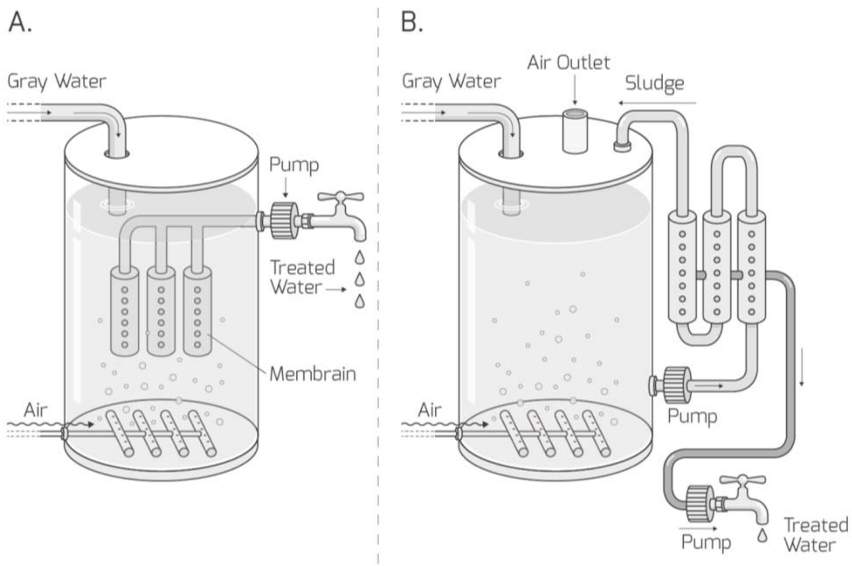
Close life support systems-Rome 2018

Greywater reuse:
Benefits, Challenges, and means for Safe Reuse

Amit Gross



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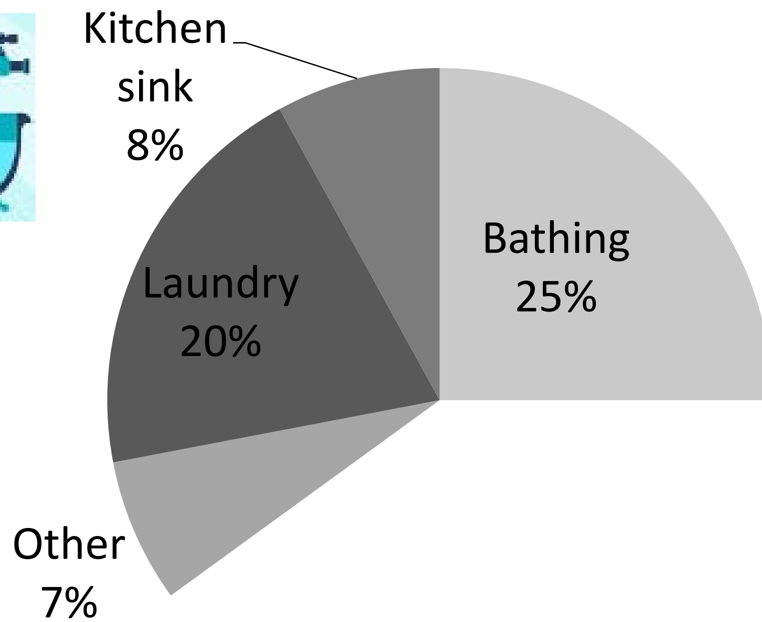
AKIS INTERNATIONAL SCHOOL FOR DESERT RESEARCH
Sede Boqer campus, Ben Gurion University of the Negev

Why greywater (GW)?

- Greywater is all domestic water excluding toilet effluents (black water)
- Reuse of greywater can potentially reduce water use by up to 50%



Major usages of water

Toilet flushing

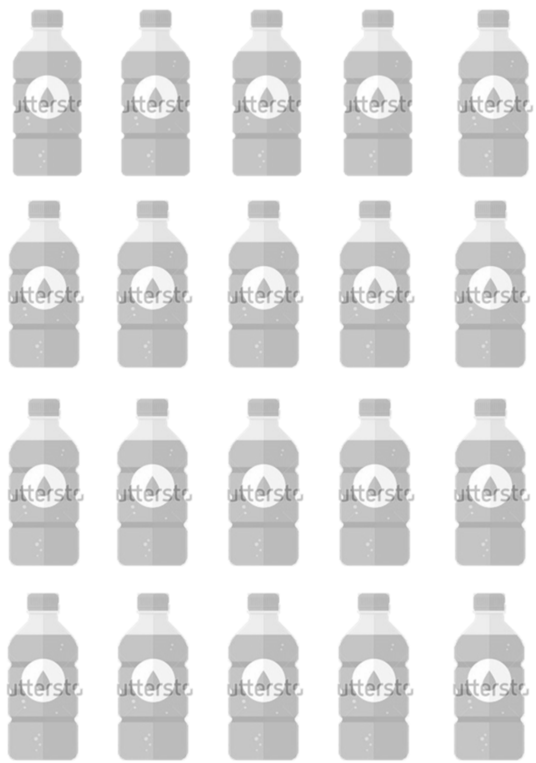
Irrigation

https://vimeo.com/51587224

Composition of domestic wastewater: quantity and quality

Most domestic effluent is greywater (GW), rather than blackwater (urine and feces)

50-200 L/person/day



30-50 L/person/day

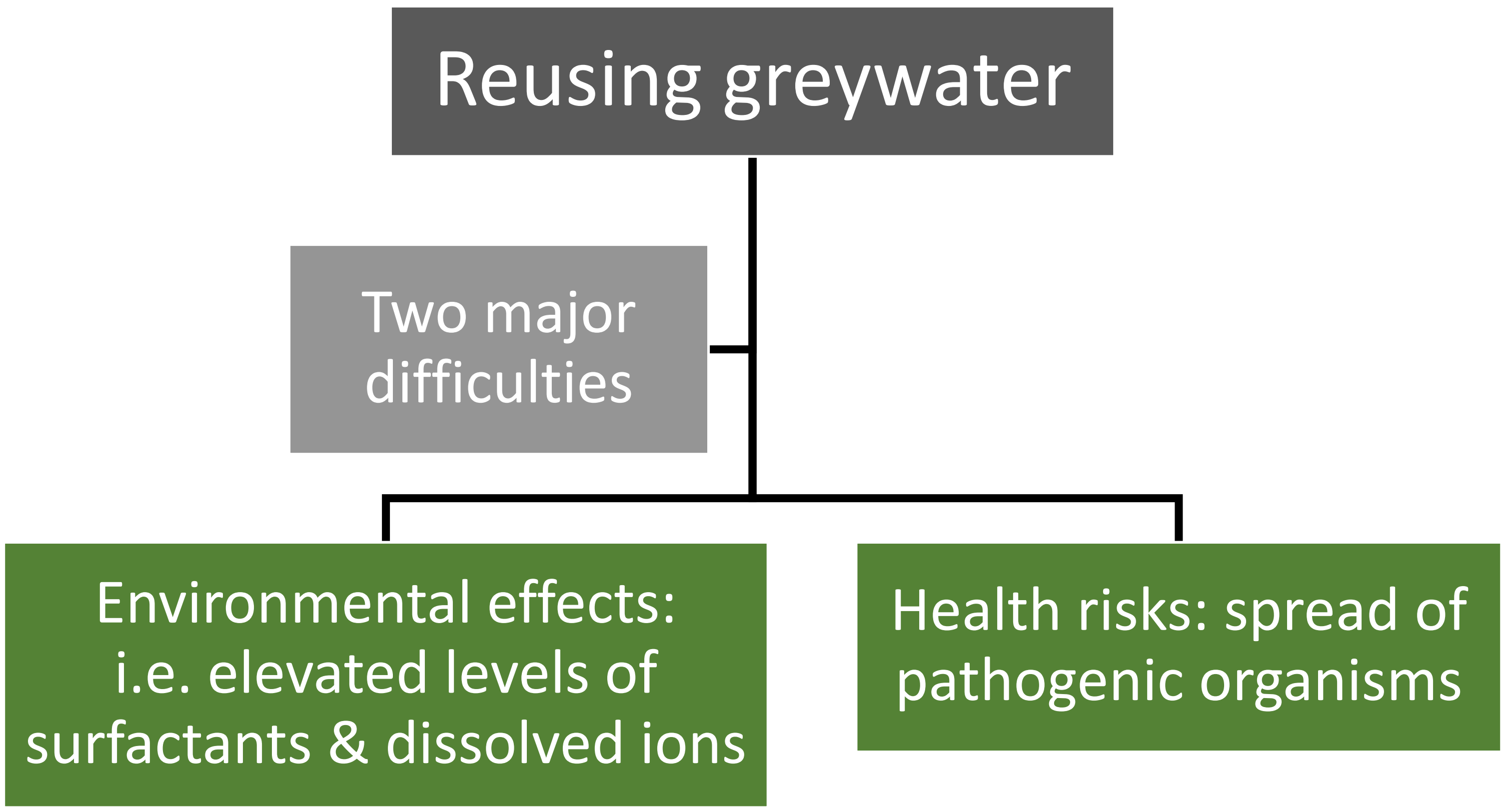
Composition of domestic wastewater: quantity and quality

Approximate loads (kg/person/year)		% in each source		
		GW	Urine	Feces
N	4-5	3	87	10
P	0.8	10	50	40
K	1.8	34	54	12
TOC	11.5	40	10	50

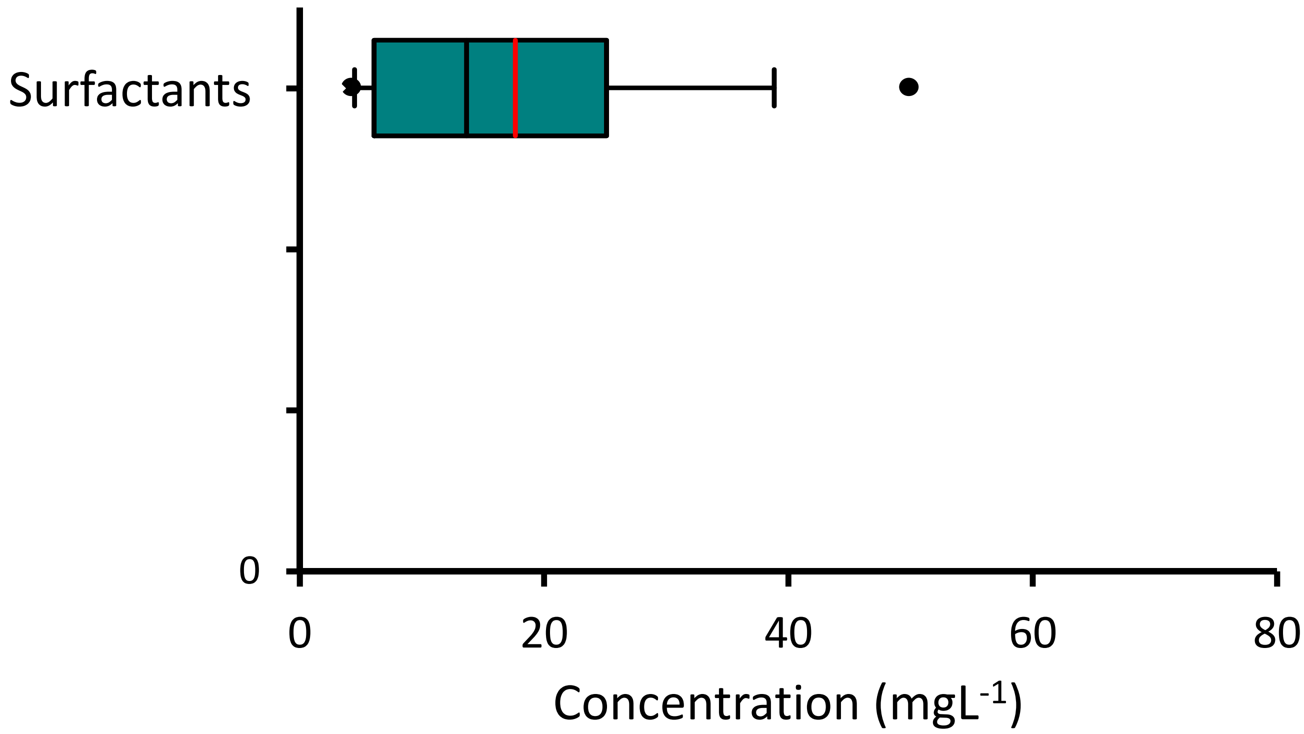
Composition of domestic wastewater: quantity and quality

1. GW is less polluted. Thus, it can be treated by simple means and be safely reused.
2. If reused for irrigation, GW can replace or lower the need for fertilization

What are the challenges?



Pollutants in raw (untreated) greywater quality varies from negligible to significantly high concentrations



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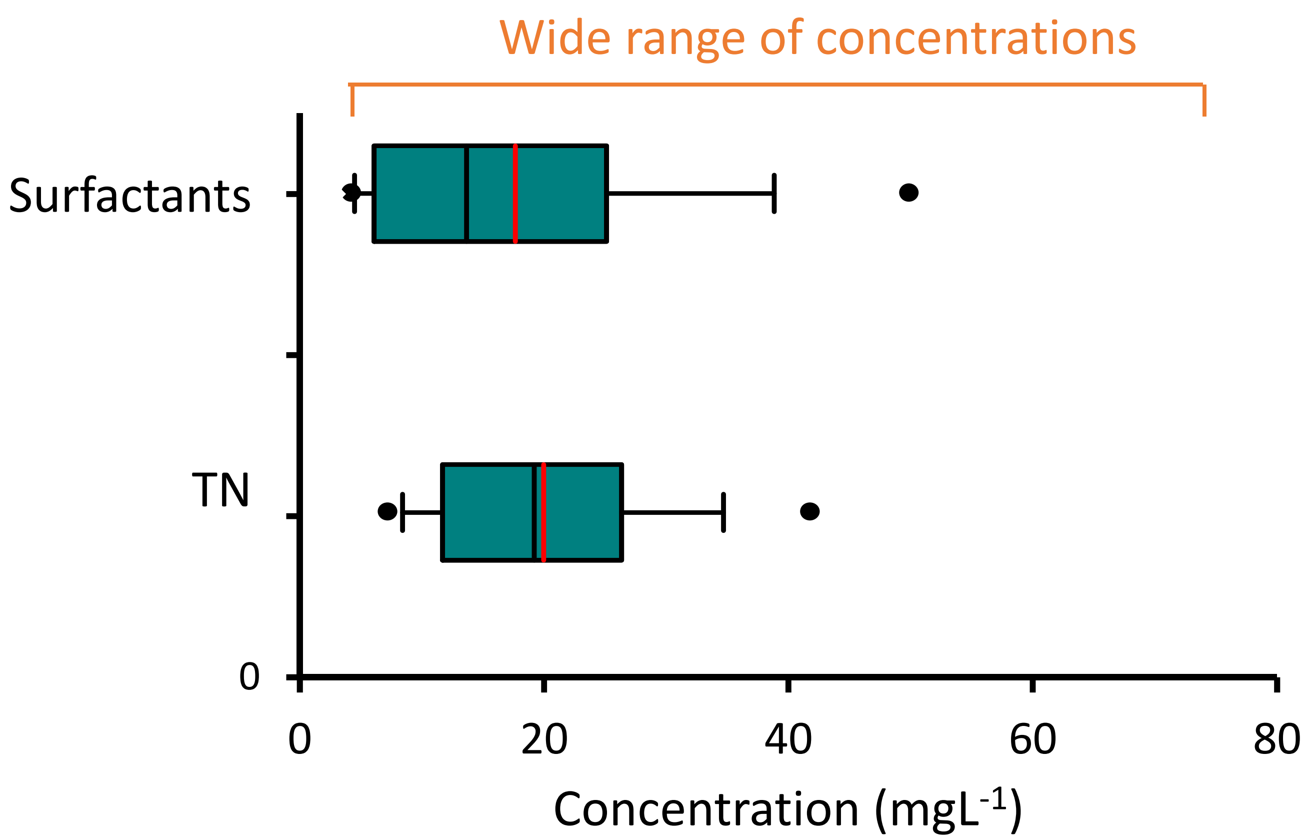
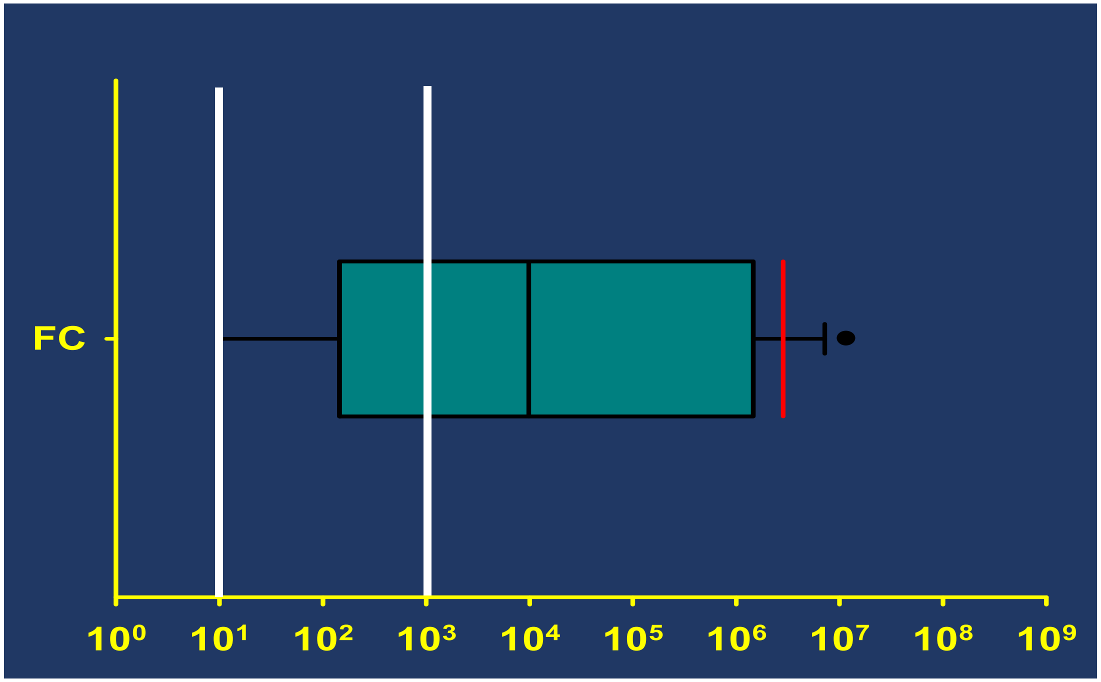


Unhealthy plants following irrigation with raw GW

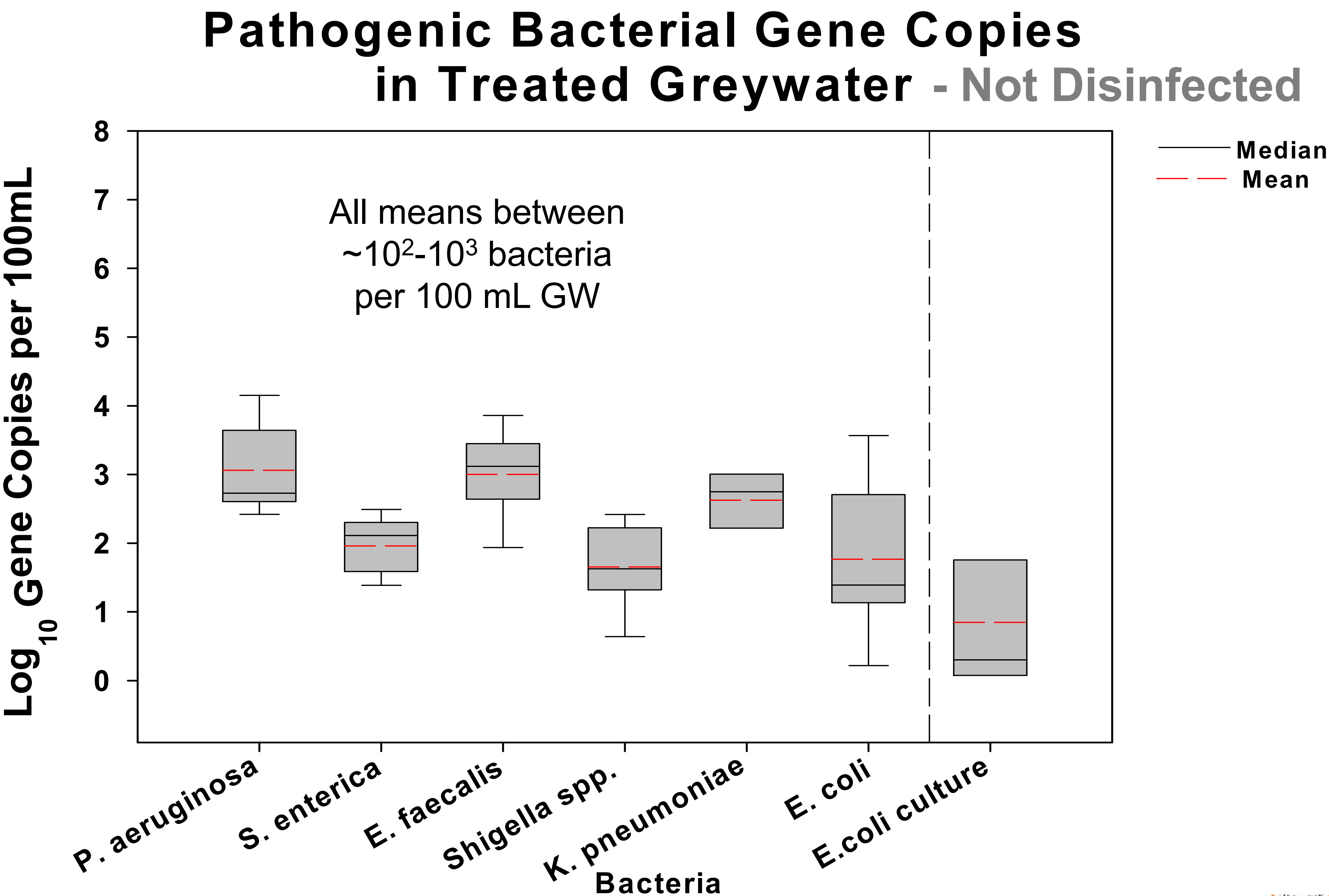
Fecal coliform

- Indicator for potential presence of pathogens
- Its concentration in raw GW varies and can be similar to full domestic wastewater

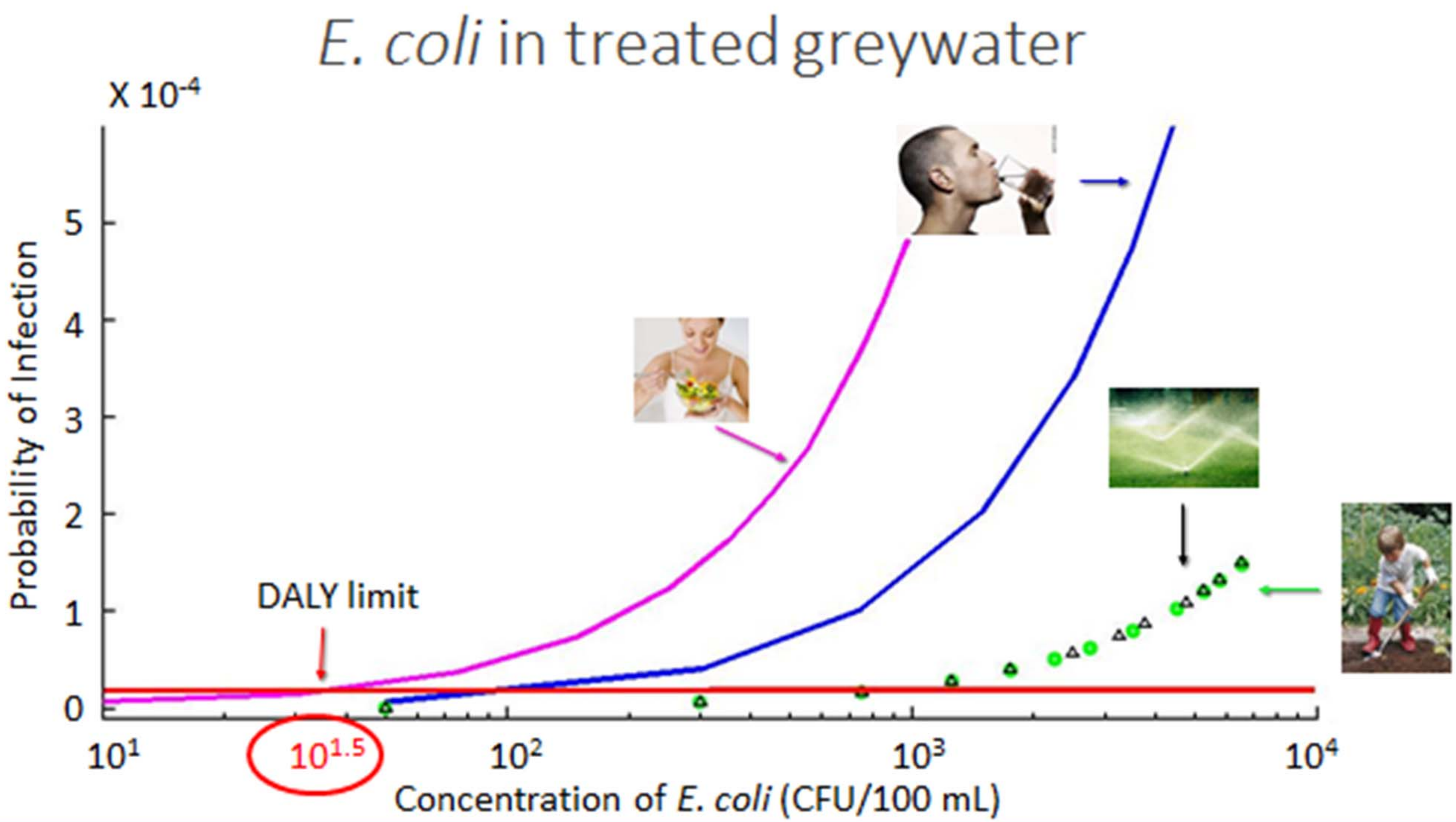


Fecal coliform (CFU/100 ml)

Potential hazards of GW – Public Health



Maximum concentration for safe reuse based on QMRA



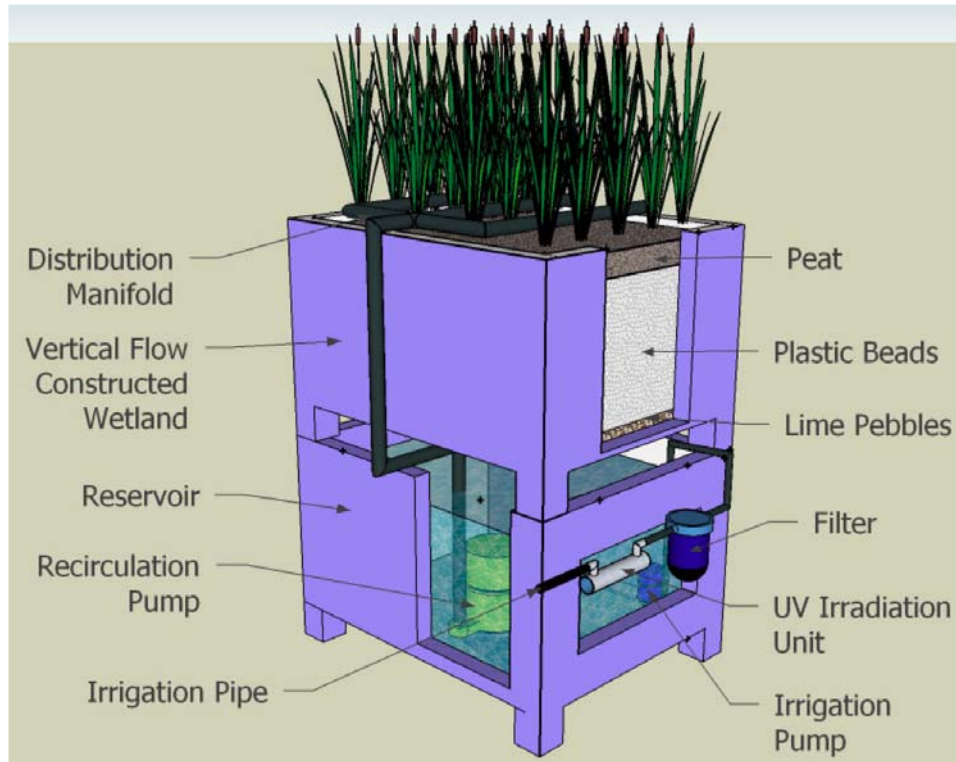
Insights so far

1. GW has great potential as an alternative water source that can alleviate water and food scarcity (if used for on-site farming).
2. There are still challenges that must be resolved for reliable and safe use of greywater.

Greywater must be treated before it can be reused.

Technological challenges of treating GW

1. Treatment must consider changing quality and quantity
2. Low tech, low cost systems are required??
3. Simplicity in operation and maintenance
4. High reliability



Reliability and failure definitions

	General definition	In GW biological treatment
Reliability	The probability that no operational interruptions will occur during a stated time interval	The probability that the system will produce treated GW effluent of satisfactory quality during a stated time interval
Failure	An event where the system stops performing as required	When the quality of the treated GW effluent is not satisfactory

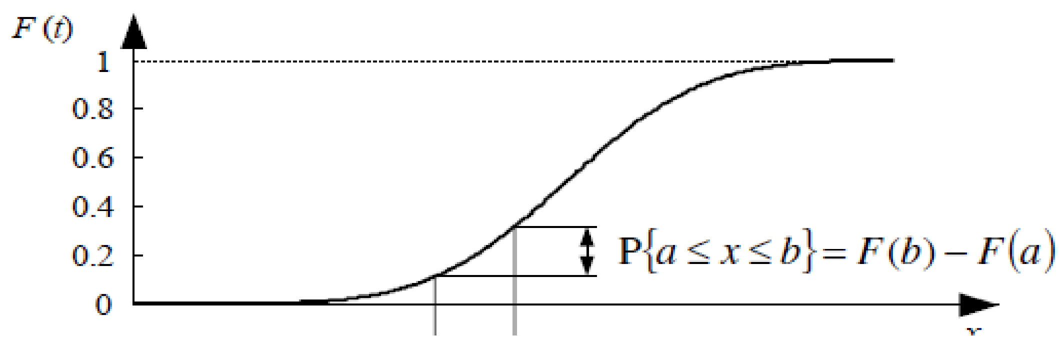
Assumption	*Failures are considered as repairable*	*After repair of a certain failure the system is "as good as new"*

Reliability function R(t)

Failure is a random variable and can be described with statistical tools:

R(t): Reliability function, is a survival function

F(t): The probability that an item will operate for a certain amount of time without a failure



$$F(t) = 1 - R(t)$$

$$F(t) = \int_0^t f(t)dt$$

(Lazzaroni 2011)

Mean Time Between Failures (MTBF)

- Mean Time Between Failures (MTBF) can be calculated by integrating the reliability function R(t)

$$MTBF = \int_0^\infty R(t)\,dt = \int_0^\infty \left[1 - F(t)\right] dt$$

- In order to calculate the MTBF, R(t) needs to be measured or assumed

- R (t) can be described by distribution models such as:

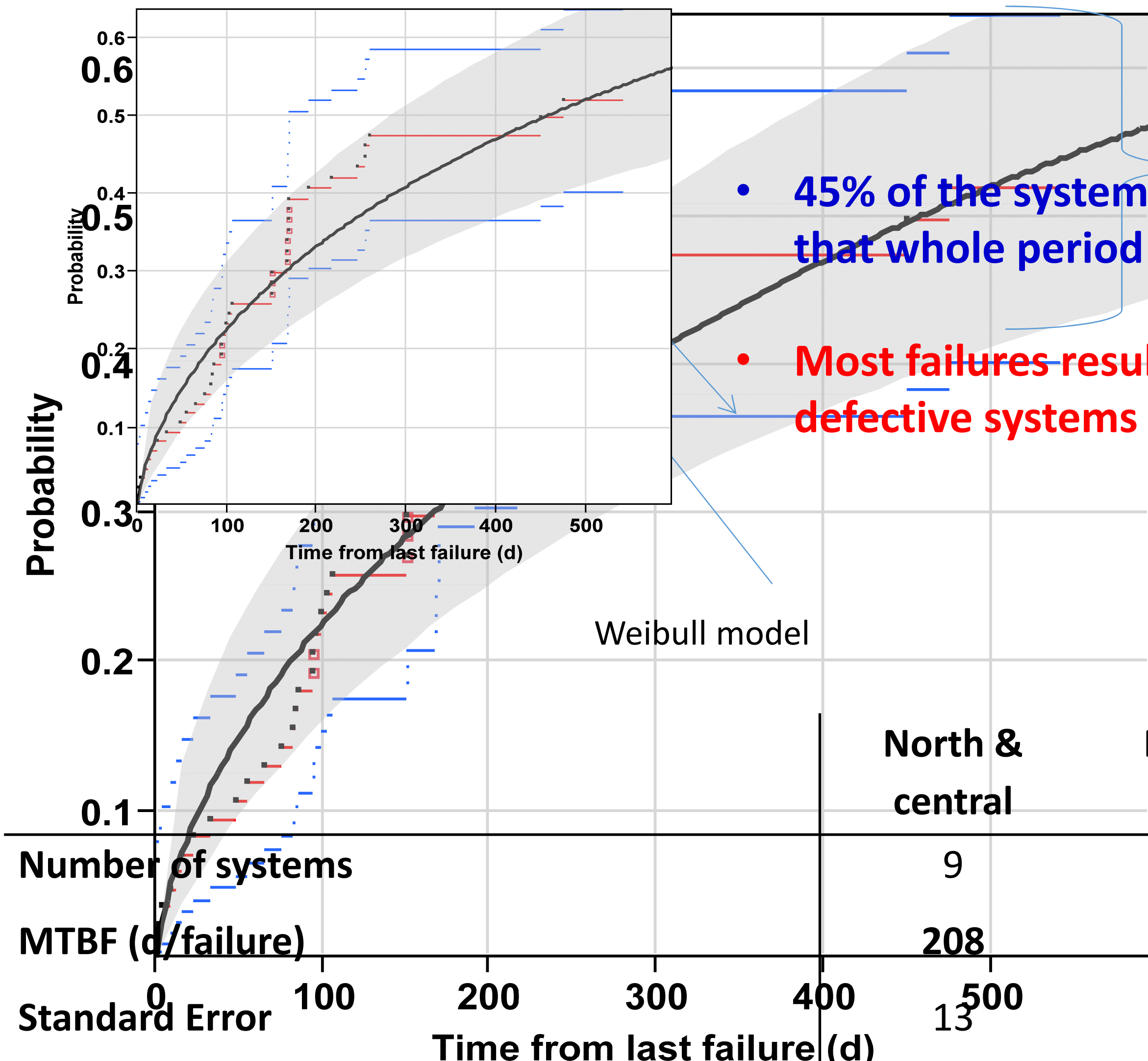
•Normal

•Exponential

•Log-normal

•**Weibull**

Reliability and MTBF



- 45% of the systems no failure occurred during that whole period
- Most failures resulted from a small number of defective systems

	North & central	Negev	Jordan rift	All 20 systems
Number of systems	9	8	3	20
MTBF (d/failure)	**208**	**336**	**128**	**305**
Standard Error	13	60	11	21
Number of systems that failed (at least once)	5	3	3	11
Number of systems that did not fail at all	**4 (44%)**	**5 (63%)**	**0 (0%)**	**9 (45%)**

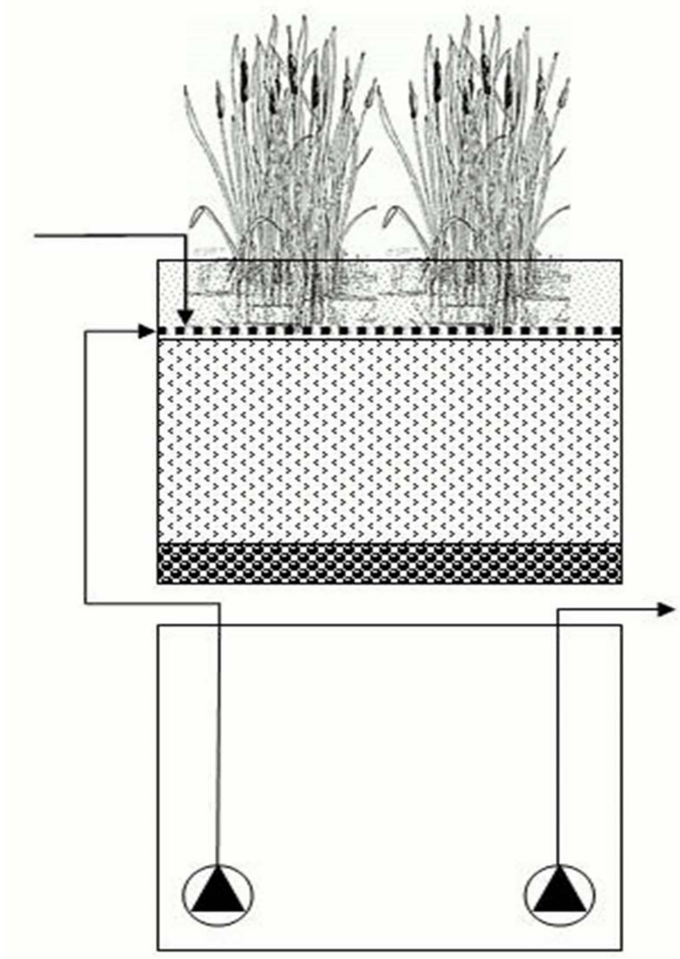
Design considerations

a) Wastewater flows directly into the plant root zone/filter

b) Water trickles down through the filter and into the reservoir

c) The bed: planted organic soil, high surface media, limestone gravel

Recirculating Vertical Flow Constructed Wetlands (RVFCW)



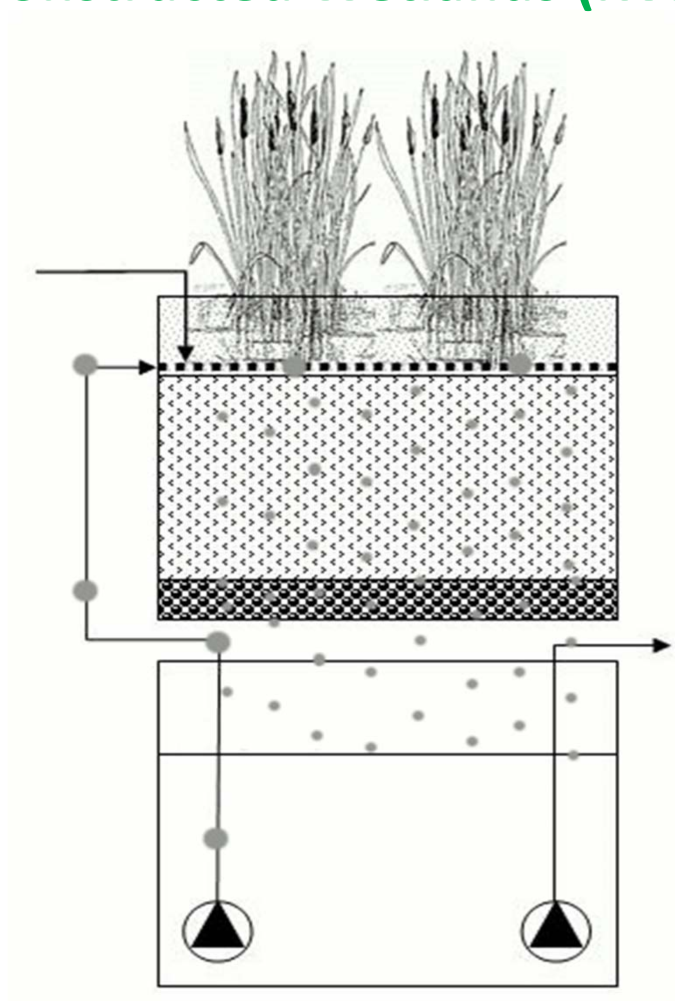
Design considerations

d) From the reservoir the water is recycled back to the bed several times

e) Recirculation pump keeps the wetland constantly wet and aerated

f) Treatment process: Mechanical filtration, microbial degradation, nitrification, and buffering by limestone gravel

Recirculating Vertical Flow Constructed Wetlands (RVFCW)

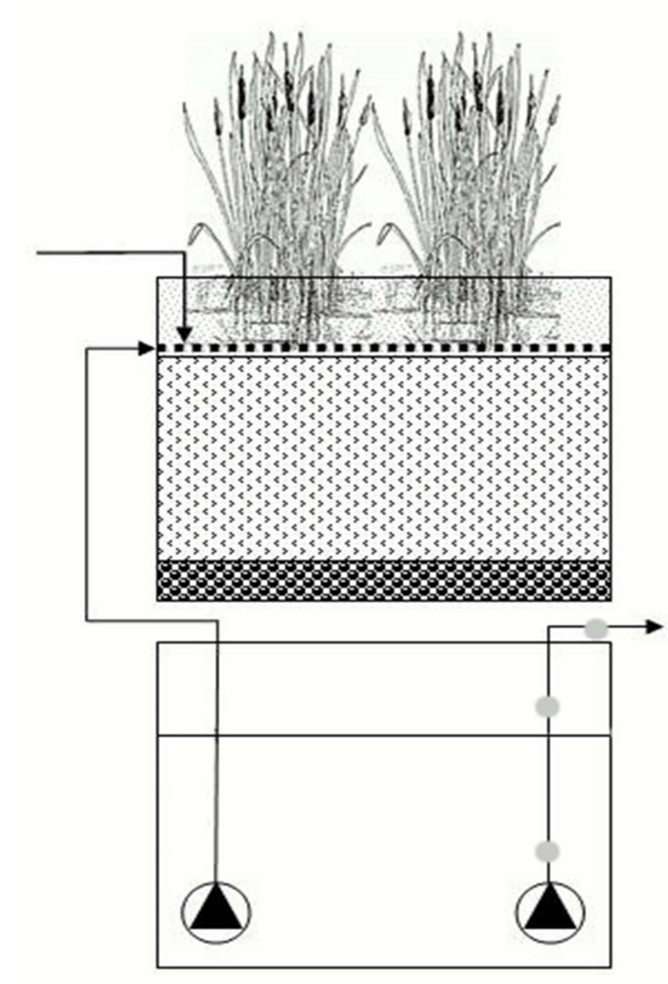


Design considerations

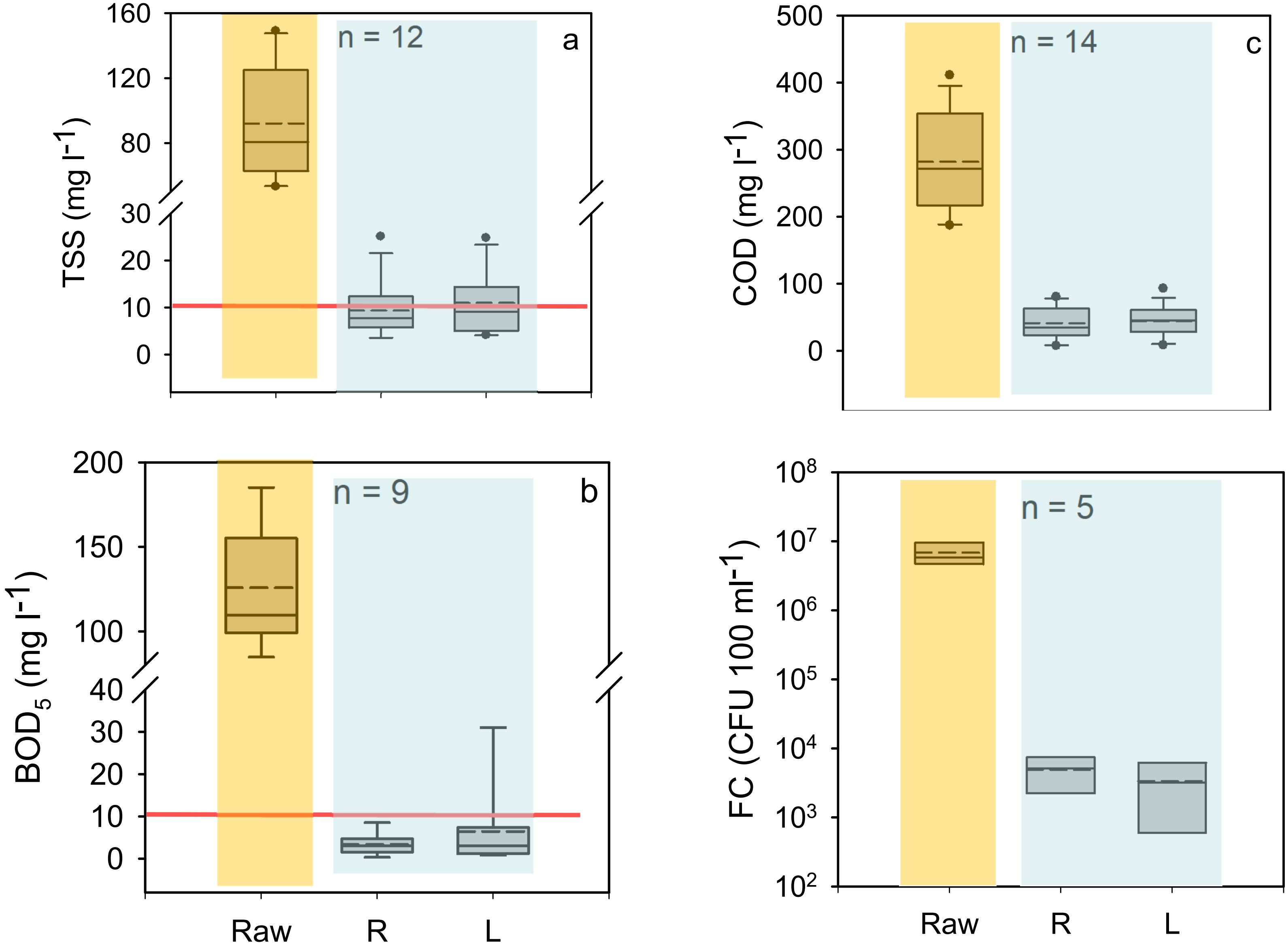
g) The treated water is released for drip irrigation via a disinfection unit (e.g. UV)

h) The system is modular, enabling the attachment of additional units

Recirculating Vertical Flow Constructed Wetlands (RVFCW)



It is possible to meet strict guidelines for unlimited irrigation even with simple biological treatment units

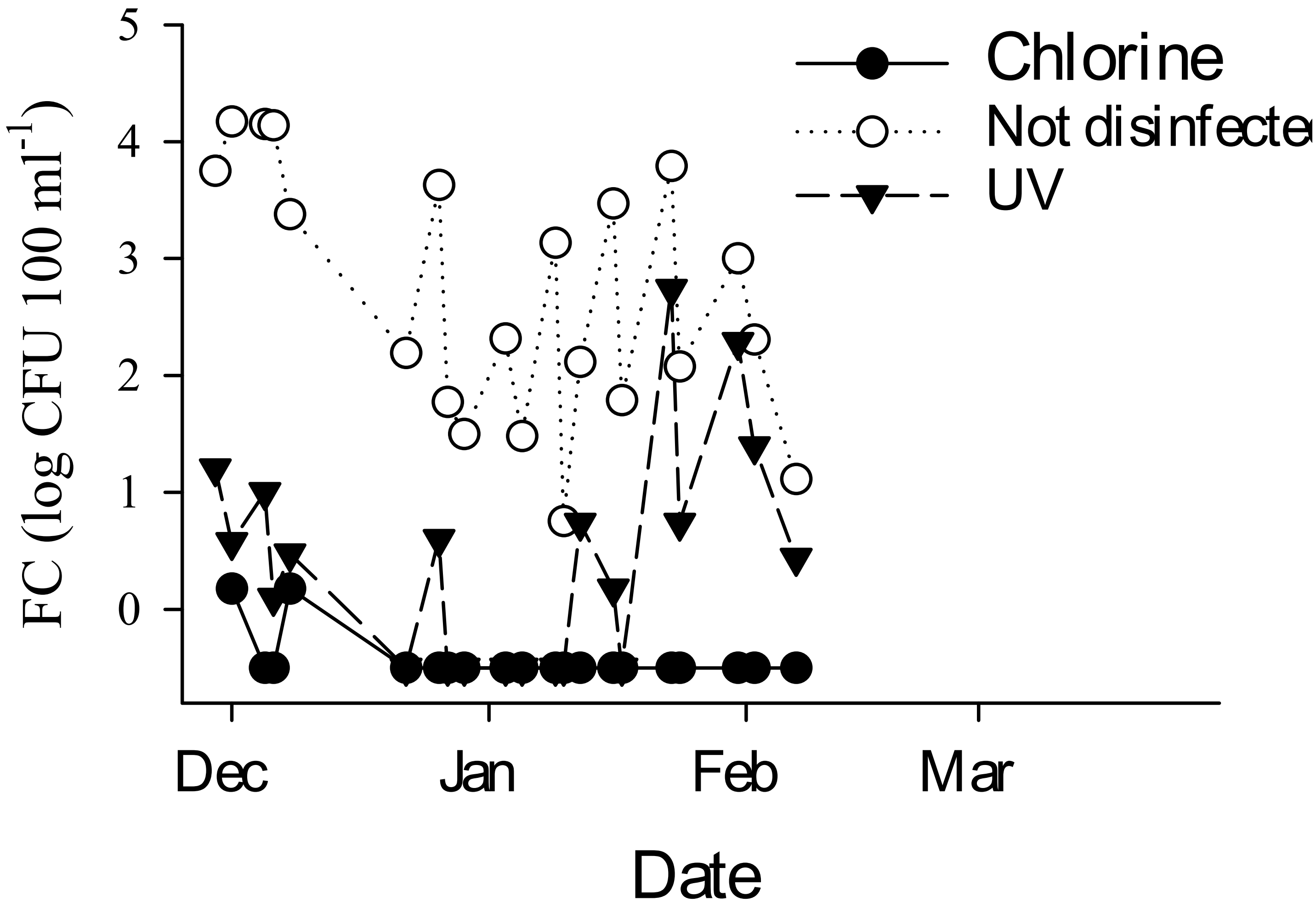


Disinfection

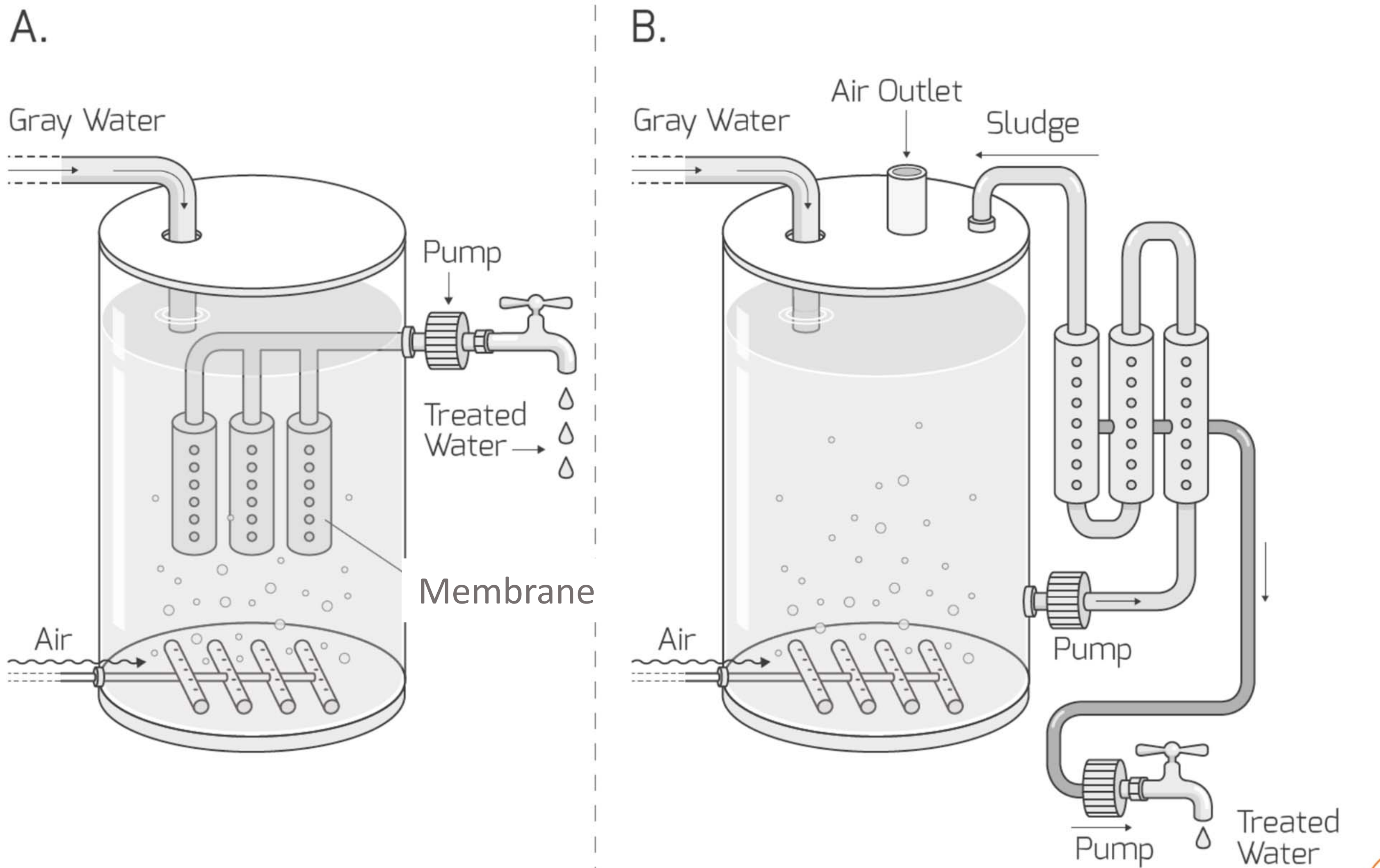
Low cost and pressure
, UV device

Simple Chlorinator, using
chlorine tablets

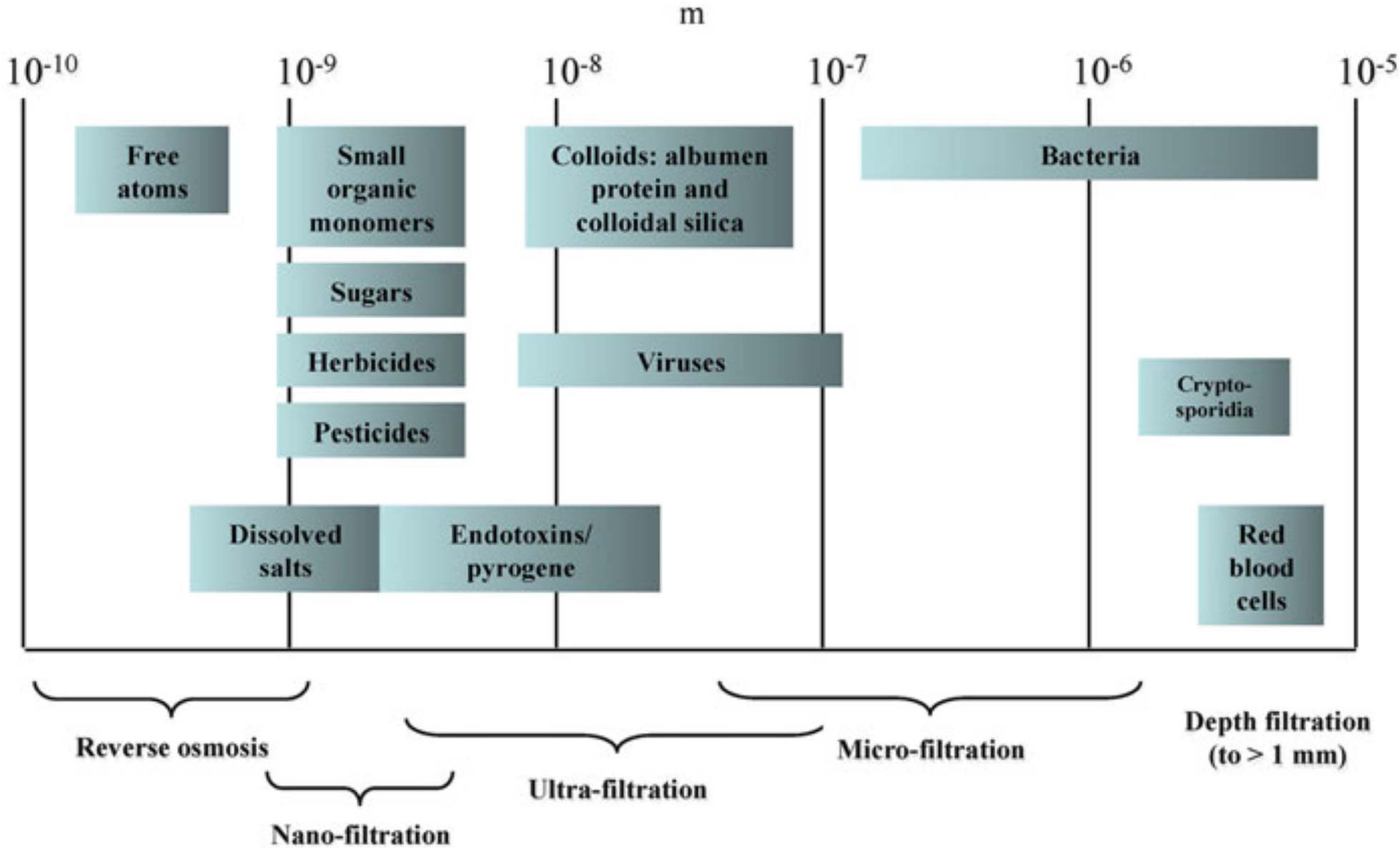
Disinfection



Membrane bioreactor (MBR) - Combines biological treatment and physical separation



Membrane pore size: MF 0.4-0.1µm UF 0.1-0.01 µm


m
10-10
10-9
10-8
10-7
10-6
10-5
Free atoms
Small organic monomers
Colloids: albumen protein and colloidal silica
Bacteria
Sugars
Herbicides
Viruses
Crypto-sporidia
Pesticides
Dissolved salts
Endotoxins/ pyrogene
Red blood cells
Reverse osmosis
Nano-filtration
Ultra-filtration
Micro-filtration
Depth filtration (to > 1 mm)

MBR: Major Pros and Considerations

- **Independent** control (decoupling) on hydraulic retention time (HRT) and sludge retention time (SRT)

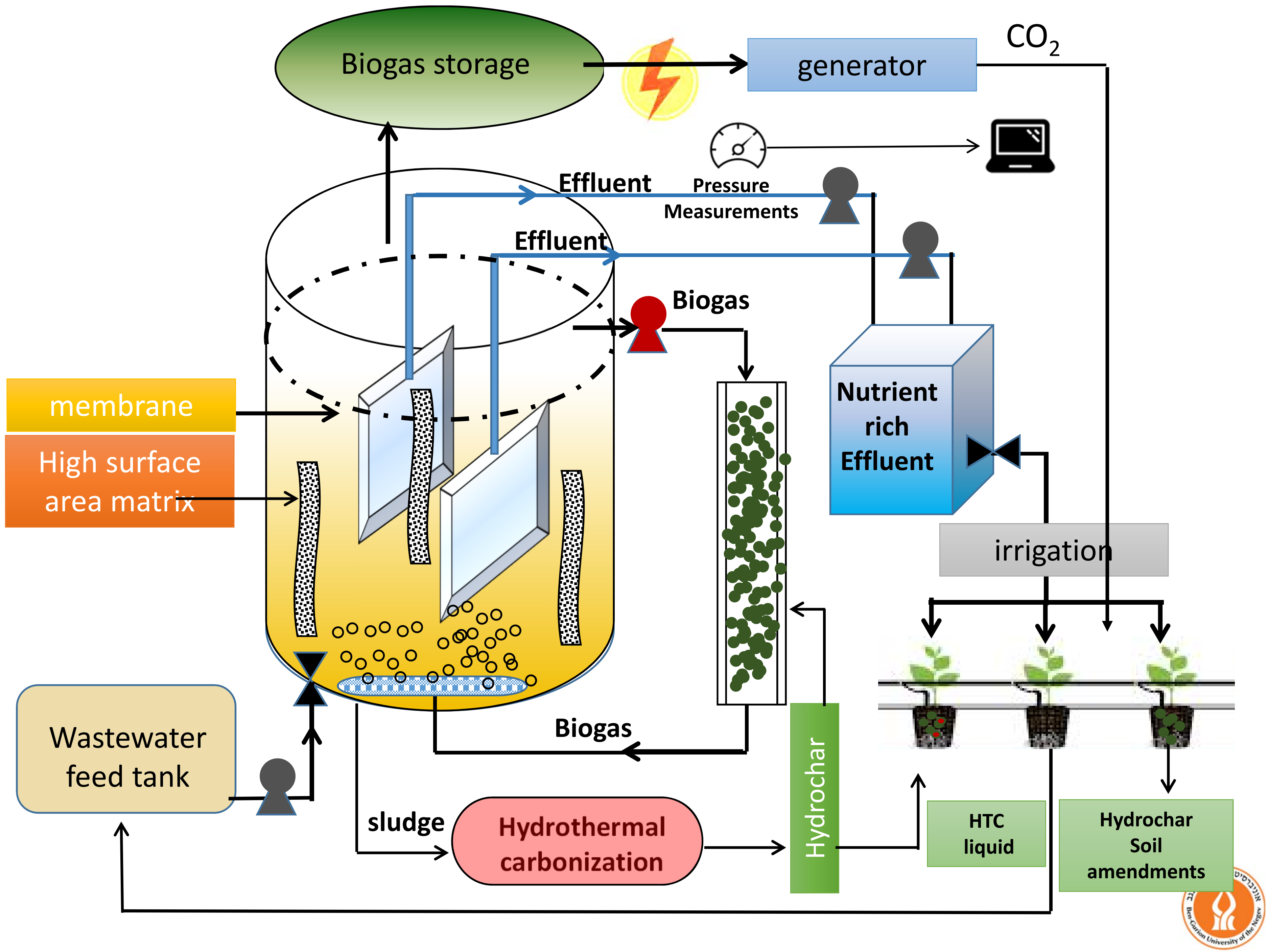
- Very high effluent quality:

no SS; low COD; pathogens free; rich in nutrients

- Membrane fouling is a significant factor

- In AnMBR (mainly) - High SRT – Fairly low sludge production

- AnMBR – biogas production



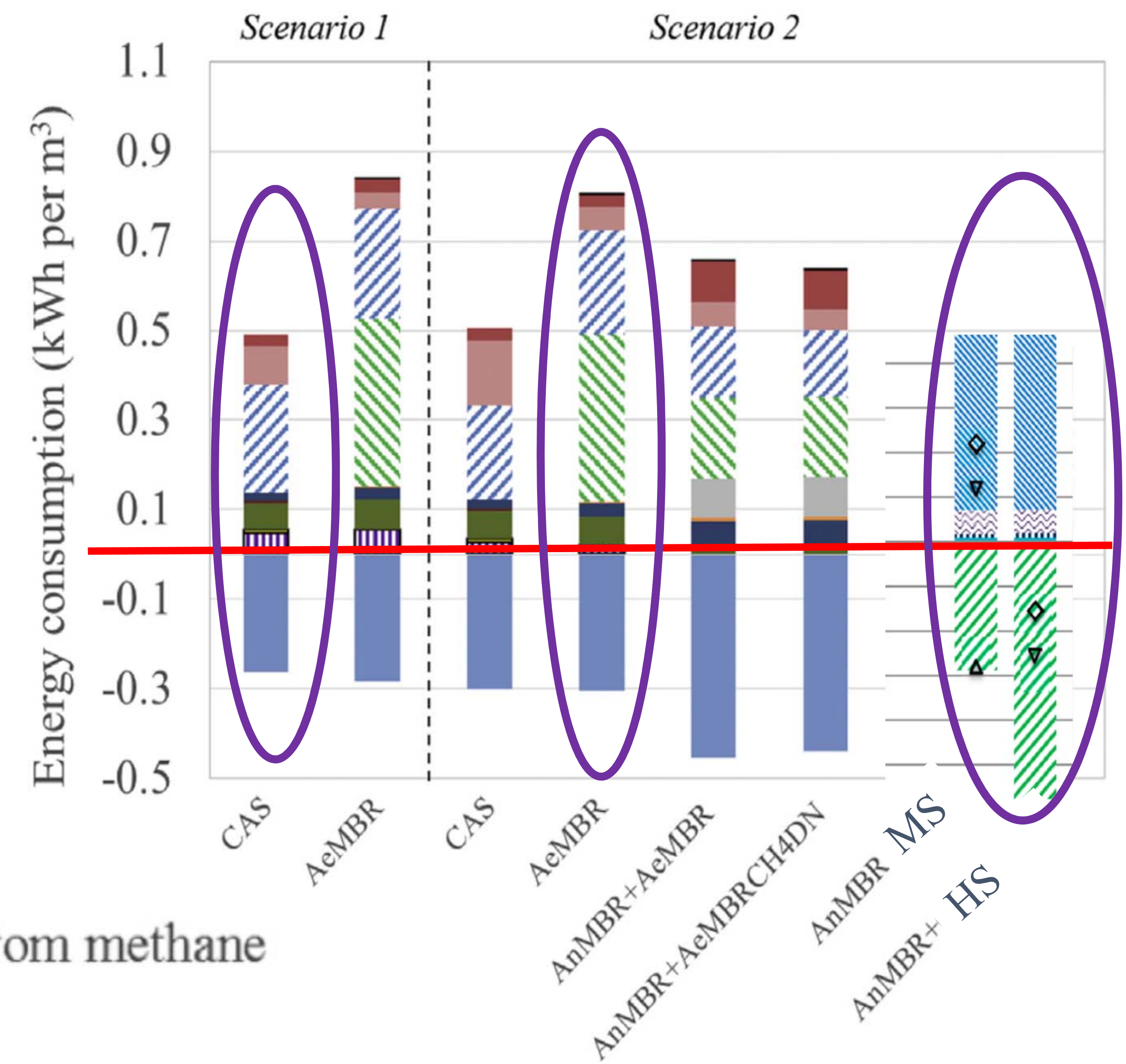
Biogas storage
generator
CO_2
Effluent
Pressure
Measurements
Effluent
Biogas
membrane
High surface
area matrix
Nutrient
rich
Effluent
irrigation
Wastewater
feed tank
Biogas
Hydrochar
sludge
Hydrothermal
carbonization
HTC
liquid
Hydrochar
Soil
amendments

Operational energy balance

Anaerobic digester / reactor stirring
AO/A2O reactor stirring & Equalisati
Air pumping
Membrane scouring by air sparging
Membrane scouring by gas sparging

Energy demand

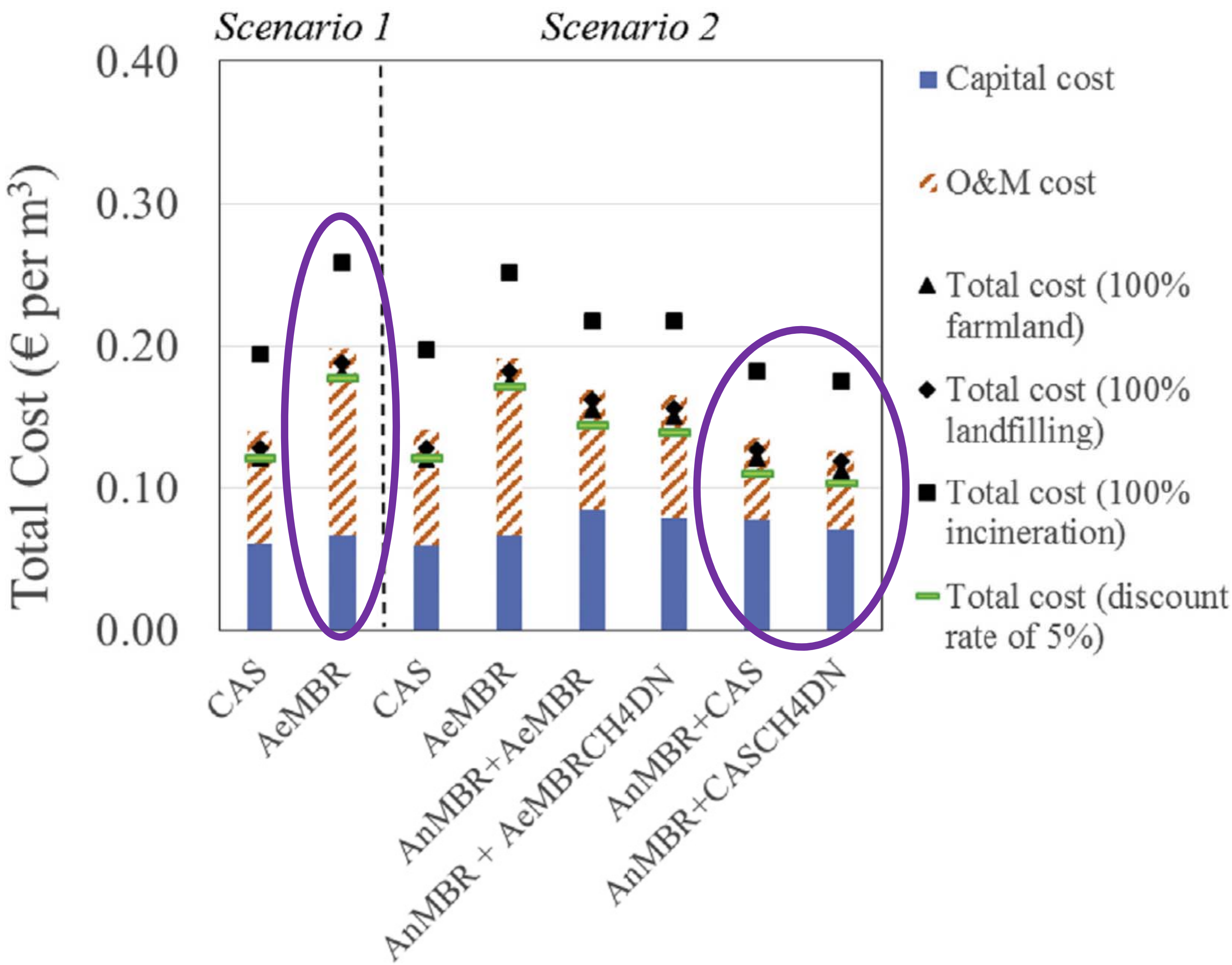
Energy Recovery



Power energy recovery from methane

Modified from: Pretel et al., 2016 (JEMA)
Smith et al. 2014 (ES&T)

Capital and operational costs



After Pretel et al., 2016 (JEMA)

Summary

- Greywater reuse can save significant amounts of water but must be treated prior to reuse.
- Treatment and reuse can recover nutrients, energy, support plant growth (food) which can also sequester CO_2 and produce O_2.
- Regardless to the treatment of choice, it must be robust, reliable, and able to endure large variations in water quality and quantity.
- Irrigation effluents can be recycled through the system and water exchange should be determined to prevent salinization.

Thanks for your attention

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Dr. Osnat Gillor
Dr. Stefan Leu
Prof. Nedbal Ladislav

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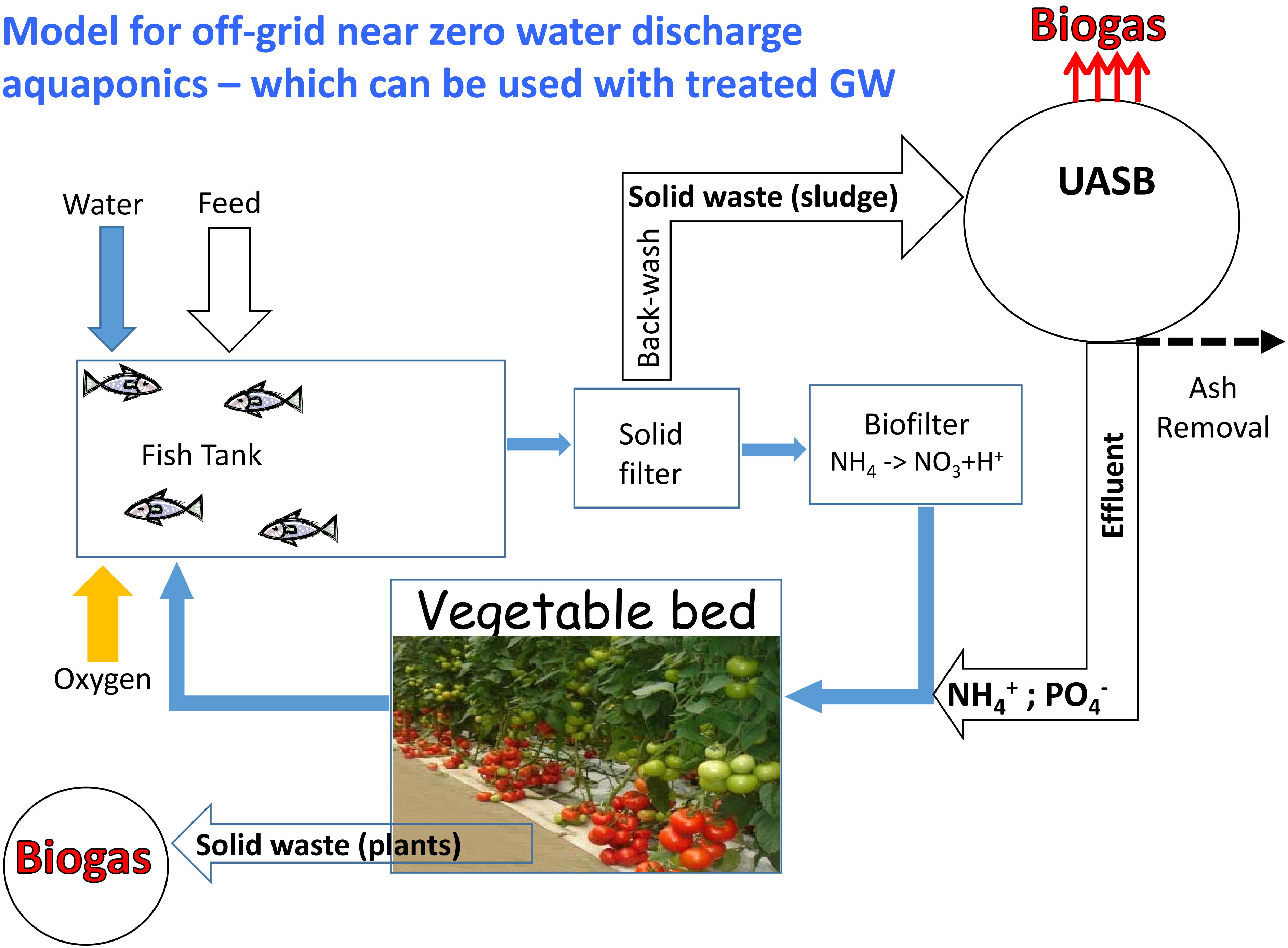
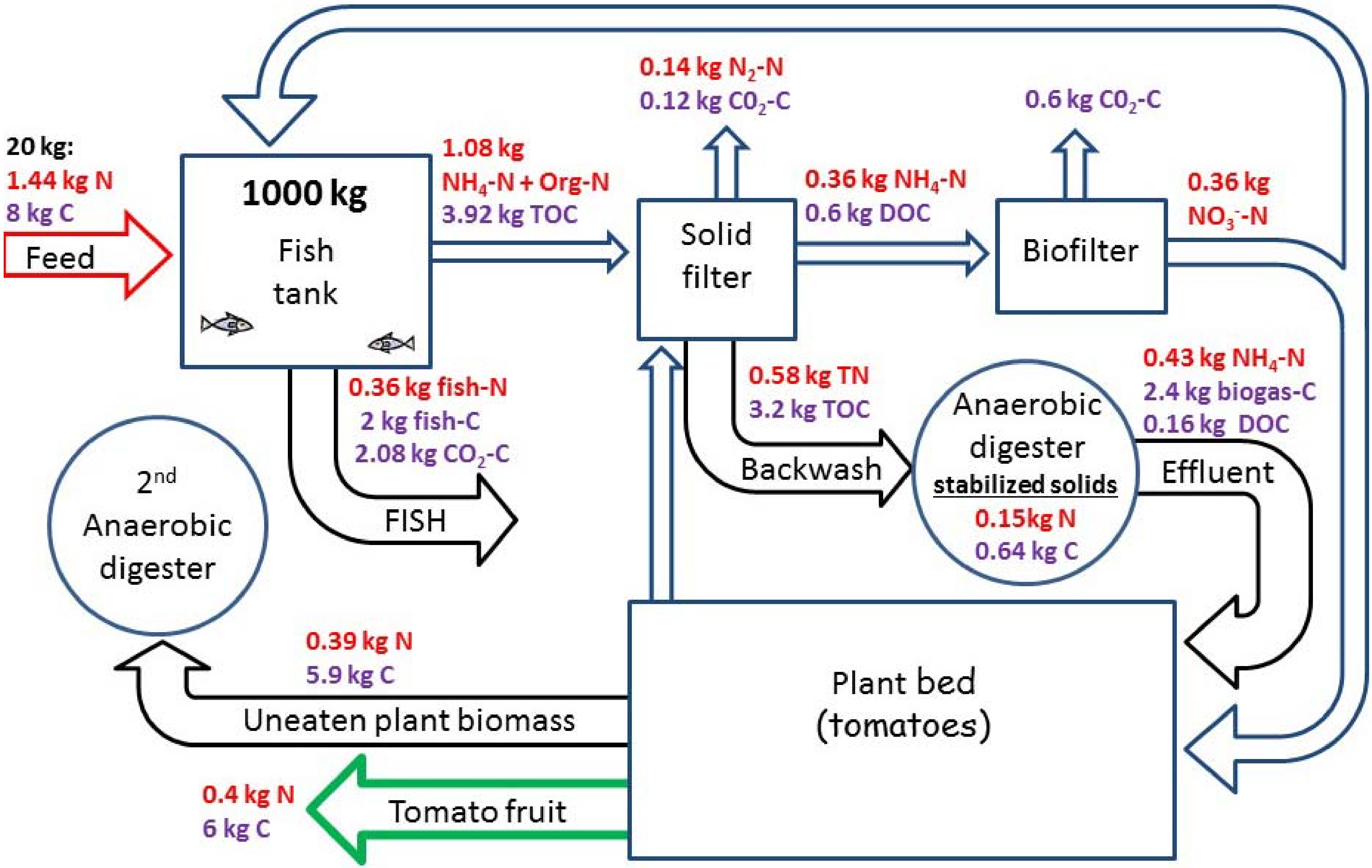
Water Authority
Koshland Foundation
RCF

Model for off-grid near zero water discharge aquaponics – which can be used with treated GW



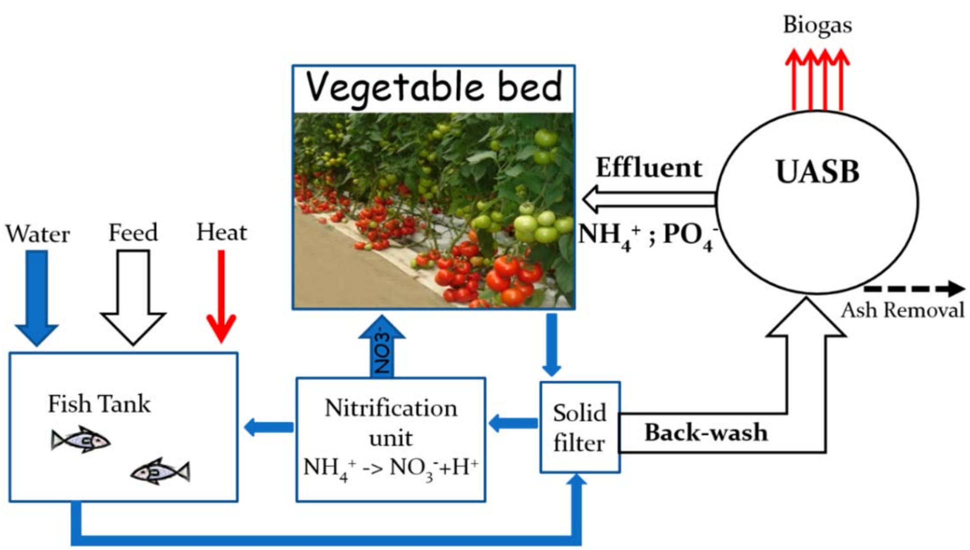


20 kg:
1.44 kg N
8 kg C
Feed
1000 kg
Fish
tank
1.08 kg
NH4-N + Org-N
3.92 kg TOC
0.14 kg N2-N
0.12 kg CO2-C
Solid
filter
0.36 kg NH4-N
0.6 kg DOC
0.6 kg CO2-C
Biofilter
0.36 kg
NO3--N
0.36 kg fish-N
2 kg fish-C
2.08 kg CO2-C
FISH
0.58 kg TN
3.2 kg TOC
Backwash
Anaerobic
digester
stabilized solids
0.15kg N
0.64 kg C
0.43 kg NH4-N
2.4 kg biogas-C
0.16 kg DOC
Effluent
2nd
Anaerobic
digester
0.39 kg N
5.9 kg C
Uneaten plant biomass
Plant bed
(tomatoes)
0.4 kg N
6 kg C
Tomato fruit

Summary: off-grid system.

- <u>Theoretic full energy recovery:</u>
  - ~1 ton fish stock
    - 2% daily feeding rate:

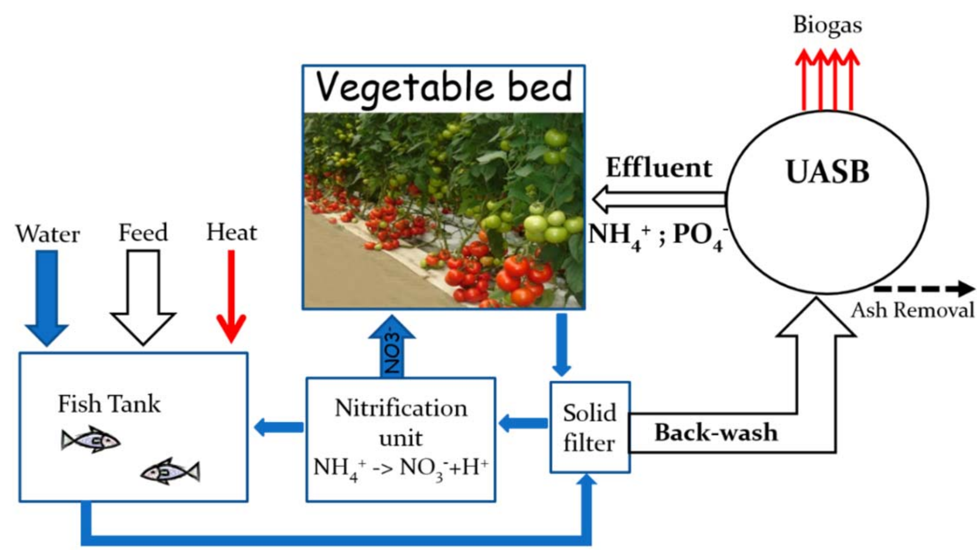
      20kg, 45%protein feed per day



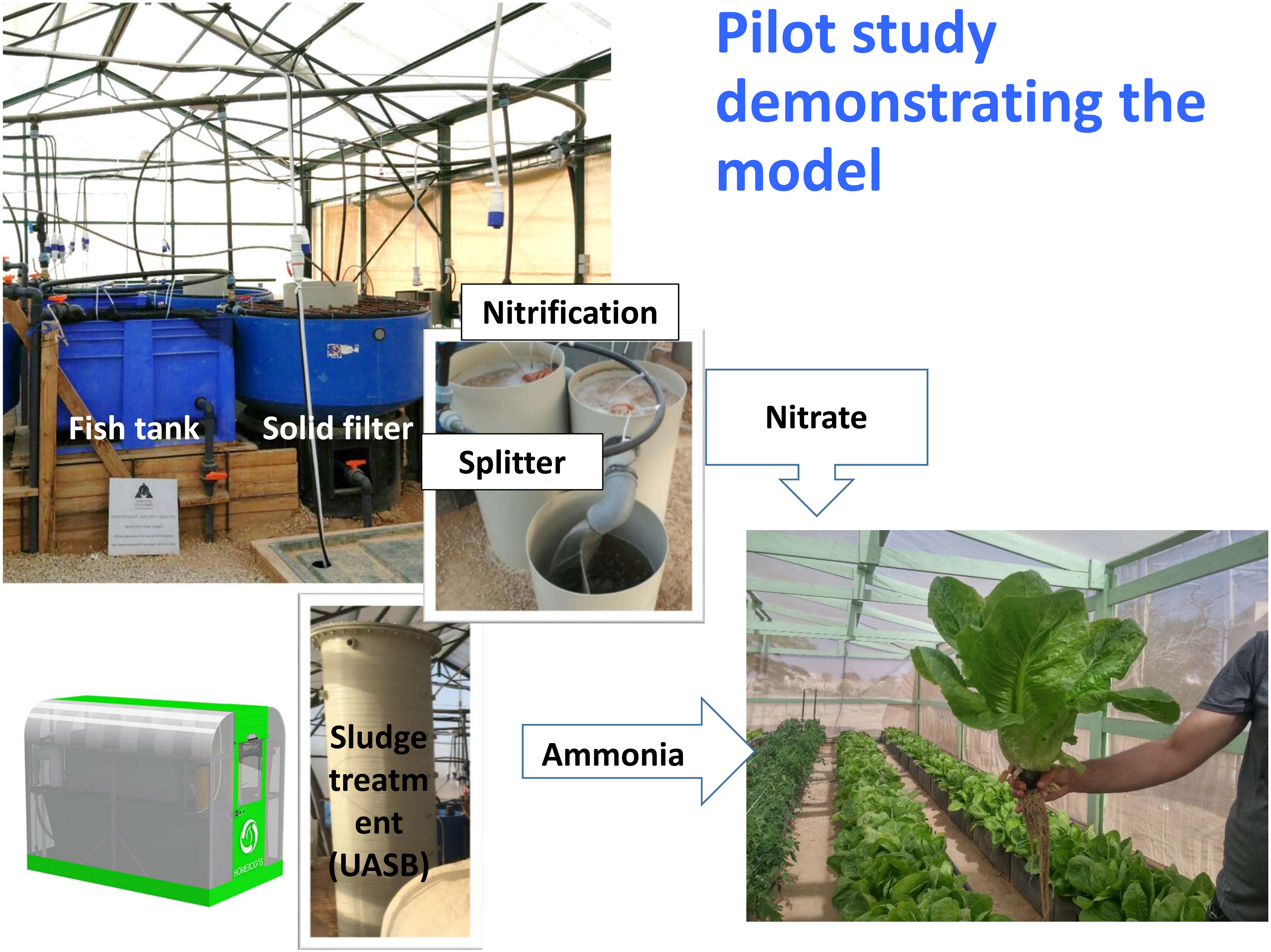
Summary: off-grid system.

- Nutrient recovery by anaerobic digestion:
  - 4-5 times bigger vegetable area
    - 3500 m^2 tomato beds Vs 750m^2
    - 250kg tomato per day Vs 60kg

Full (99.5%) water recovery (recirculation) except for evapotranspiration



Pilot study demonstrating the model



Required and Available Energy for Wastewater Treatment, Exclusive of Heat Energy

- Energy required for secondary wastewater treatment

  1,200 to 2,400 MJ/1000 m^3

Energy available in wastewater for treatment (assume COD = 5.0 g/m^3)

  Q = [500kg COD/1000 m^3) (1000 m^3) (13 MJ/ kg COD)

  6,000 MJ/1000 m^3

- Energy available in wastewater is 2 to 4 times the amount required for treatment

Based on G. Tchobanoglous