BIOL 252: MICROBIAL ECOLOGY
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Water Treatment

THOUSANDS HAVE LIVED WITHOUT LOVE NOT ONE WITHOUT WATER

W.H. AUDEN

- Drinking water should be essentially free of disease-causing microbes, but often this is not the case.
  - A large proportion of the world's population drinks microbially contaminated water, especially in developing countries
- Using the best possible source of water for potable water supply and protecting it from **microbial** and **chemical contamination** is the goal
- The burden of providing microbially safe drinking water supplies from contaminated natural waters rests upon **water treatment processes**
  - The efficiency of removal or inactivation of enteric microbes and other pathogenic microbes in specific water treatment processes
  - The ability of water treatment processes and systems to reduce waterborne diseases

Sustainable Development Goals (SDGs)

Render water safe, palatable, clear, colourless, odourless etc.

Pre-Treatment

- Pass through a series of **core screens** to remove debris
- Cascade and settle it in the open

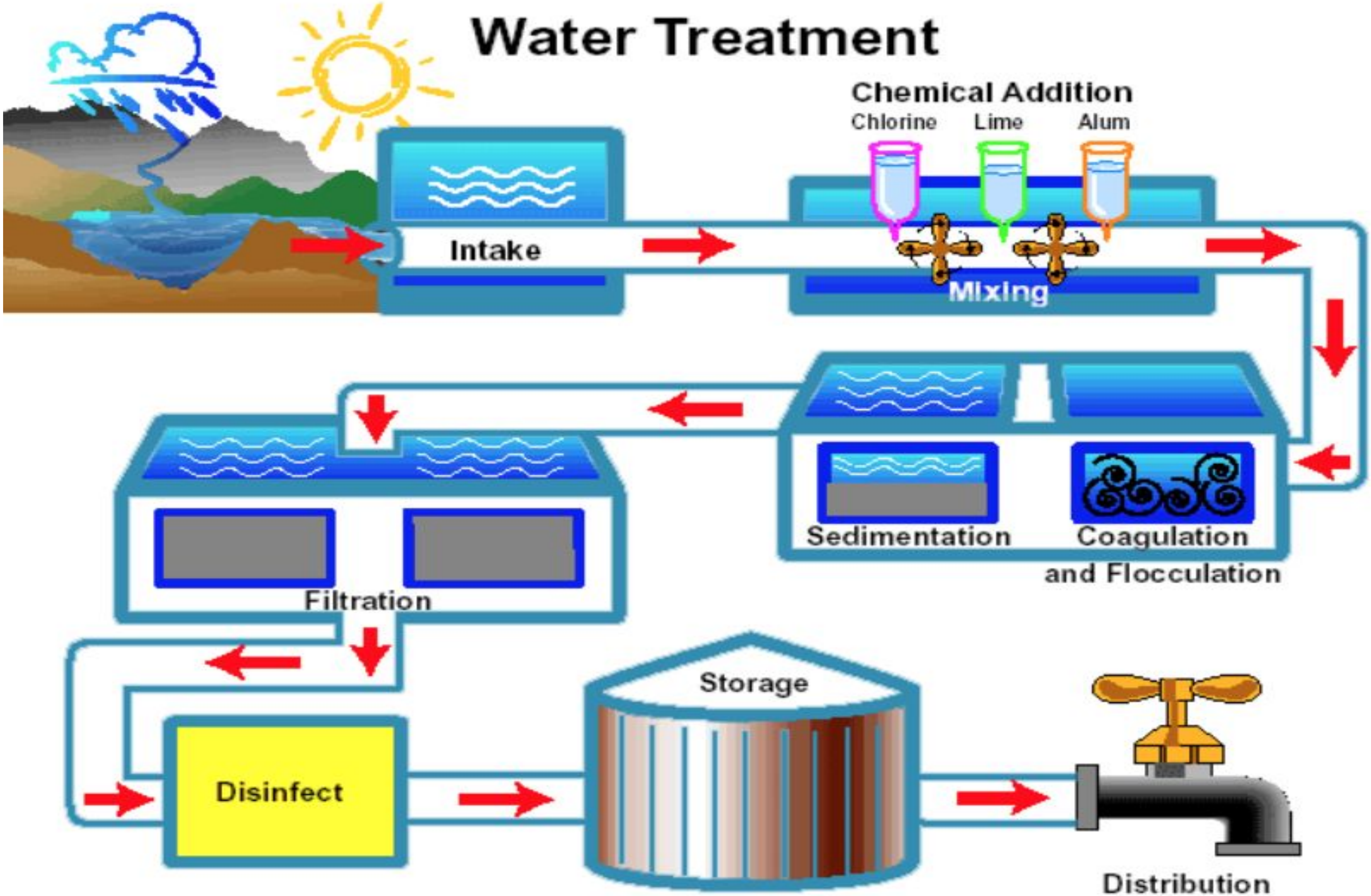
✔ settling particulate matter

✔ microbes exposed to lethal effect of sunlight

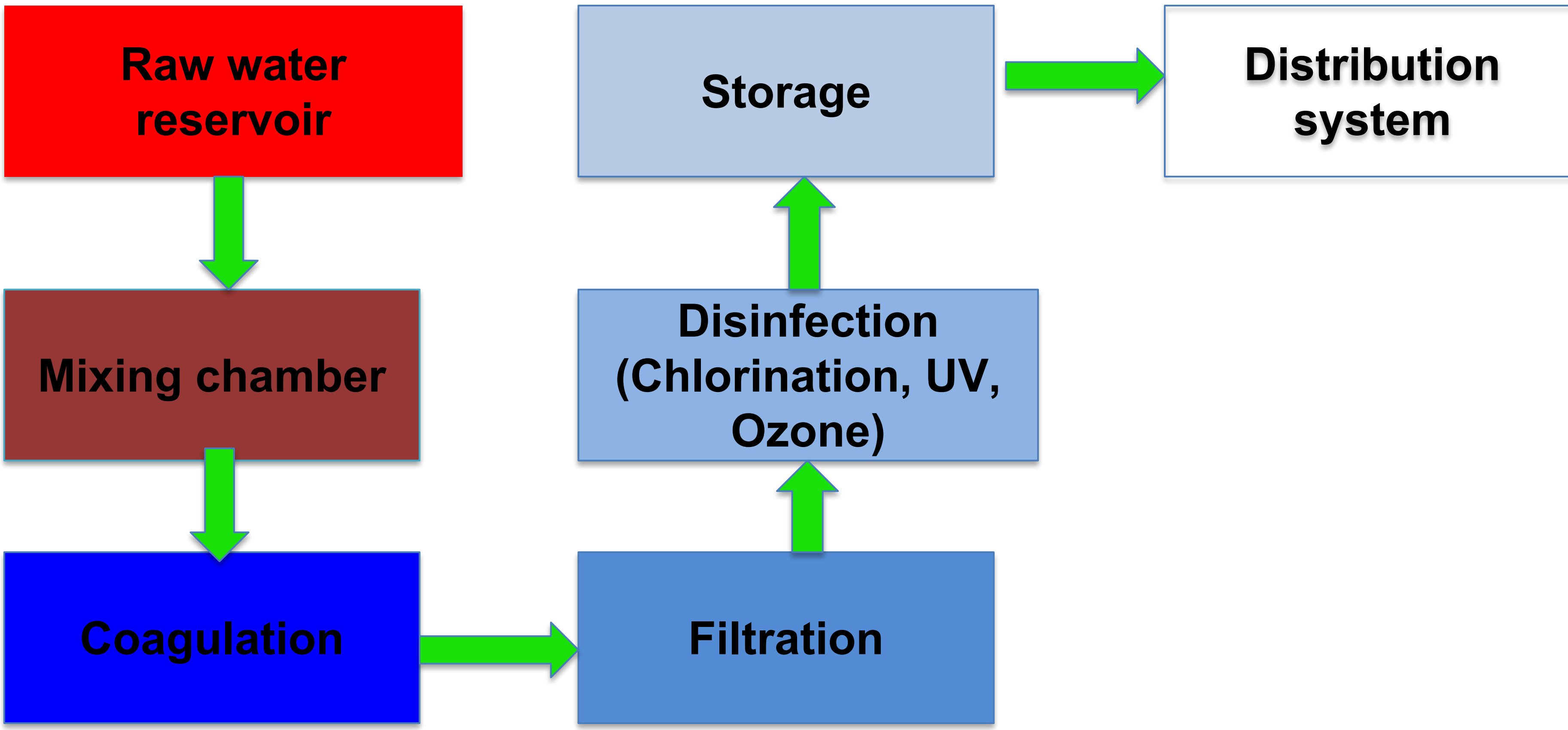
✔ reduce colour by bleaching

✔ oxidizing the impurities that may affect taste.

Sometimes pre-chlorination may be done when the **bacterial count** in the raw water is **high** with **low turbidity** BUT this may sometimes be a waste and expensive


Water Treatment
Chemical Addition
Chlorine
Lime
Alum
Intake
Mixing
Sedimentation
Coagulation
and Flocculation
Filtration
Disinfect
Storage
Distribution

A schematic flow chart of a typical water treatment plant



The treatment process

1. Mixing Chamber

Raw water mixed with a **flocculant** (a substance that promotes clumping)

Examples of flocculants:

Aluminum sulphate (ALUM)

Aluminum hydroxide

Ferrous sulphate

NOW Organic POLYMERS

Role: Encourages sedimentation, removes high numbers of microbes

Flocculation:

Slow mixing (flocculation) that provides for a period of time to promote the **aggregation** and **growth** of the insoluble particles (flocs).

- The particles collide, stick together and grow larger
- The resulting large floc particles are subsequently removed by gravity sedimentation (or direct filtration)
- Smaller floc particles are too small to settle and are removed by filtration

2. Coagulation

Removes suspended particulate and colloidal substances from water, including microorganisms.

Coagulation: Colloidal destabilization

- Typically, add alum (aluminum sulfate) or ferric chloride or sulfate to the water with rapid mixing and controlled pH conditions
- Insoluble aluminum or ferric hydroxide and aluminum or iron hydroxo complexes form
- These complexes entrap and adsorb suspended particulate and colloidal material.

3. Filtration

This is through a series of clean sand with different sizes.

Aim: Removes most microbes particularly the protozoans (*Giardia*, *Cryptosporidium*)

- Rapid granular media
- Slow sand and other biological filters
- Membrane filters: micro-, ultra-, nano- and reverse osmosis

Other physical-chemical removal processes

- Chemical coagulation, precipitation and complexation
- Adsorption: e.g., activated carbon, bone char, etc,
- Ion exchange: synthetic ion exchange resins, zeolites, etc.

If filter becomes blocked due to biofilms and retention of debris, its cleaned by forcing clean water back through the filter (**backwashing**)

Cryptosporidium outbreak in Milwaukee and Oxford

4. Disinfection

- Physical: Reverse osmosis, heat, membrane filters

- Chemical: Chlorine, ozone, chlorine dioxide, iodine, other antimicrobial chemicals

- UV radiation

Physical methods:

Reverse Osmosis (RO)

- Separation of particles contained in water from the aqueous component. It is primarily used for the desalination of seawater

Advantage:

- It is relatively low in energy consumption

Disadvantages:

- Potential clogging of RO membranes
- Chemical reaction with RO membranes (e.g. cellulose acetate membranes) if feed water is too acidic or alkaline

Physical method:

Distillation

- Uses heat to separate the aqueous phase of water from the solid phase or particulates
- It provides the purest water which is often free from all pathogens

Disadvantage

- Not a practical alternative as a means for the production of potable water.
- Requires high energy input

Chemical method

- Chlorine may be added as the gas(Cl_2), as sodium hypochlorine (NaOCl)
- Chlorine gas introduced into water hydrolyzes according to the following equation:
- $Cl_2 + H_20 \leftrightarrow HOCl + H^+ + Cl^-$

Chlorine gas

Hypochlorous acid

Hypochlorous acid dissociates in water according to the following:

- $HOCl \leftrightarrow H^+ + OCl^-$

Hypochlorous acid

Hypochlorite ion

Chlorination

- Chlorine can be added by gas, liquid or solid

- Chlorine hydrolyses to form hypochlorous acid which dissociates to produce hypochlorite

- Chlorine ensures microbiological safety in water supplies

- Residual chlorine is usually 0.1 to 0.3 mg/l high enough to kill most bacteria within 30mins but not high for protozoans and enteric viruses

- High chlorine affects taste

Mechanism of action of Chlorine

Chlorine causes two types of damage to bacterial cells:

- ***Disruption of cell permeability***: Free chlorine disrupts the integrity of the bacterial cell membrane, thus leading to loss of cell permeability and to the disruption of other cell functions.

Exposure to chlorine leads to a leakage of proteins, RNA and DNA

- ***Damage to nucleic acids and enzymes***. Chlorine also damages the bacterial nucleic acids as well as enzymes like catalase.

UV radiation:

- Thymine dimerization

OZONE

Protozoan cysts
Bacteria spores
Viruses
Vegetative bacteria

Advantages of UV

- Efficient deactivation of bacteria and viruses
- No production of any known undesirable carcinogen
- No taste or odour problems
- No handling and storage of chemicals
- Small space required

Disadvantages

- No disinfection residual in treated water
- Difficulty in determining UV dose
- Biofilm formation on the lamp
- Problems of cleaning and maintenance
- High cost of disinfection than chlorine
- Potential problems of photo-reactivation

Factors influencing disinfection

Type of disinfectant

- Some disinfectants are stronger oxidants than others

Type and age of microorganisms

- Spore forming bacteria are more resistant than vegetative bacteria
- Young microbes are easily destroyed than older ones

Disinfectant concentration and contact time

- Inactivation of pathogens with disinfectants increases with time and ideally should follow a first order kinetics

Effect of pH-depends on the chemical in use

- E.g. pH controls the amount of Hypochlorous acid and hypochlorite ion in solution (Best pH range 5.5 and 7.5)
- Disinfection effectiveness increases with pH

Temperature

- Pathogen and parasite inactivation increases as temperature increases
- Increase in temperature can also decrease disinfection because the disinfectant falls apart or is volatized

Other Considerations

To maintain water quality during distribution:

- Construction materials should NOT promote growth.

- Non-metallic materials should comply with BS 6920, which includes a test for growth promotion.

An equivalent standard does exist for metals which although they can become colonised with biofilms, cannot provide organic nutrients for growth

5. Storage

Reservoirs, aquifers & other systems:

- store water
- protect it from contamination

Factors influencing microbe reductions (site-specific)

- Detention time
- Temperature
- Microbial activity
- Water quality: particulates, dissolved solids, salinity
- Sunlight
- Sedimentation
- Land use
- Precipitation
- Runoff or infiltration

Ecological Sanitation (Eco-San)

What does sanitation include?

Main Focus of Ecosan

- ✔ safe collection, storage, treatment and recycling of **human excreta** (faeces and urine) and **sewage effluents**
- ✔ drainage and disposal (re-use, recycling) of **household grey water**
- ✔ management/ recycling of (organic) **solid wastes**
- ✔ treatment and disposal/ recycling of drainage of **stormwater**

- ✔ collection and management of **industrial waste products**
- ✔ management of **hazardous wastes**, including hospital wastes, and chemical/radioactive and other dangerous substances.

Problems we currently face: Not working Sanitation…

- Users not involved in sanitation decisions
- Users do not acknowledge importance of sanitation
- Sanitation not adapted to local conditions
- No sense of ownership by the people
- ***Sanitation systems are working improperly… or not at all***

Ecological Sanitation

Basic principles:

- Use nutrients in human excreta
- Avoid dilution (with flush water and sullage) of excreta
- Isolate urine (major source of excreted nutrients) – "urine diversion"

WHY?

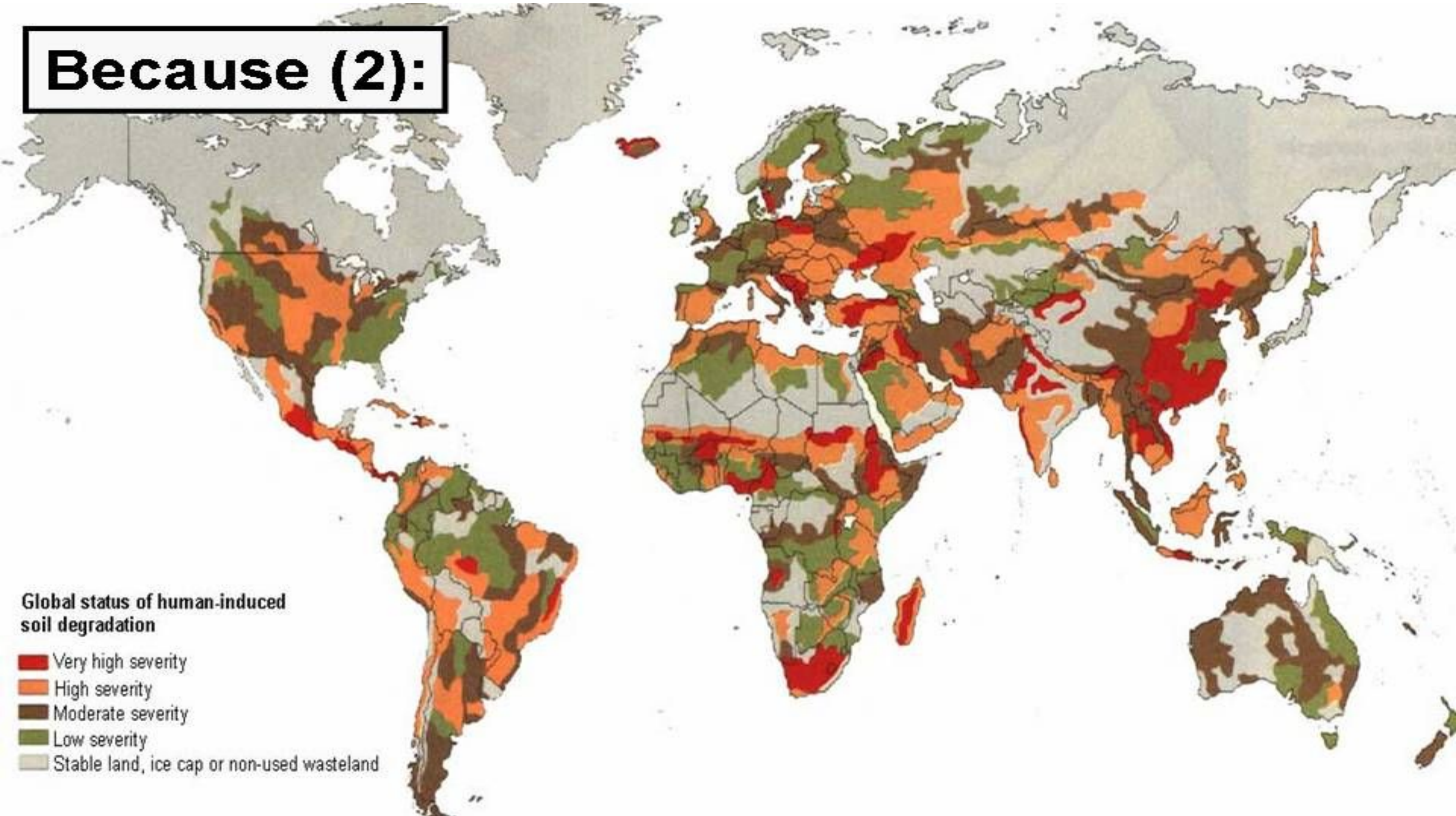
Why EcoSan?

Because (1):

"Ecological sanitation is one option being practised in some communities in China, Mexico, Vietnam, etc. Excreta contains valuable nutrients. We produce 4.56 kg nitrogen, 0.55 kg phosphorus, and 1.28 kg potassium per person per year from faeces and urine. This is enough to produce wheat and maize for one person every year."

WSSCC.

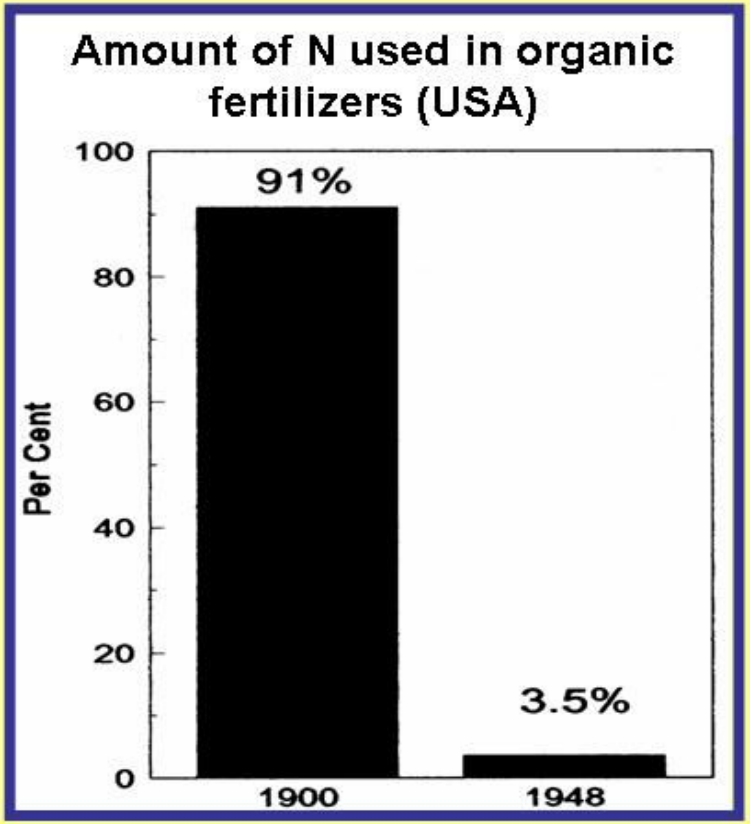
Because (2):



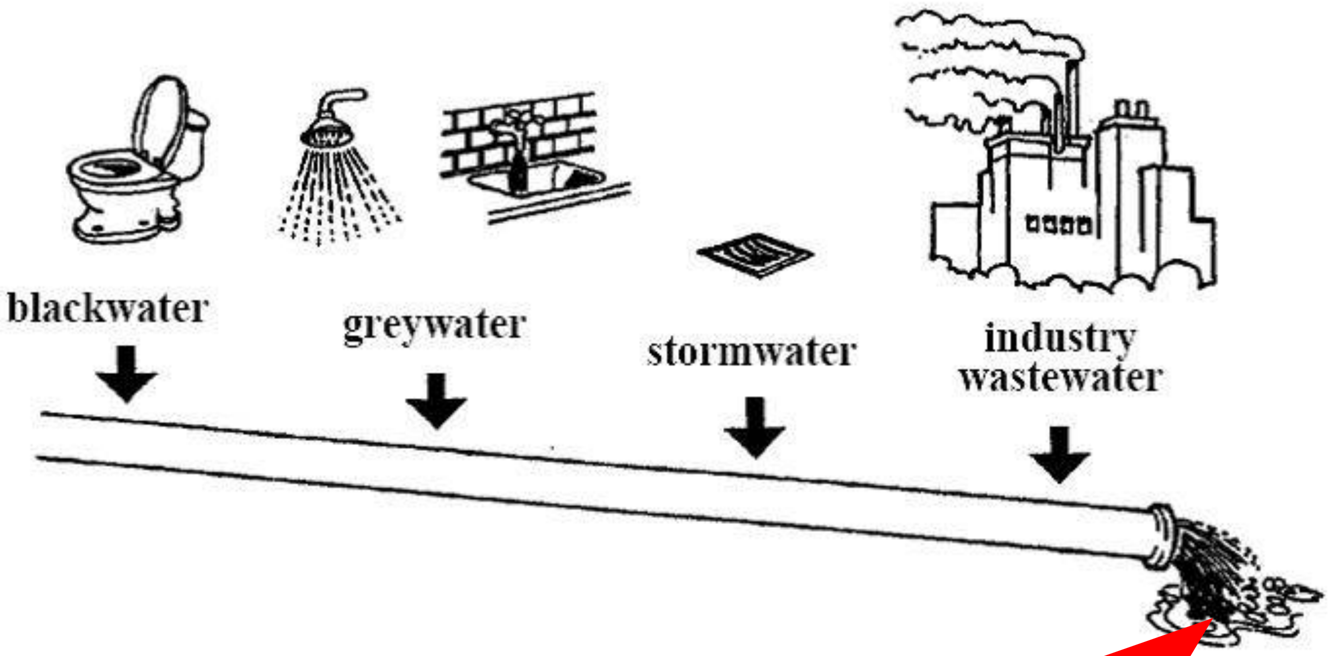
Human-induced soil degradation (FAO)

Because (3):

- Nutrients in human excreta generally wasted (and they cause eutrophication)
- Artificial fertilizers almost exclusively used in industrialized countries, but expensive for poor subsistence farmers in developing countries



•…are “flush and forget” sanitation solutions, where human wastes are flushed away with **huge amounts of scarce freshwater**, polluting rivers and the drinking water of people living further downstream.



What happens at the end of the pipe?

What happens at the end of the pipe?

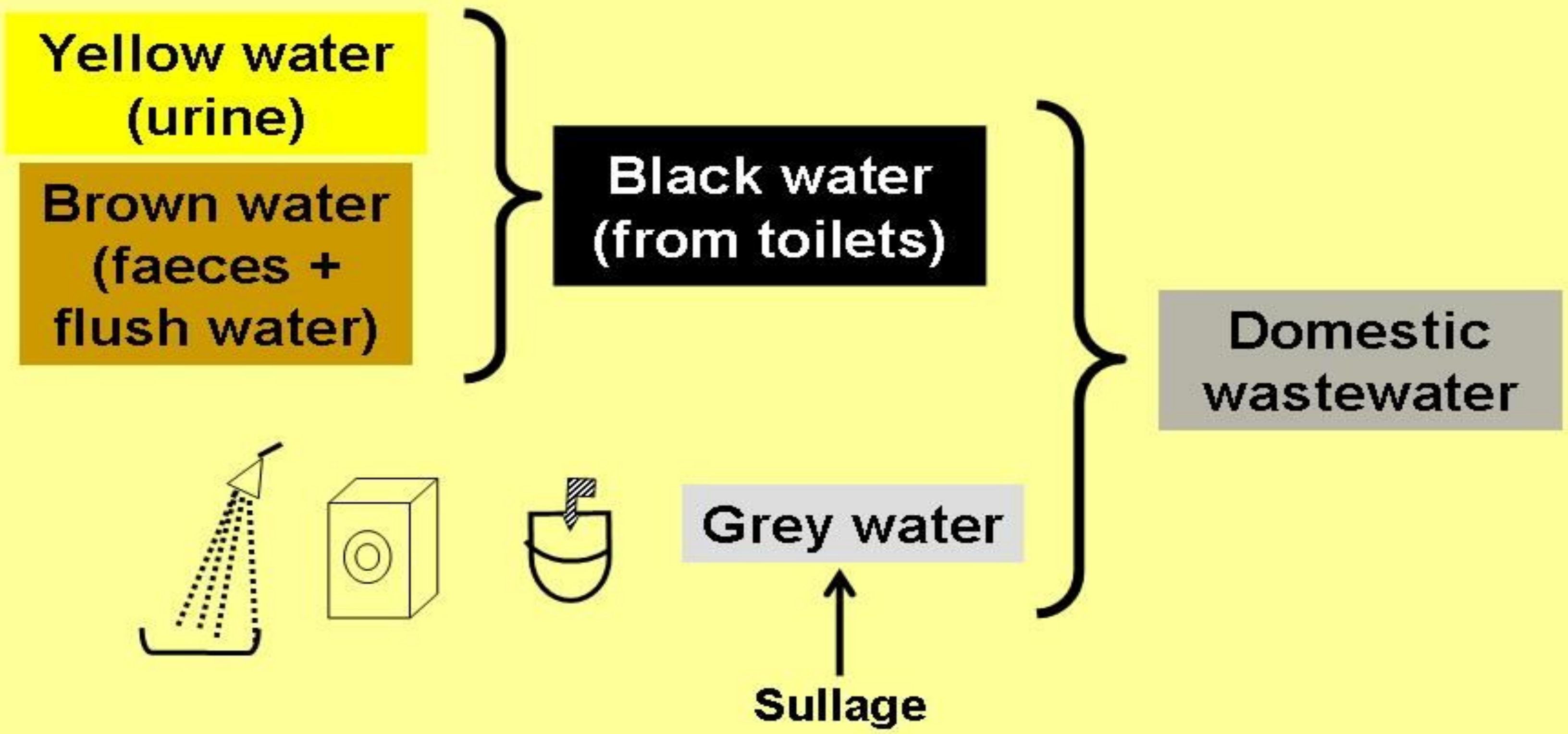
If we are very lucky, there might be a “state of the art” conventional Sewage Treatment Plant:

Which will need:

- Long **sewer network** & **pumps** to get the wastewater to the plant
- **Electricity** for aeration, pumps and other moving parts
- Skilled (and thus expensive) **operation & maintenance** staff
- Backup **generator** for powercuts
- **Diesel** for generator

Who will pay for this?

Domestic wastewater is a mixture of:



Volumes of wastes

Litres per person per year:

1. Brown water: ~50
2. Yellow water: ~500
3. Grey water: ~10,000–100,000

– ie, domestic wastewater volume of ~30–275 litres per person per day

NPK in waste streams

kg/person yr:		Brown	Yellow	Grey
N	~4.5	~10%	~87%	~3%
P	~0.75	~40%	~50%	~10%
K	~1.8	~12%	~54%	~34%
[COD	~30	~47%	~12%	~41%]

Urine has most of the NPK

Therefore

don’t mix it

with brown or grey waters

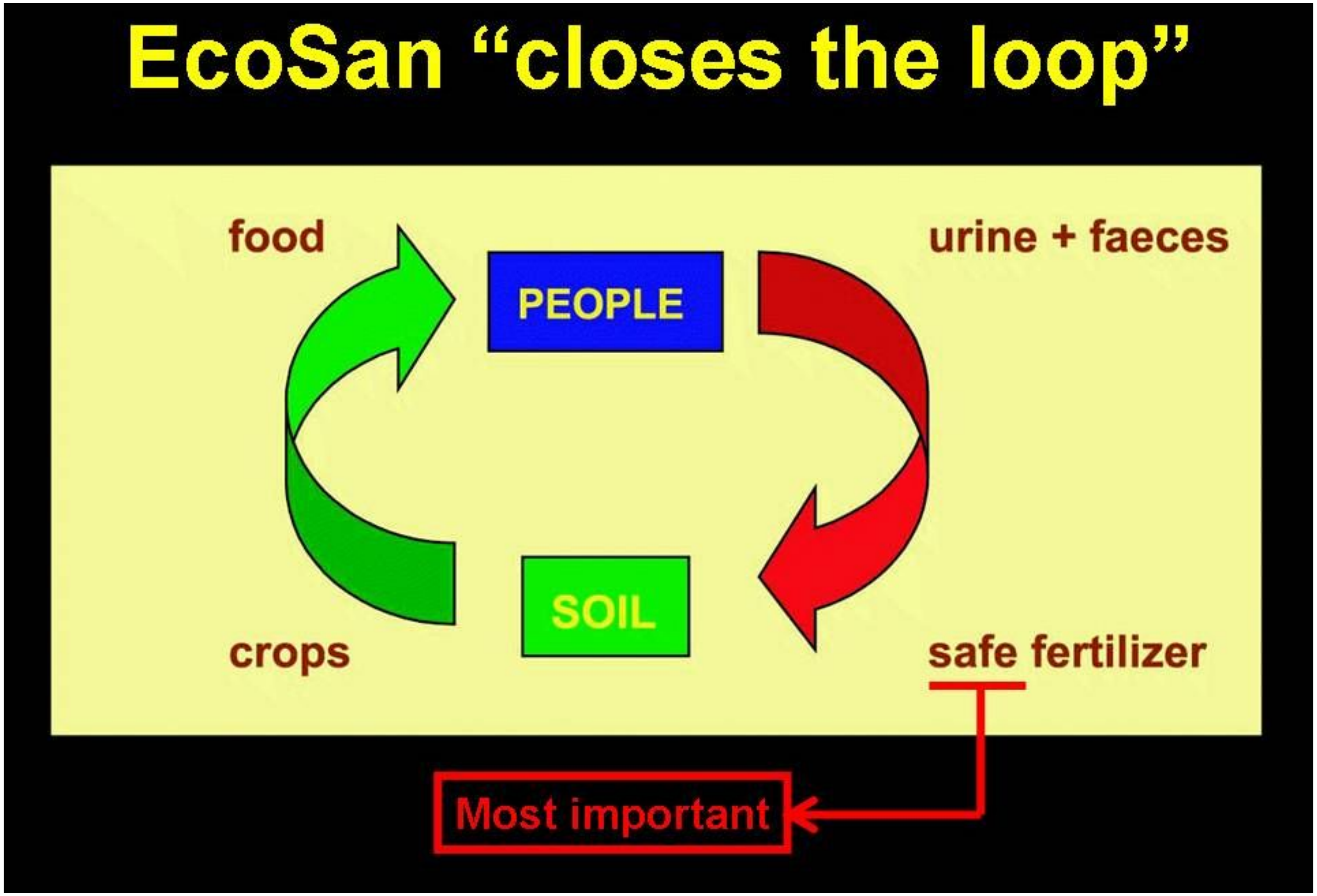
Urine diversion (or separation) is a basic principle of EcoSan

Alternative, *sustainable* solutions are needed!

We need to rethink our sanitation approach; a new philosophy is needed!

Sustainable sanitation solutions :

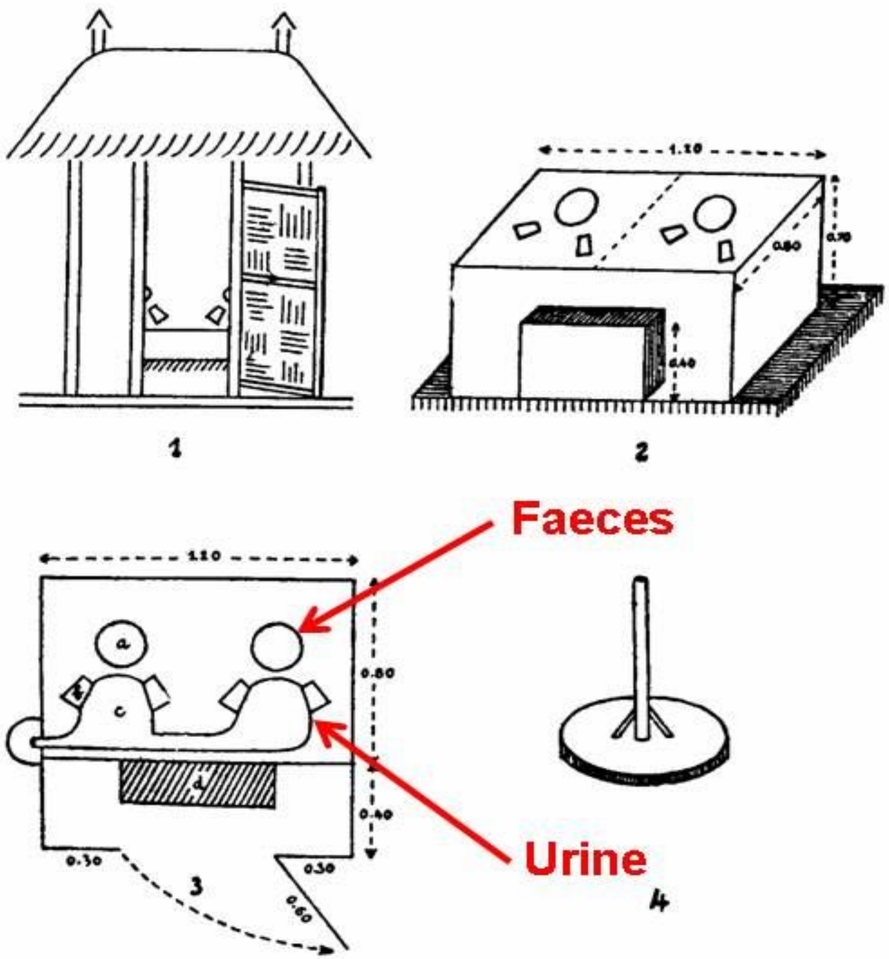
1. should be **eco-friendly** (no pollution of ground- and surface water)
2. need to be **user**-friendly
3. should need **low** maintenance
4. should be **cost effective**
5. should **produce** and not require **energy** (e.g. biogas)
6. are usually **decentralized**
7. should **reuse nutrients**, and **water** contained in



The basic principle of ecological sanitation is to close the loop between sanitation and agriculture without compromising health

Urine-diverting toilets

DIAGRAM OF A DOUBLE SEPTIC TANK USED IN THE NORTH VIETNAM COUNTRYSIDE



Vietnam:

Double-vault urine-diverting composting toilet

SQUAT & AIM AT SQUAT HOLE

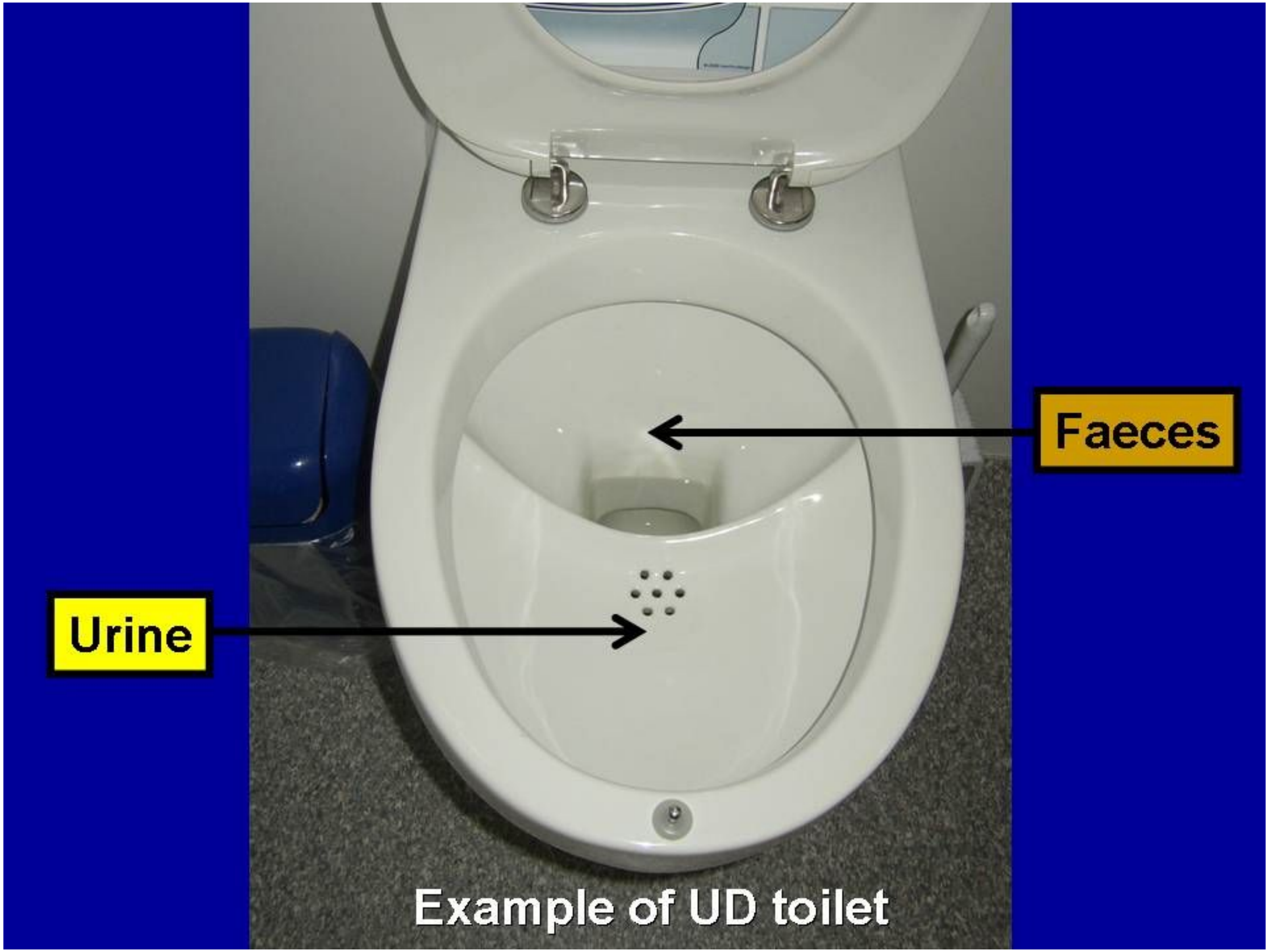
AFTER HELPING YOURSELF, CLEAN BOTTOM
& THROW CLEANSING MATERIAL IN SQUAT HOLE

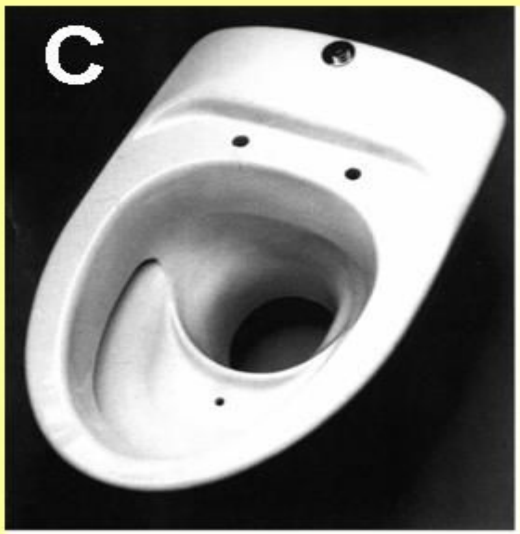
FOR MOSLEMS, WASH YOUR BOTTOM
IN THE WASHING SINK

POUR ASH IN SQUAT HOLE AFTER EVERY USE

Double-vault Urine diverting composting Toilet

Double Vault Toilet with Urine Separation


Faeces
Urine
Example of UD toilet



A Urine-diverting pedestal unit from South Africa

B Urine-diverting squat-pan from China

C Urine-diverting porcelain unit from Sweden

Reuse Possibilities:

Biogas as a sustainable energy source from wastewater:

- ⇨ For cooking
- ⇨ For heating
- ⇨ For lights
- ⇨ For electricity production

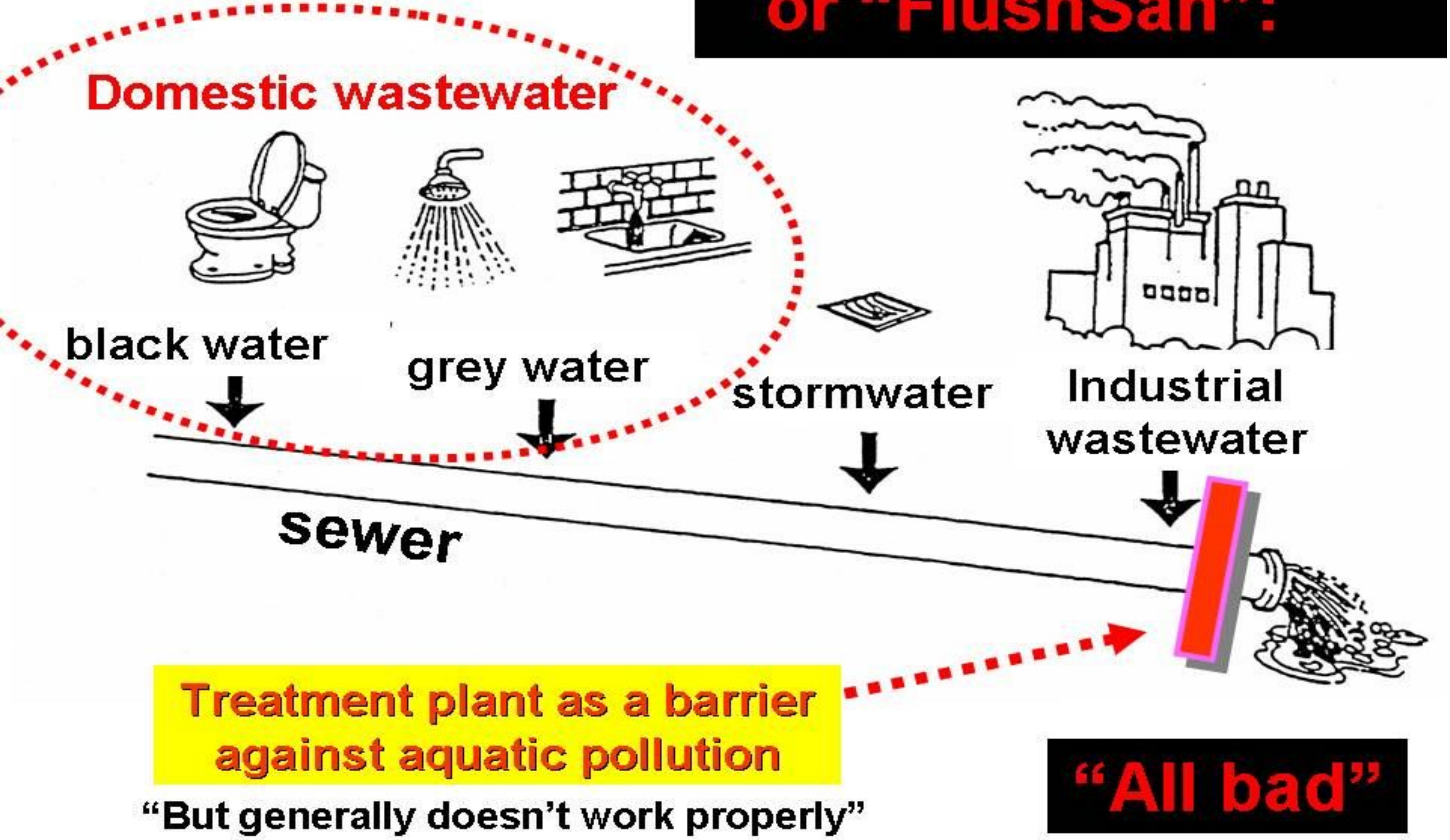
Reuse of water after treatment:

- ⇨ Irrigation in agriculture
- ⇨ Industry, flush for toilets
- ⇨ Recharge of groundwater

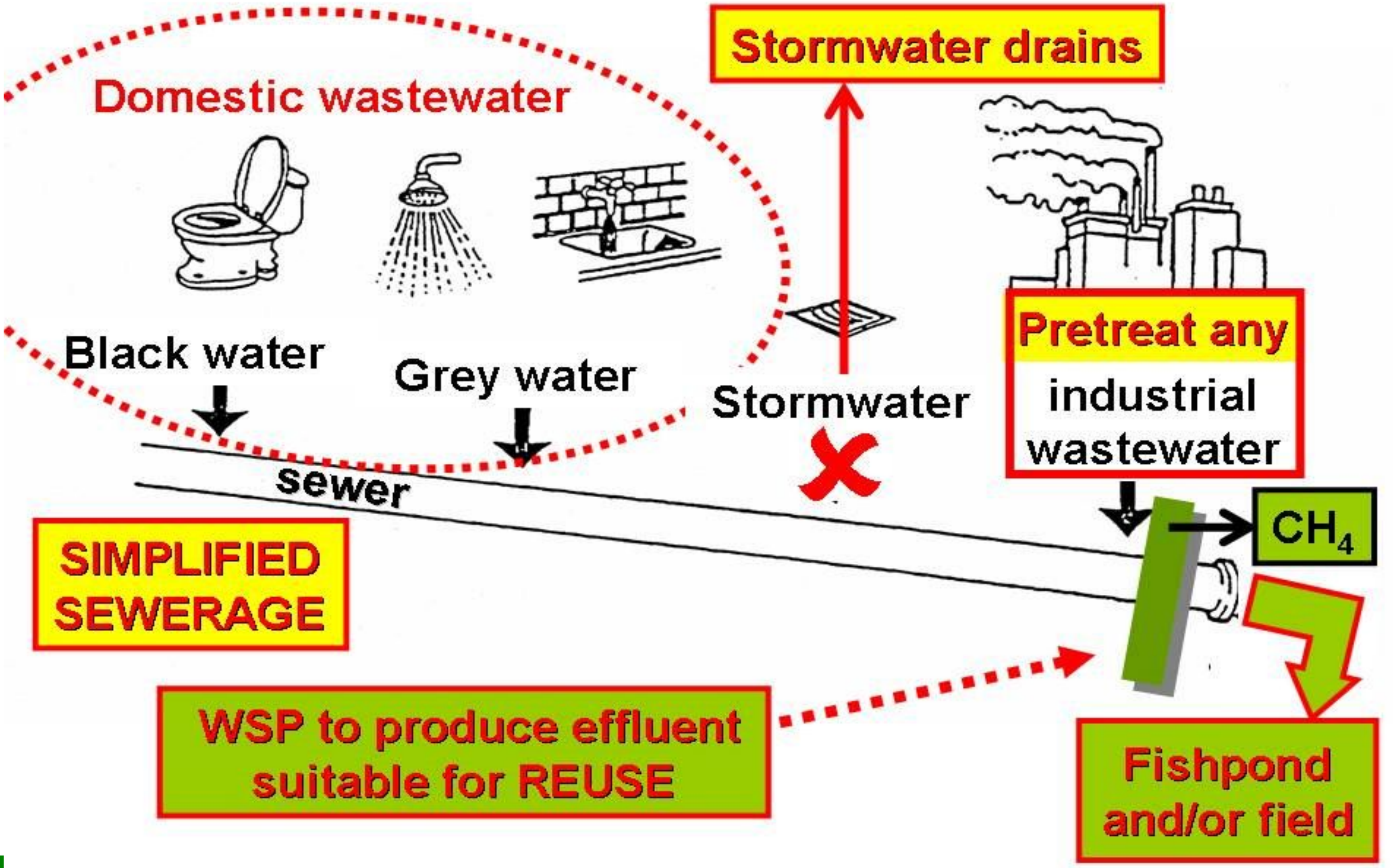
Applicability of EcoSan

- Clearly applicable in rural areas where people want to use, or have a tradition of using, excreta for crop fertilization.
- Now becoming increasingly and *very* enthusiastically recommended for towns and periurban areas (OK if people want to use urine and composted faeces locally, or can sell both to local farmers – but outside Asia this might be difficult to organize).

The flush and discharge system or "FlushSan":



But in dev. countries, esp. high-density periurban areas:



Sewerage

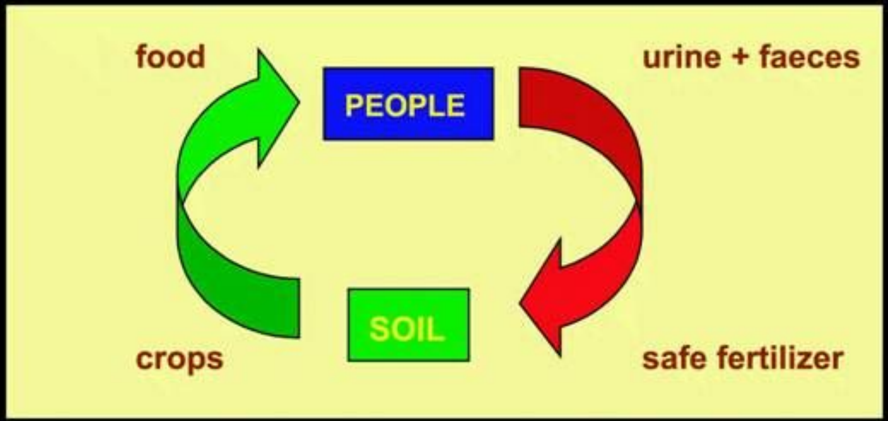
+ wastewater treatment

+ biogas collection

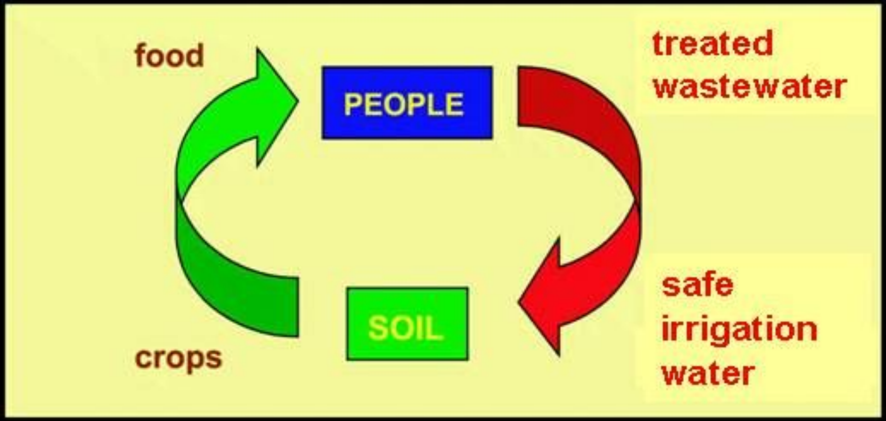
+ aquacultural and/or agricultural reuse

is as ecological as EcoSan!

EcoSan may close the loop,



but so does wastewater reuse

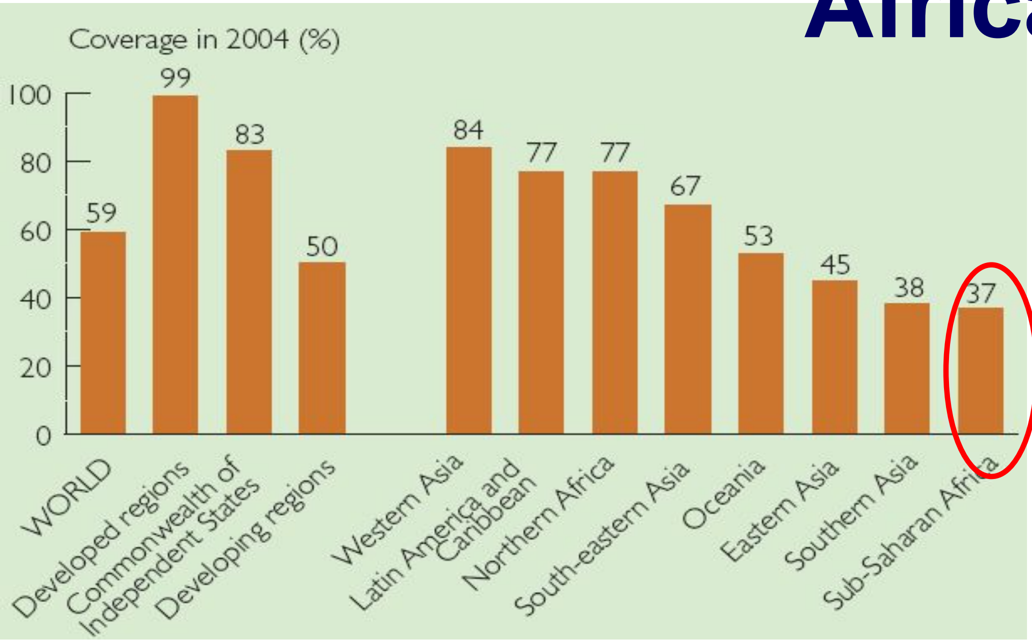


Advantages of Ecosan Systems

Source: (18)

- **Improvement of health**
- Promotion of **recycling**
- **Conservation** of resources
- Preference for modular, **decentralised** partial-flow systems
- Contribution to the preservation of **soil fertility**
- Improvement of agricultural productivity and hence contributes to **food security**
- **Increasing user comfort/security**, in particular for women and girls Promotion of a holistic, interdisciplinary approach.
- **Cyclic Material-flow** instead of disposal.

Sanitation conditions in Sub-Saharan Africa



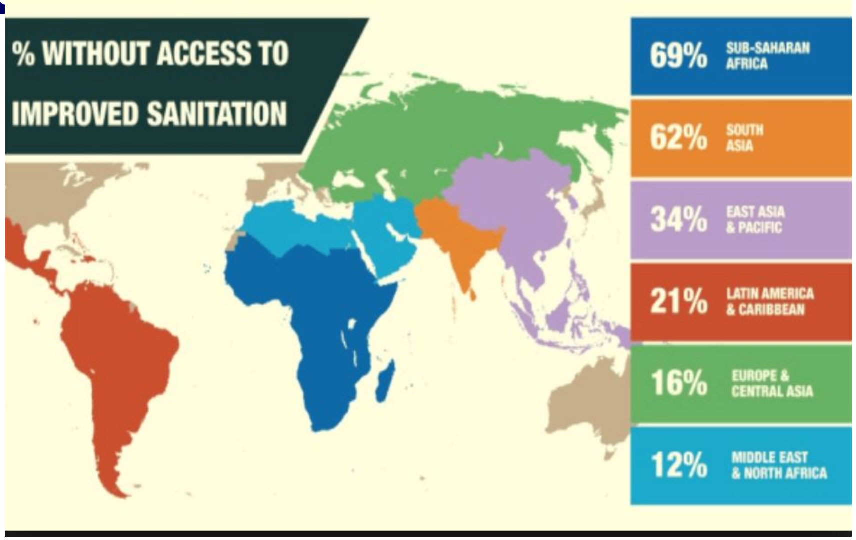
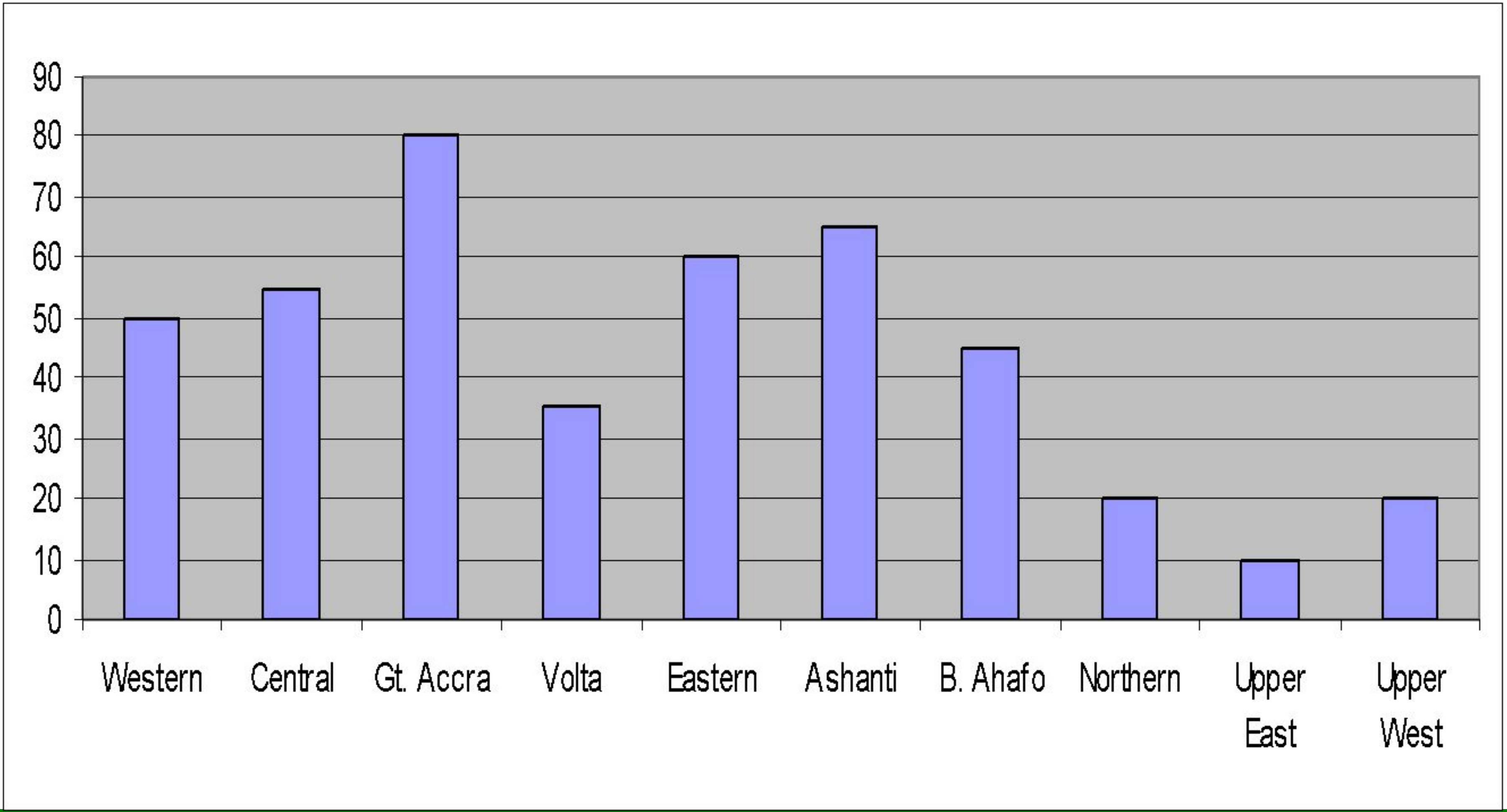


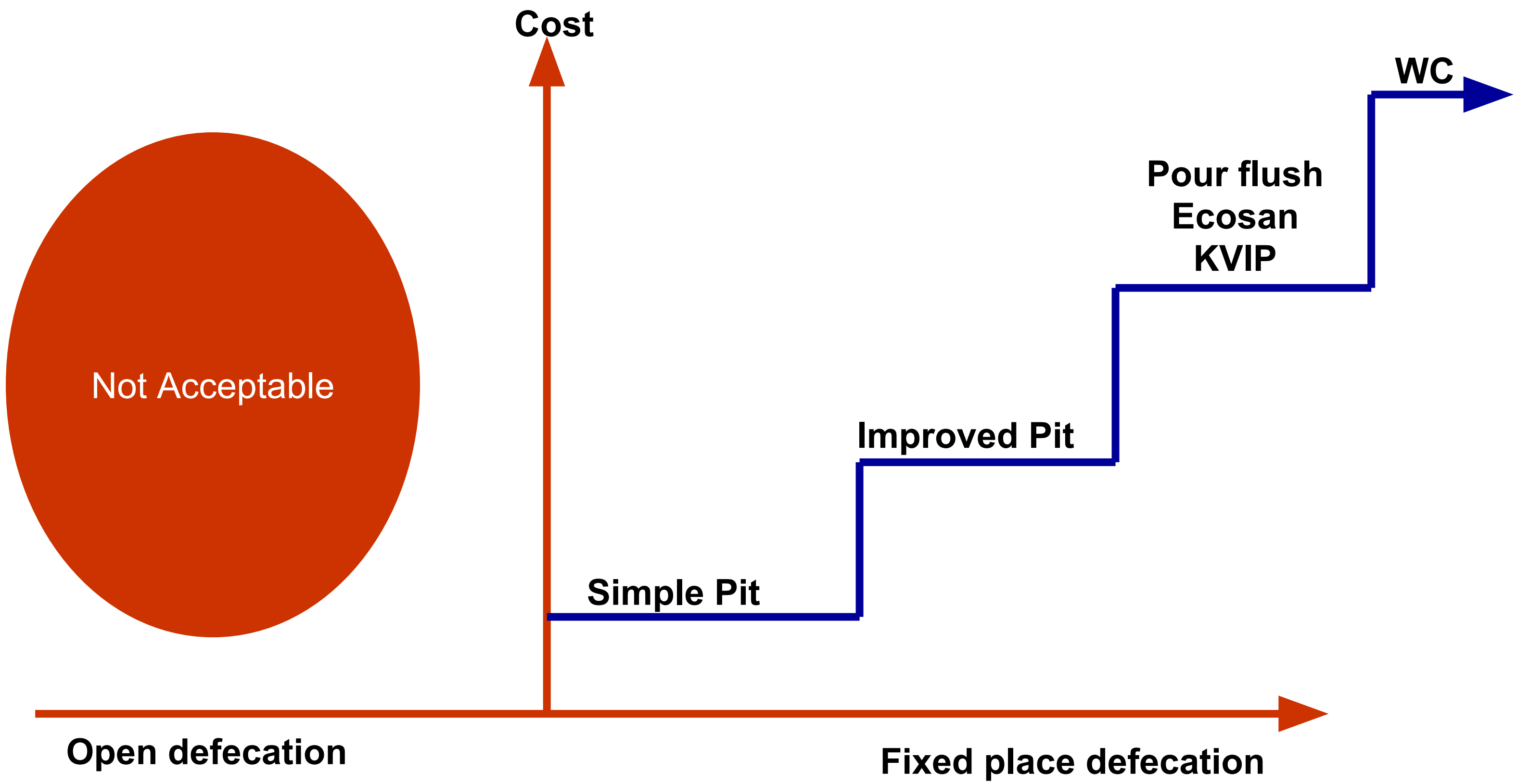
Figure 1.- Coverage with improved sanitation by region in 2004 (WHO and UNICEF, 2006)

*To achieve the year 2015 goal for urban and rural sanitation coverage in Sub-Saharan Africa – halving the percentage of those without access – **35 million people annually** will have to be provided with service.*

Cummulative Coverage Data for Sanitation in Regions



THE SANITATION LADDER



MAJOR TECHNOLOGY OPTIONS of SANITATION SYSTEMS IN GHANA

- K(VIP)
- Aqua Privy
- Water Closets (WCs)
- Enviro - Loo
- Limited sewerage systems in Accra, Tema, Kumasi (some barracks and selected Housing Estates)
- Pan latrines **
- Pit latrines **
- Open defaecation ***
- Bio-Gas
- “Menu-Sack” Compost Toilet
- Etc.

DON’T TOUCH ME !!

Opportunities - Practical Cases…

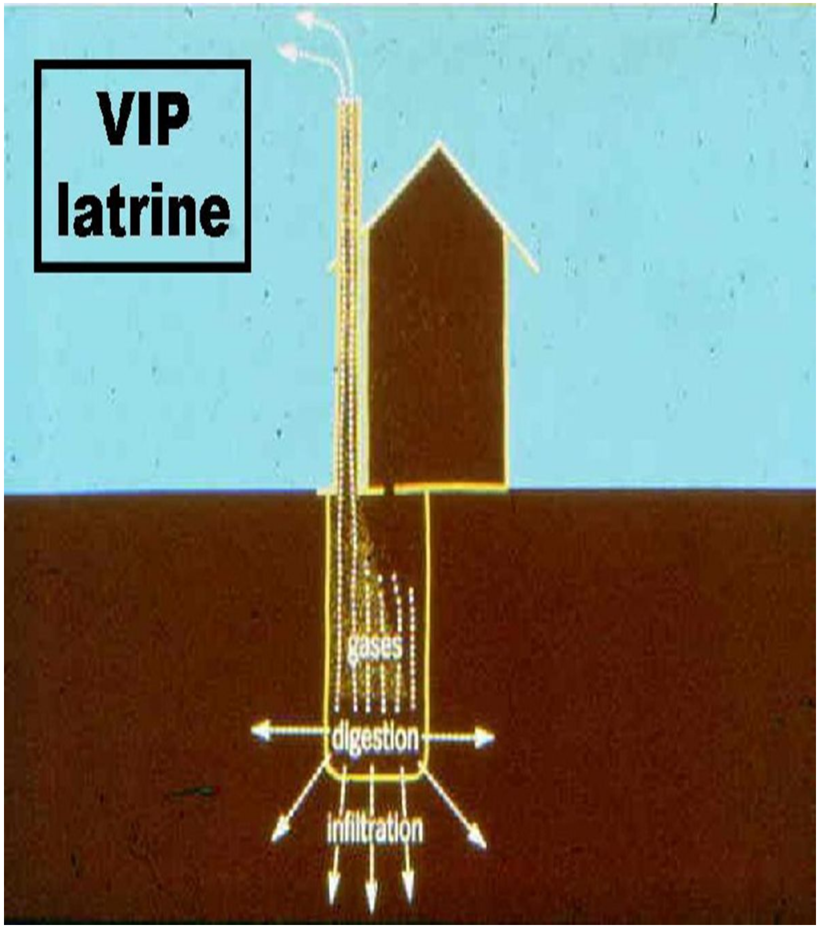
Segment 1: Lack of space in "poor" areas

Van's Biological (Compost) Toilet is easily retrofited into existing building. (Accra Ghana)

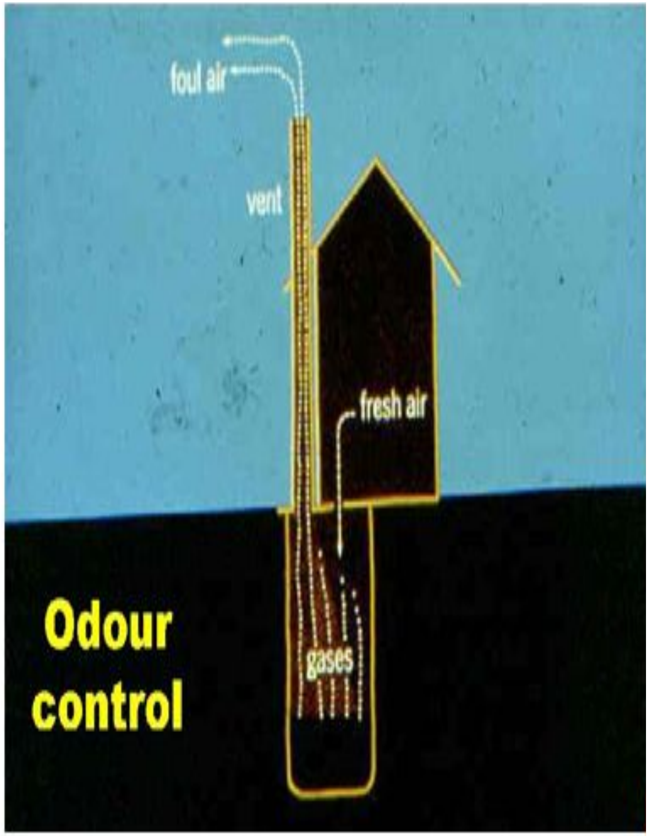
- Willingness-to-Pay versus Affordability ?

Cost is important and

We need to be innovative and use more appropriate lower-cost designs & options if we are to meet SDGs



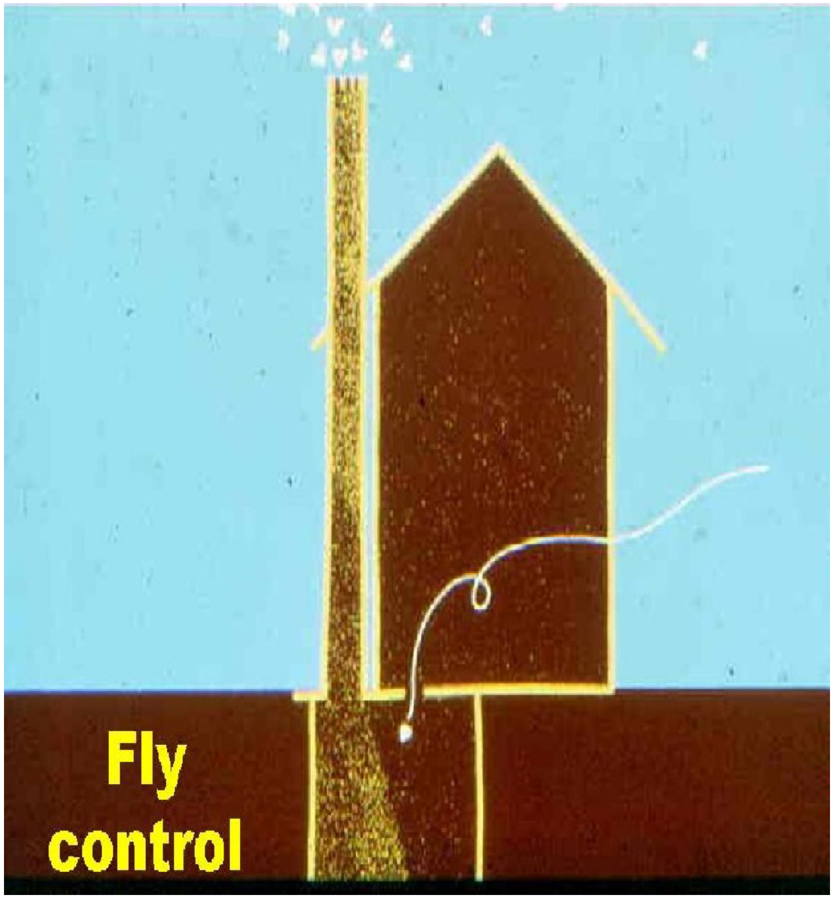
- VIP latrines control odour and fly nuisance
- In VIPs the superstructure is slightly offset from the pit, so that a vertical vent pipe can be installed
- Vent pipe is key to controlling both flies and odours
- Excreta are deposited into the pit via the squat-hole, the liquid (mainly urine) infiltrates into the surrounding soil, and the solids are digested anaerobically.



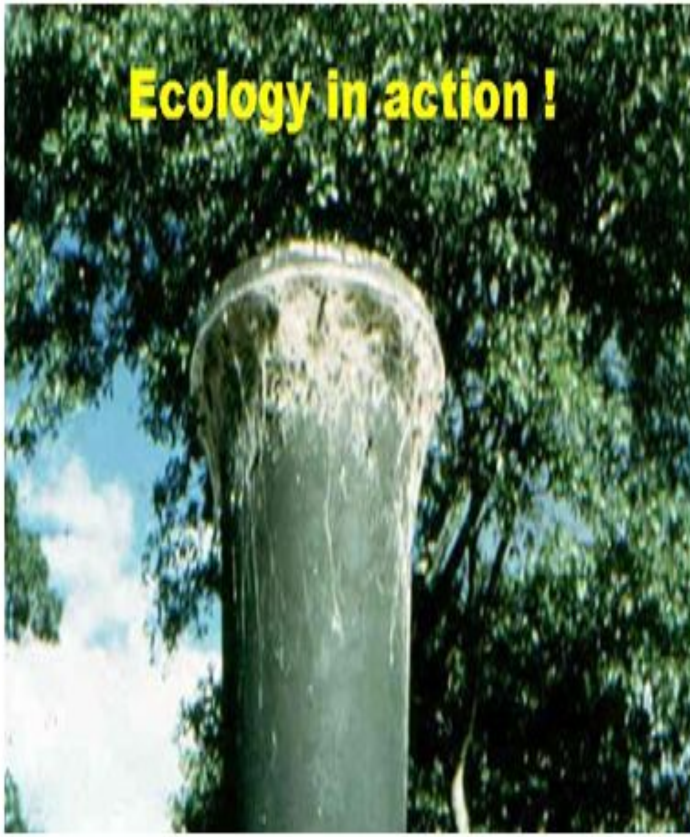
In Odour control wind

blowing across the top of the vent pipe sucks out some of the air at the top of the Vent pipe and this is replaced by air from below; so this sets up an airflow pattern in which fresh air enters the pit through the squat-hole.

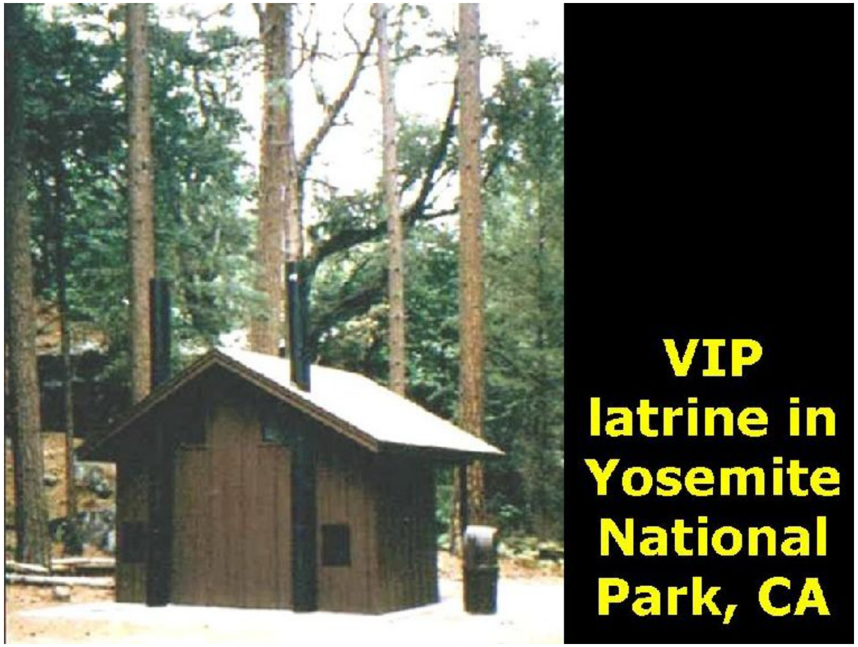
Gases generated in the pit are then sucked up and out of the vent pipe, so leaving the superstructure totally odour-free

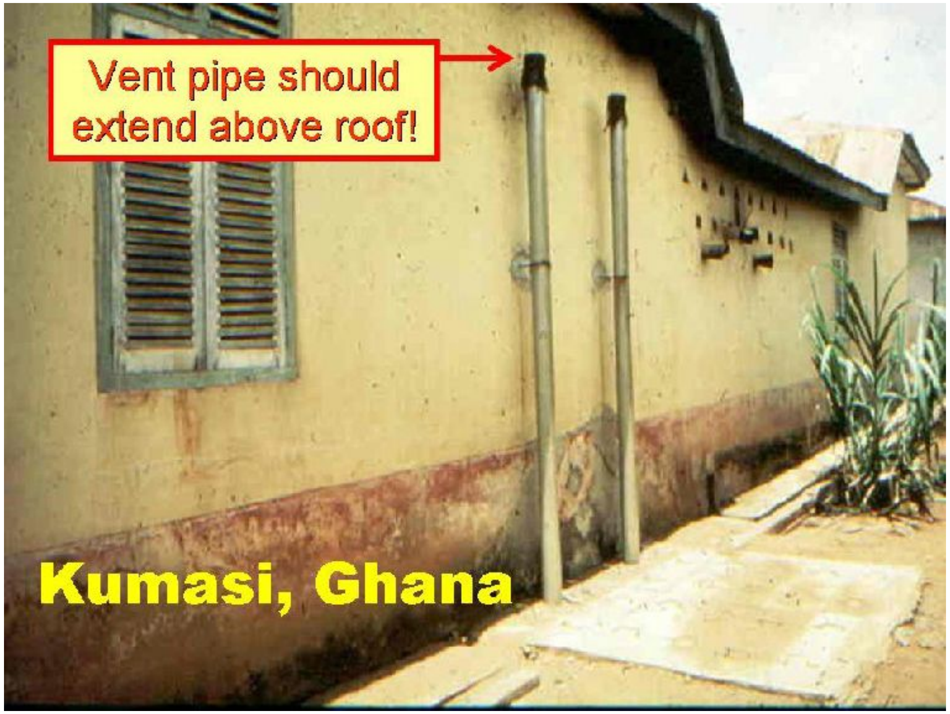


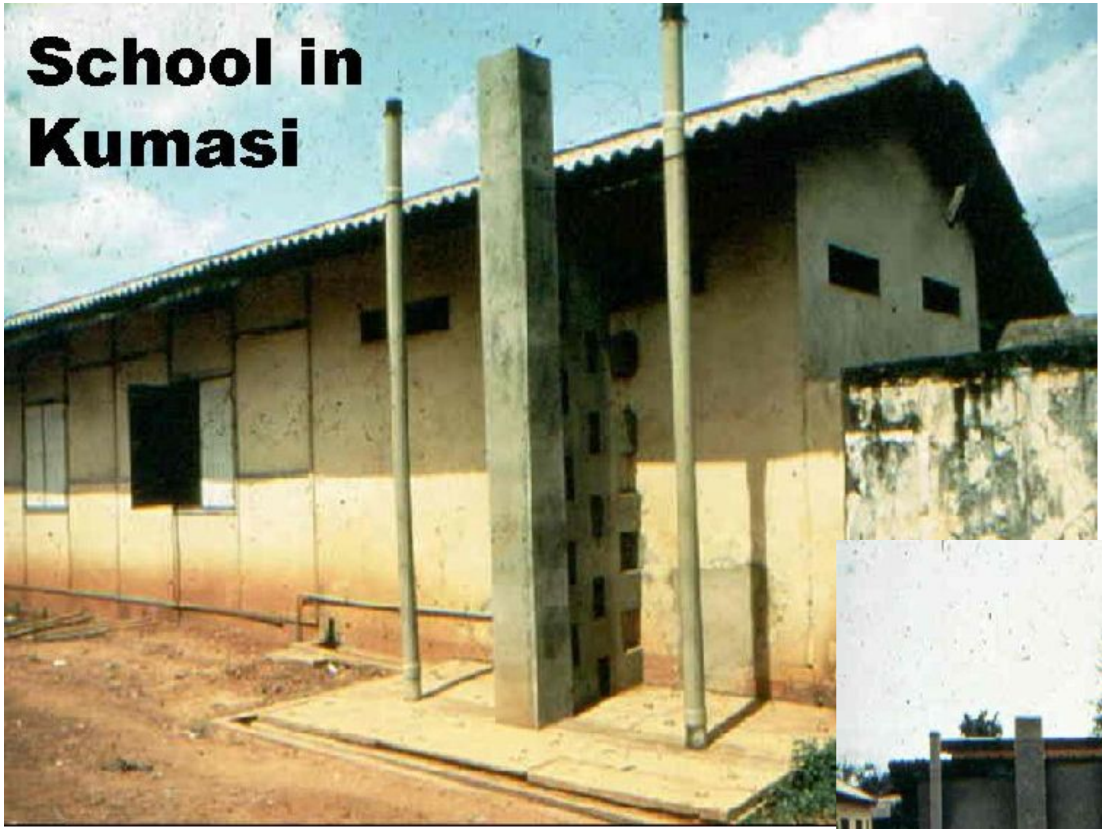
- In fly control, gravid female flies know that human faeces are a good place to lay their eggs, so they are attracted to latrines by faecal odour.
- With VIP latrines all the odour comes out of the vent pipe, so this is where the gravid flies fly to.
- To prevent the flies entering the pit, a fly screen is placed over the top of the vent pipe.
- However, a few flies will enter the pit via the squat-hole and lay their eggs.

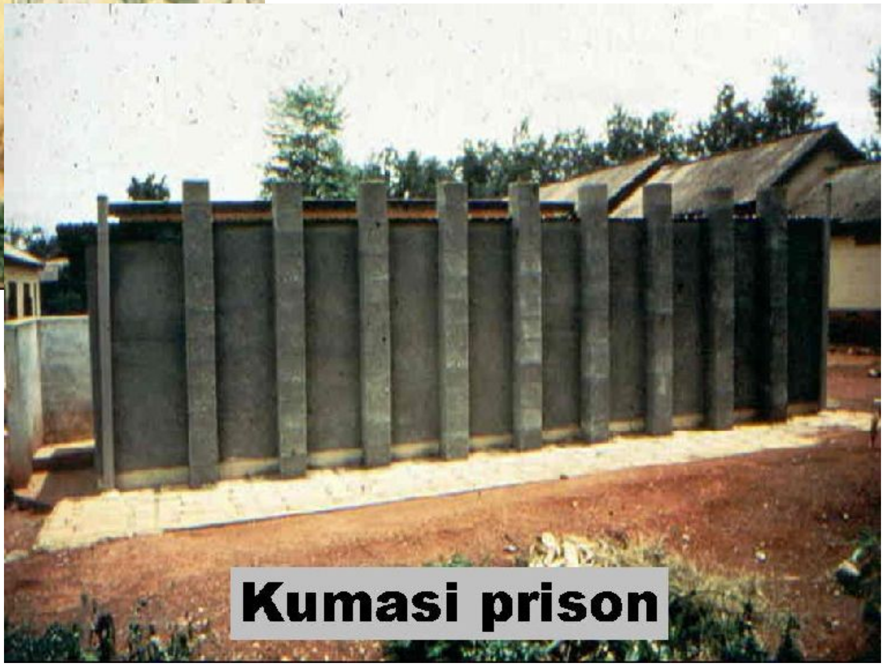


It is not uncommon to see cobwebs at the top of the vent pipe as spiders soon learn that this is a good place to catch their food.


VIP
latrine in
Yosemite
National
Park, CA


Vent pipe should
extend above roof!
Kumasi, Ghana


School in
Kumasi


Kumasi prison

Pathogen types potentially present in human excreta

Type of pathogen	Example organisms	Examples of diseases caused by type of pathogen
Bacteria	Total coliforms Faecal coliforms *E. coli* *Salmonella* Faecal streptococci Enterococci	Gastroenteritis Typhoid fever Salmonellosis Cholera
Protozoa	*Giardia lamblia* *Cryoptosporidium*	Giardiasis
Helminths (worms)	Nematoda *Ascaris lumbricoides*	Roundworm infestation Dwarf tapeworm
Viruses	MS2 coliphage Hepatitis A virus Enteroviruses	Gastroenteritis Respiratory disease Meningitis, hepatitis

Source: Metcalf & Eddy (2003), page 110

- Safe disposal of human excreta is second to the provision of pathogen free drinking water that promotes **good health** for every population

- Human faeces contain large numbers of microbes. For example one person with cholera excretes 10^{13} per day and since infective dose of cholera is 10^{6} one person could infect 10 million people

- It is therefore important to separate disposal of excreta from drinking water

- To achieve this we must build latrines or septic tanks that confines excreta