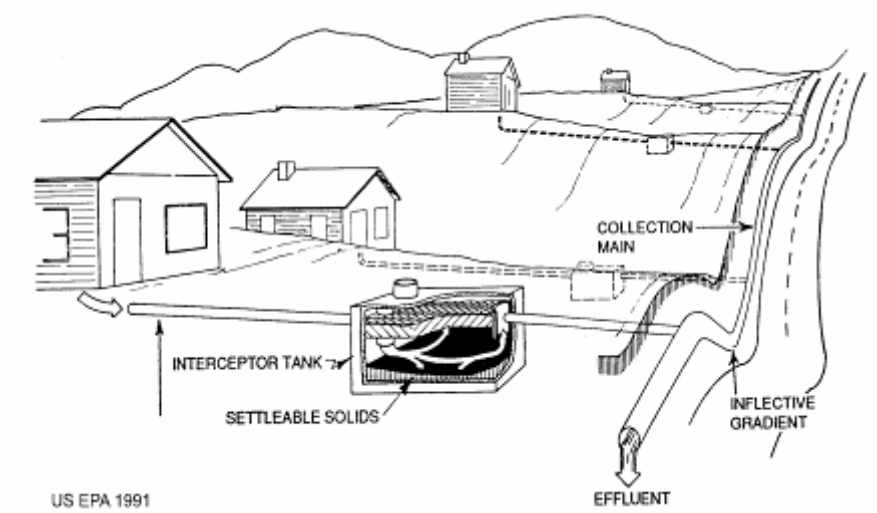
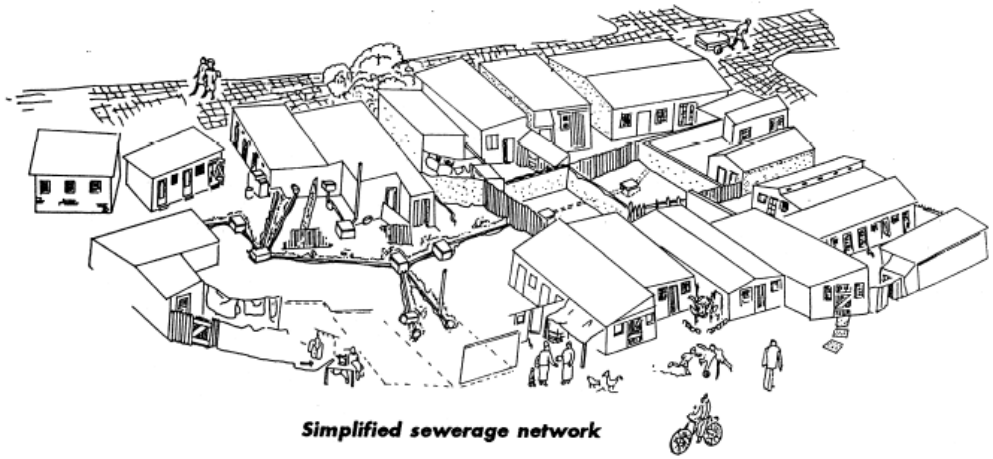
Sewers

Settled sewer



- especially adequate where septic tanks already exist.
- Less strict- negative gradients
- relies on good solid removal in septic or interceptor tanks

Simplified sewer



- Simplified eg. fewer manholes, smaller pipe diameters, flatter gradients, shallow etc.
- sewers laid inside housing blocks or under pavements.
- cheaper than common sewers

Faecal sludge emptying and transport

Mechanized

+ high efficiency
- High O&M and capital cost
- Spare parts often lacking
- Difficulty in manoeuvring (vehicle size, traffic congestion, infrastructure)

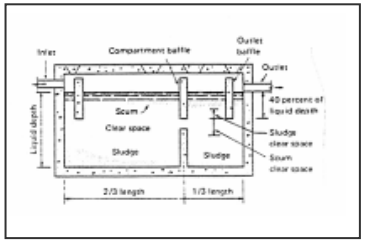
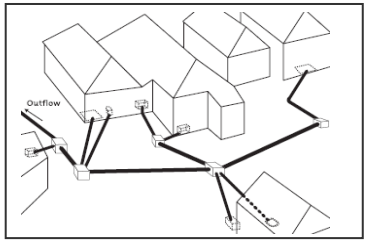
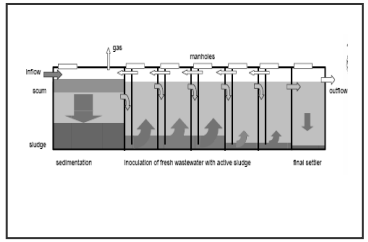
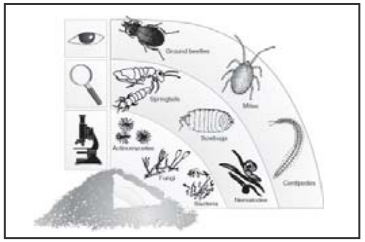
Manual

+ Low-cost operation and maintenance
+ Maintenance skills and spare parts available
- Limited efficiency

Manual FS Emptying and Transport- GULPER

Photo: Steve Sugden

Treatment technologies

User Interface	Collection and Storage	Conveyance	(Semi-) Centralised Treatment	Reuse and Disposal
				
-Dry Toilet -Urine Diverting Dry Toilet -Urinal -Pour Flush Toilet -Flush Toilet	-Single Pit -Single Pit VIP -Alternating Dry Double Pit -Alternating Wet Double Pit -Double Dehydr. Vaults -Aquaprivy -Septic Tank -Composting Chamber	-Manual Emptying -Mechanical Emptying -Simplified Sewers -Small-Bore Sewer -Conventional Gravity Sewer -Jerry can/tank	-Imhoff Tank -Anaerobic Baffled Reactor -Anaerobic Filter -Trickling Filter -Waste Stabilization Ponds -Finishing Pond -Constructed Wetland -Co-composting etc.	-Application of Urine -Application of Dehydr. Faeces -Compost -Irrigation with Wastewater -Aquaculture -Soak Pit -Leach Field -Incineration -Land application -Surface Disposal

Waste stabilization pond

Anaerobic Pond	Facultative Pond	Maturation Ponds

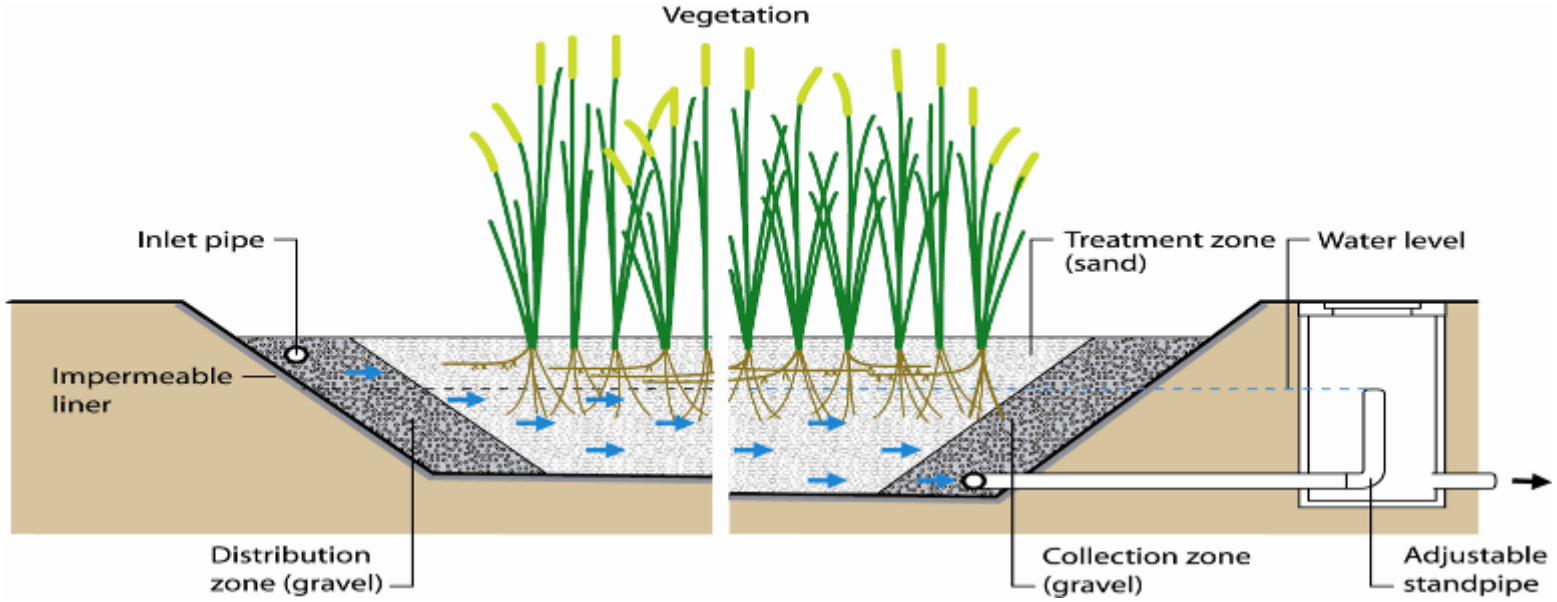
Sedimentation and anaerobic stabilisation of sludge (BOD reduction 40-50%) → **settling**	Aerobic degradation of suspended and dissolved matter (BOD reduction 50-70%) → **degradation**	Final sedimentation of suspended solids, bacteria mass and pathogens → **hygienization**

\+ Can treat high strength wastewater to high quality effluent
\+ Generally reliable and good functioning
\+ Very inexpensive compared to other centralized options

\- Not always appropriate for colder climates
\- Potential for bad odours if poorly designed
\- Requires expert design and supervision
\- Requires a lot of space

Constructed wetlands (here: horizontal sand filter)

→ For treatment of (pre-settled) domestic or industrial WW

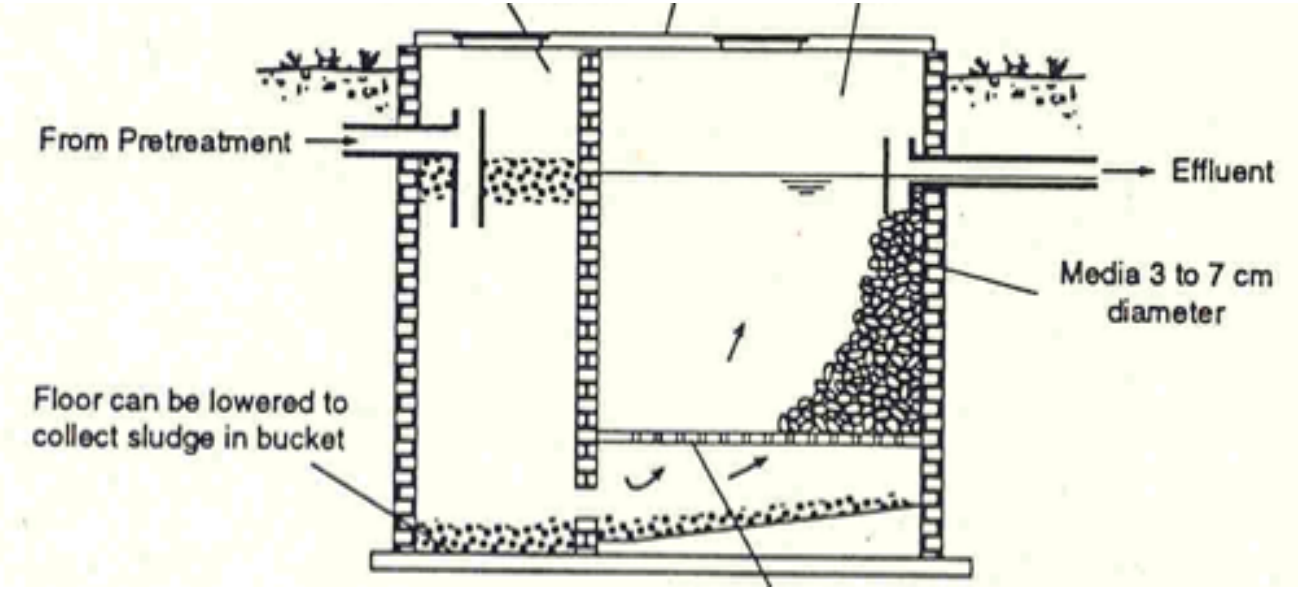


+ high treatment efficiency for COD (up to 95% COD removal) but not for N or P
+ no WW above ground, no nuisance of odour, high nutrient removal
- high space requirement, costly (gravel), great care required during construction

Anaerobic filter

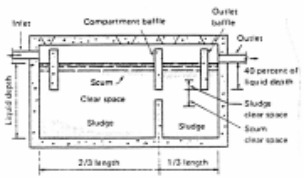
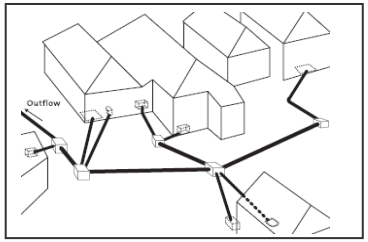
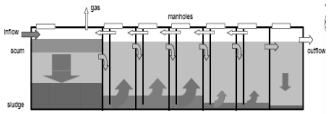
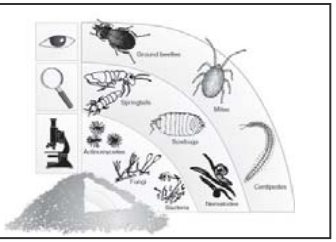
Used for pre-settled domestic wastewater (e.g.greywater)

Principle: close contact of wastewater with active bacterial mass on filter media



+ simple and durable if operated correctly
+ high treatment efficiency (for COD but not N or P)
+ little space requirements
- high construction costs (filter media)
- blockage of filter possible
- maintenance costly and difficult

Reuse and disposal technologies

User Interface	Onsite Storage and Treatment	Conveyance	Treatment	Reuse and Disposal
				
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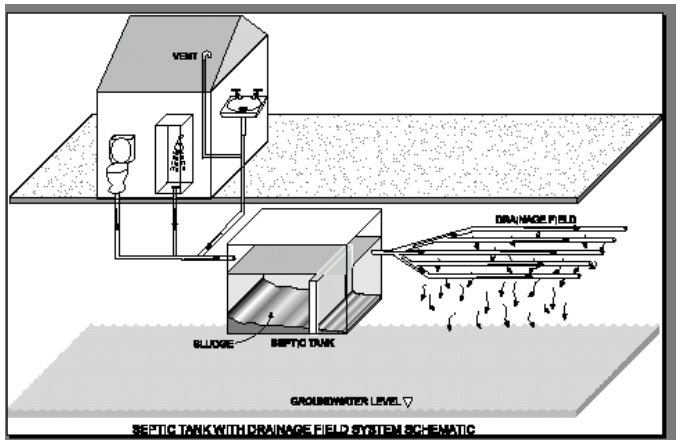
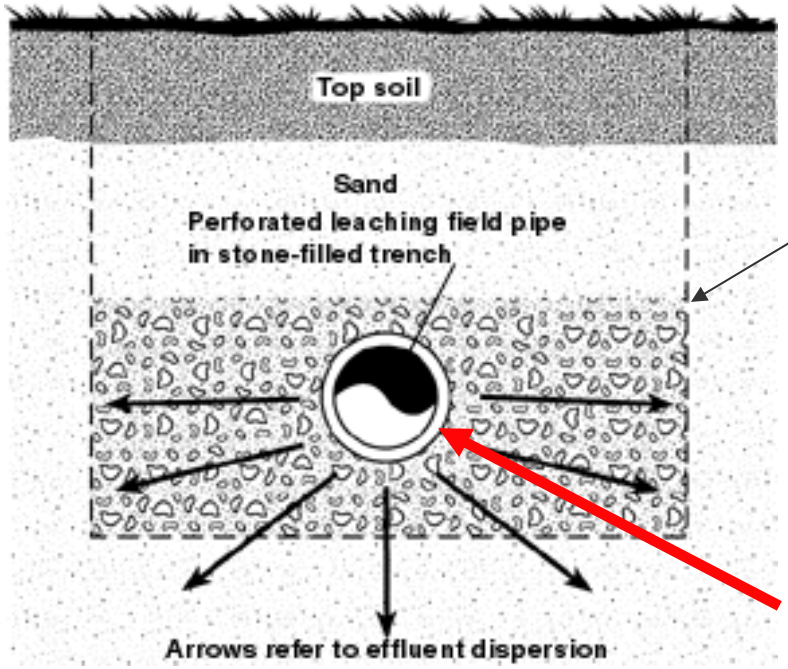
Leaching fields

system of trenches that is used to dissipate the effluent from a septic tank

or discharge of non-solid septic tank effluent

+ little maintenance required
- Space and skills required !





sand and/or topsoil

fabric, to prevent plugging of pipe

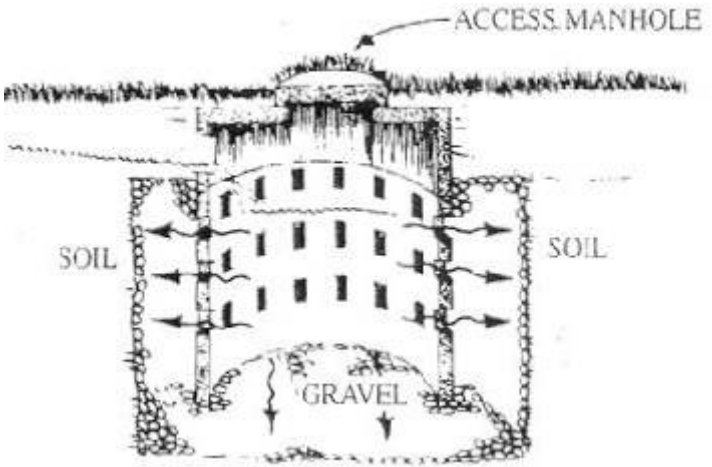
clean rock

perforated distribution pipe

Soak pits

Covered, porous-walled chamber that allows water to slowly soak into the ground.

for non-solid septic tank effluent (clogging!)



Between 1.5 and 4 m deep

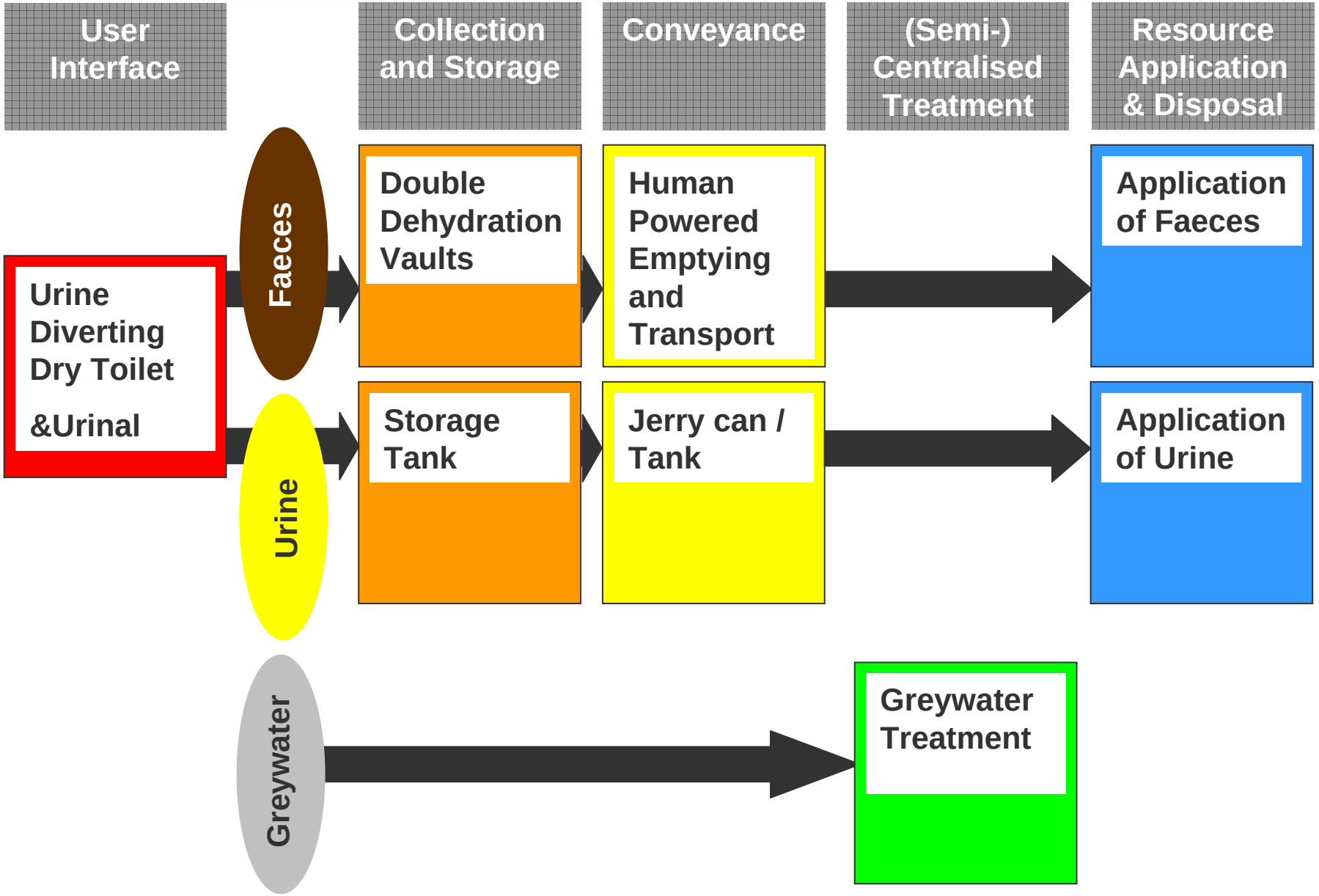
+ simple and cheap
+ little space required

- not adequate for shallow ground water table (>1.5 m)
- not adequate in clay or rocky soils

Quality standards for reuse of waste products

Waste product	Reuse Application	WHO Guidelines		
Urine	Irrigation of food and fodder crops to be processed	≥1 month storage (4°C)		
	Irrigation of food and fodder crops to be processed, fodder crops unprocessed	≥6 month storage (4°C)	or	≥1 month storage (20°C)
	Irrigation of all crops	≥6 month storage (20°C)		
Treated Wastewater	Unrestricted irrigation	≤10-100 EC/100ml	≤1 Helm.eggs/l	
	Restricted irrigation	$\leq 10^5$-10^3 EC/100ml	≤1 Helm.eggs/l	
	Localized irrigation	$\leq 10^6$-10^5 EC/100ml	≤1 Helm.eggs/l	
Greywater	Unrestricted irrigation	$<10^5$-10^6 EC/100ml	<1 Helm.eggs/l	
	Restricted irrigation	$<10^4$-10^3 EC/100ml	<1 Helm.eggs/l	
Excreta (untreated FS)	Agriculture (Soil conditioner)	$<10^3$ EC/g total solids	<1 Helm.eggs/g total solids	
	Aquaculture	$\leq 10^{-6}$ EC/100ml	≤1 Helm.eggs/l	No detectable trematode eggs

Example: Urine separation and application



New approaches and new technologies

Photos: Bastian Etter

Some major problems

Transport:
- sewers are expensive
- faecal sludge handling is tidious

Treatment:
- low performance for nutrient removal
- environmental pollution
- little nutrient recovery

Organization:
- institutional structure and political will is missing
- for private initiative, excreta need to have a value

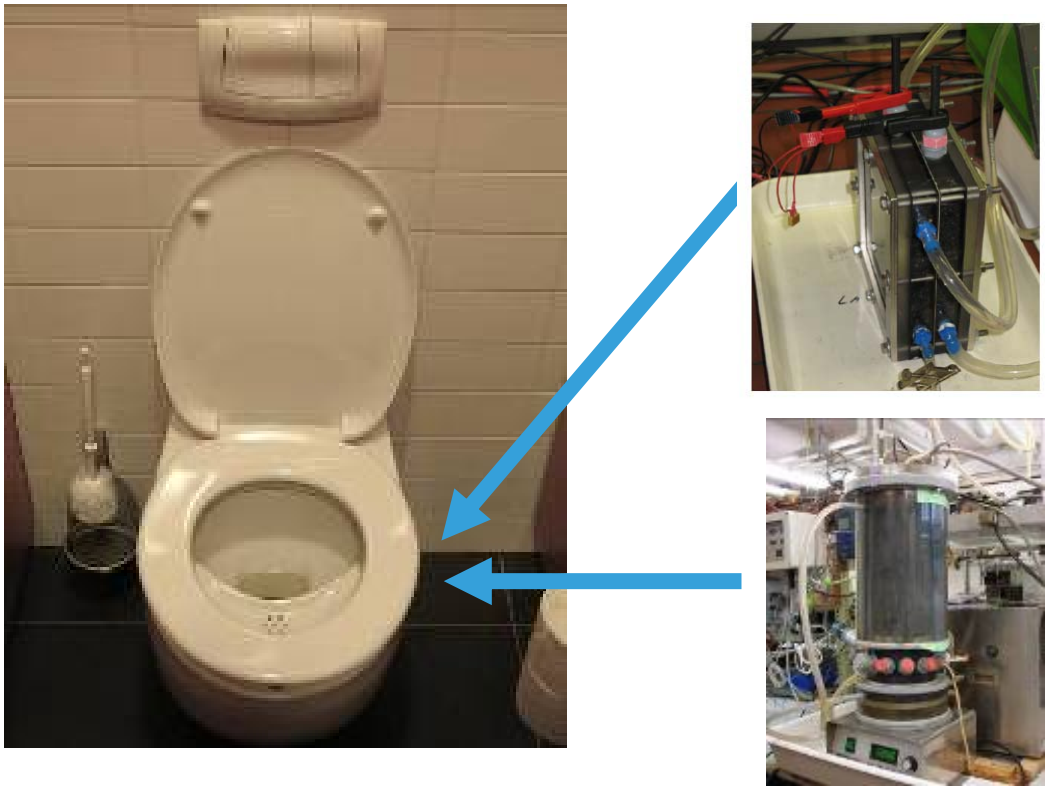
Possible solution

High efficient, industrially produced reactors

Decentralized treatment

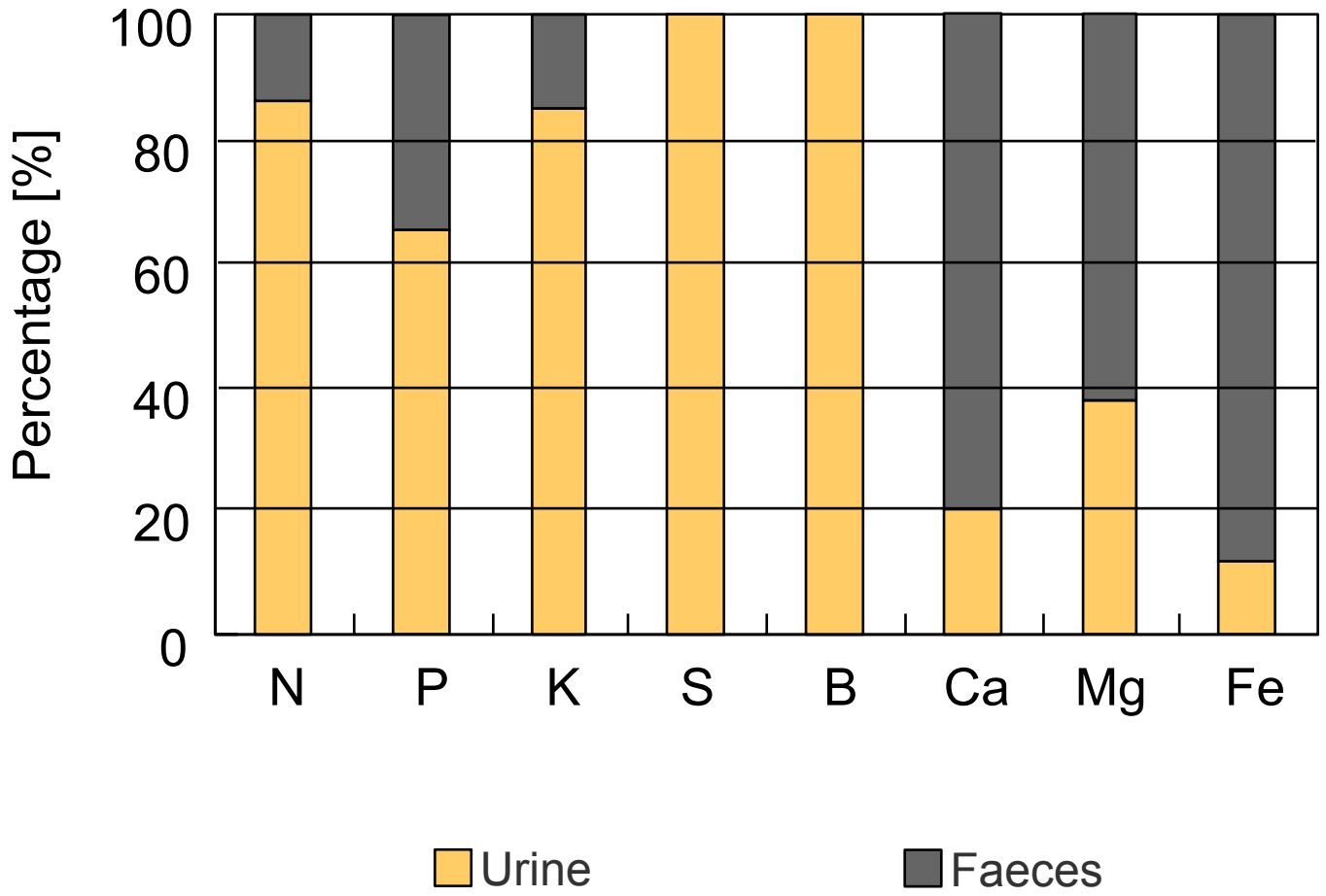
Source-separation

Producing a fertilizer



Can we integrate urine treatment in a toilet?

Nutrients from Human Metabolism



Changes during urine storage

		Fresh	Stored
Urea	$g_N\ m^{-3}$	7700	0
Ammonium	$g_N\ m^{-3}$	500	8200
Phosphorus	$g_P\ m^{-3}$	740	540
Bicarbonate	$g_C\ m^{-3}$	0	2900
Magnesium	$g\ m^{-3}$	100	0
Calcium	$g\ m^{-3}$	190	0
pH		6.2	9.1

What to do with phosphorus?

Struvite precipitation by magnesium addition:

$Mg^{2+} + NH_4^+ + PO_4^{3-} \rightarrow MgNH_4PO_4 \cdot 6H_2O$

fast reaction (<10 min)

efficient P removal: 99%

micropollutants are not incorporated in struvite fertilizer

Struvite ($MgNH_4PO_4 \cdot 6\ H_2O$)

STUN: Struvite Recovery from Urine in Nepal

Hypothesis

- urine from UD toilets is not used optimally
- transport and spreading limit usefulness
- struvite could supplement chemical fertilizers and reduce urine waste

Goal

- develop an economically and environmentally sustainable urine-derived fertilizer that can be produced at the community scale

MOVIE