KWB

Interreg Baltic Sea Region

Co-funded by the European Union

SUSTAINABLE WATERS WaterMan

WaterMan – 1st method & tool workshop

Water reuse with focus on risk & life cycle assessment

12.06.2023

Rest of day 1: table of contents

1. Joint reflection on the site visit
2. Focus & aims of the workshop (day 2)
3. Water for reuse
    - introduction & basics
    - water reuse types
    - stakeholders & challenges
4. Treatment technologies for water reuse
   (“fit for purpose”)

Nutzwasser project – Joint reflection

- WP1: permit implementation
- WP2: water quality requirements
- WP3: needs assessment
- WP4: needs provision
- WP5: needs-based treatment
- WP6: economic and ecological assessment
- WP7: public relations work

Stakeholder process

Impressions?

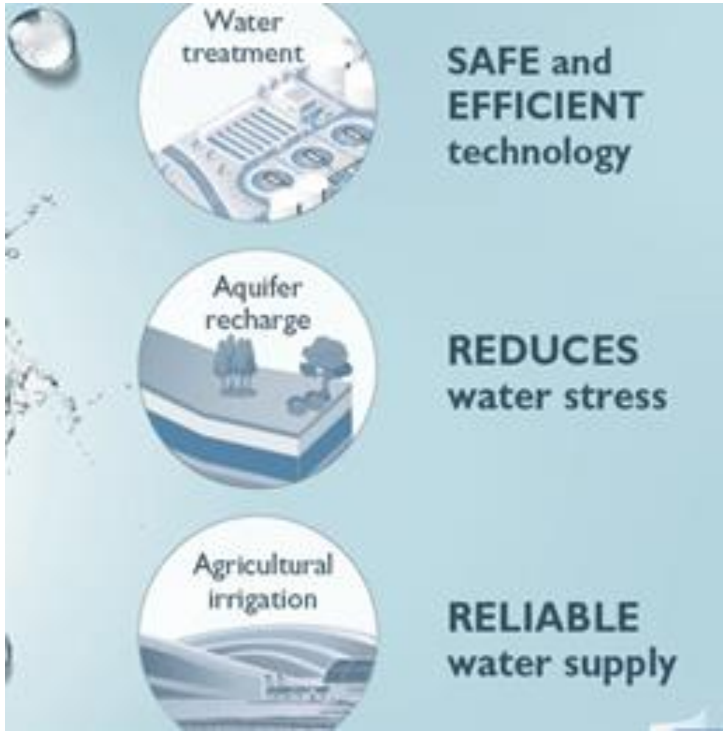
What do you take home?

What's useful for WaterMan?

Aim of the workshop

- **Capacity building:**
  - water reuse
  - water quality & wastewater treatments
  - risk assessment (RA) and management
  - life cycle assessment (LCA)
- Build **common basis & wording** for communication and (local/national) stakeholder work
- Introduction to available tools to **facilitate and support decisions**

Water reuse



Definition: „'Water Reuse, is the use of reclaimed water from treated wastewater" (UBA)

"Water reuse […] reclaims water from a variety of sources then treats and reuses it for beneficial purposes" (EPA)

Motivation: More resilient water supply & security in the context of climate change & water scarcity

→ supplements limited freshwater resources

→ enables circular water use

→ fosters further elimination of pollutants & pathogens

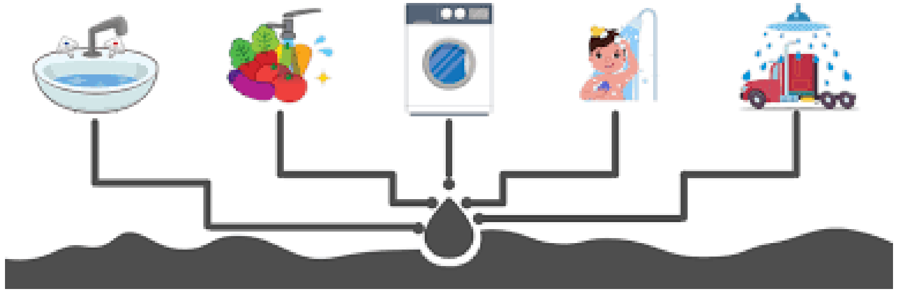
→ (reduces wastewater discharge)

➡ **long-established reality in industry & many (semi)arid countries**

Water reuse sources

Where does the water for water reuse mainly come from?

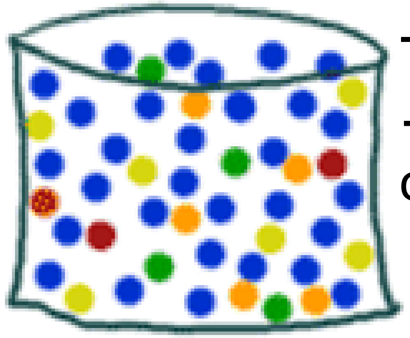
Municipal and/or industrial wastewater effluent



Greywater (sink, laundry, shower, etc.)

Run-off/ retained rainwater

Water reuse sources – What´s inside?



- **Organic material** (carbohydrates, proteins, fats)

→ reference parameters to determine the amount of oxygen consumed to oxidize organic water compounds to inorganic end products

> **BOD** (biological oxygen demand) for measuring easily biodegradable organics
>
> **COD** (chemical oxygen demand) for measuring all organics

- **Inorganic material** (e.g. **salts** like chlorine, nitrate, phosphorus; **heavy metals** like lead (Pb), copper (Cu))
- **Compounds of emerging concern** (e.g. persistent, mobile and toxic (PMT) organic compounds like PFAS; trace organic substances like pharmaceuticals)

  → Mainly targeted analyses (individual and sum parameters)

- **Microbiological organisms** (pathogenic & non-pathogenic, e.g. bacteria, viruses, fungi)

Chemical substances in municipal wastewater

Substances in usually small concentrations (< 0,1 ng/l) which can have ecotoxicological relevance in surface water and human toxicological relevance in drinking water

Compounds of emerging concern (CEC)

Trace organic substances (TOrCs, TrOCs)

Micropollutants (MP)

Active pharmaceutical ingredients (APIs)

Many terms describe more or less the same thing

One class, however, is different:

very (v) – persistent (P) – mobile (M) – toxic (T) pollutants: PM, vPvM, PMT

Persistent: low degradation potential (half-life ranges in water/sediment/ soil)

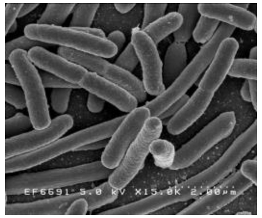
Mobile: low sorption potential to sediments & soils → mobile in pore water

Toxic: e.g. carcinogenic/ mutagenic/ toxic for reproduction OR no-observed effect concentration (NOEC) for freshwater organisms < 0.01 mg/l

Microbiology in municipal wastewater

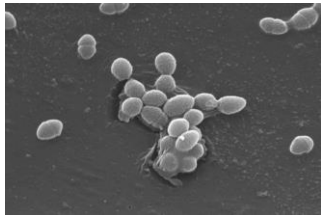
Indicator organisms indicating faecal pollution

Escherichia Coli



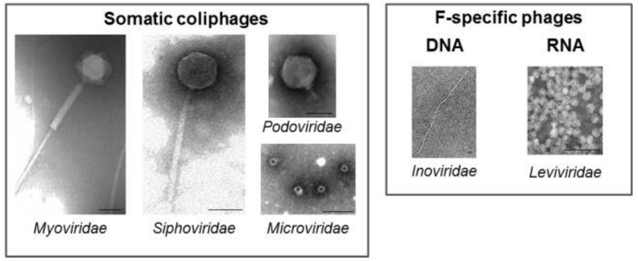
Source: Rocky Mountain Laboratories

Intestinal enterococci



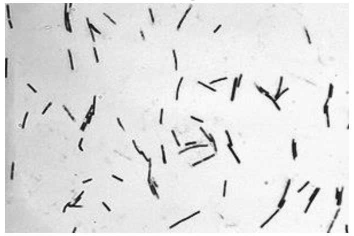
Source:https://commons.wikimedia.org/w/index.php?curid=1669200

Coliphages



Source:https://www.mdpi.com/2073-4441/8/5/199

Clostridium perfringens

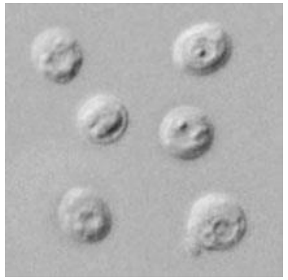


Source:https://de.wikipedia.org/wiki/Clostridium_perfringens#/media/Datei:Clostridium_perfringens.jpg

Real pathogens causing illness (e.g. gastroenteritis)

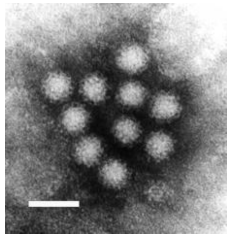
Parasites

Giardia intestinalis

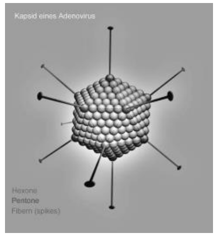


Cryptosporidium parvum

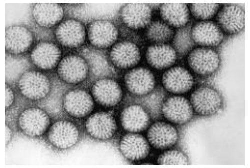
Viruses



Norovirus



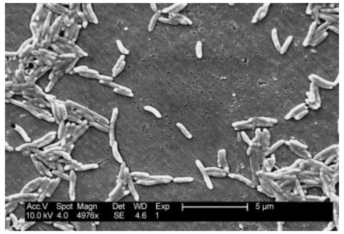
Adenovirus



Rotavirus

Von Gleiberg - Eigenes Werk, CC BY-SA 2.0 de, https://commons.wikimedia.org/w/index.php?curid=11869453

Bacteria



Campylobacter jejuni

Microbiology in municipal wastewater

Table 2
Size and examples of pathogens of human health concern detected in municipal wastewater (adapted from (Pepper et al., 2014)).

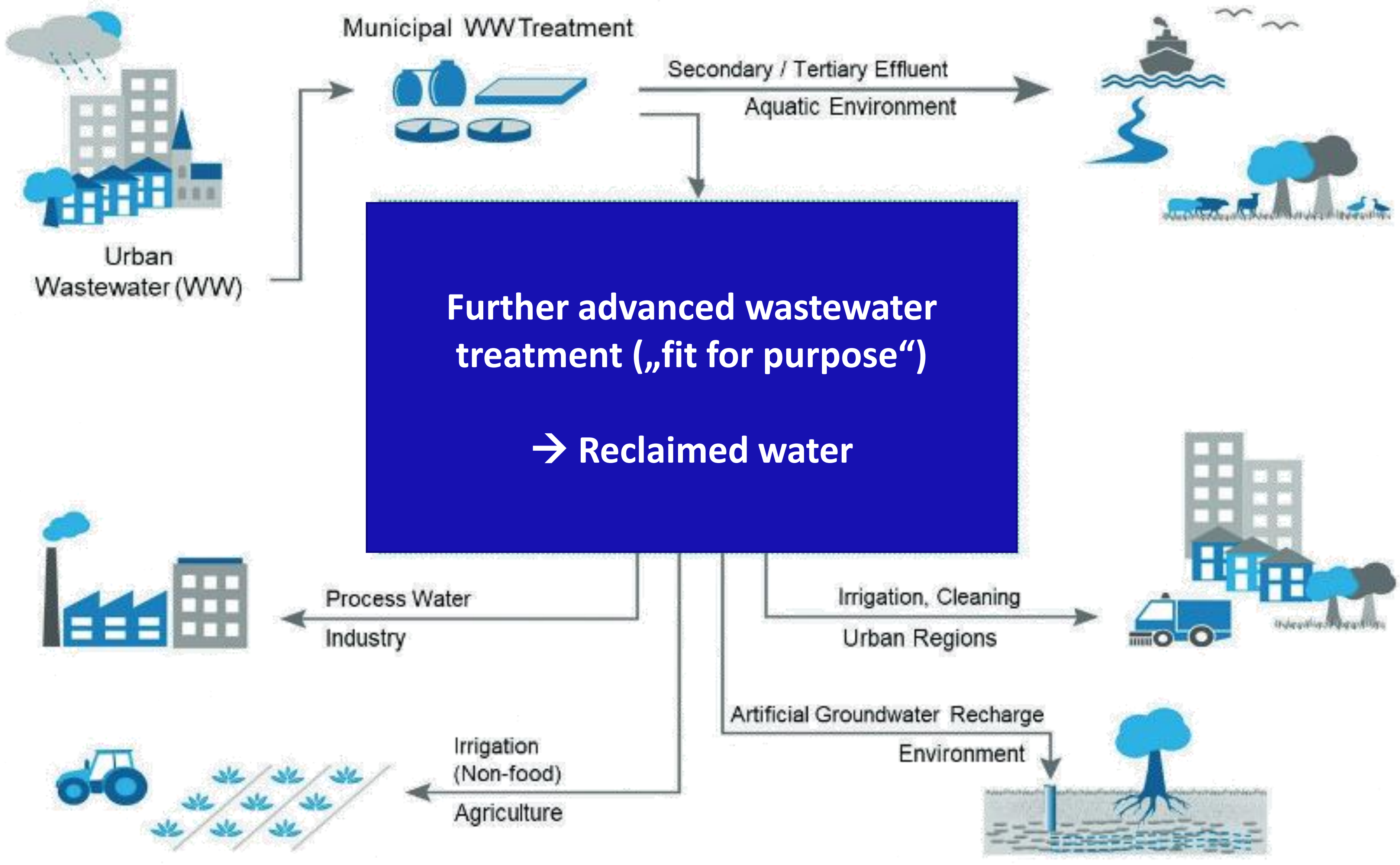
Protozoa (several μm)	Bacteria (≥ 1 μm)	Viruses nm		Indicator / Surrogate viruses
Cryptosporidium spp.	*Salmonella spp.*	Rotavirus (60-80)	Achi virus (23)	MS2
Giardia lamblia	*Campylobacter spp.*	Adenovirus (70)	Parvovirus (18-23)	Qβ
Entamoeba histolytica	*Shigella spp.*	Norovirus (23-40)	Circovirus (15-22)	ΦX-174
Cyclospora cayetanensis	*Yersinia*	Astrovirus (28-35)	Bocavirus (18-26)	FRNAPH
Toxoplasma gondii	*Vibrio spp.*	Hepatitis A and E (27-34)	Saprovirus (27-49)	PMMoV
Microsporidia	*Pathogenic E. coli*	Enteroviruses (Coxsackie, Echo) (23-30)		CrAssphage
Toxoplasma gondii	*Listeria spp.*			Bacteroides phage
				Somatic coliphages

Source: Zhiteneva et al., 2023. 10.1016/j.watres.2023.119836

Water reuse sources – Characteristics

Water sources	Characteristics
Greywater (sink, shower, laundry, etc.)	- Organics like soap, fats, proteins - Inorganics like phosphorous, nitrogen - (pathogens → analytical tests required)
Municipal wastewater	- Diluted mix of everything: Low concentrations of organics/inorganics (suspended & dissolved) solids - persistent, mobile and toxic (PMT) organic compounds like PFAS & trace organic substances - Heavy metals (e.g. Cu, Zn)
Industrial wastewater	Very specific depending on industry
Mixture of both	Diluted mix of municipal & industrial wastewater (maybe with high specific contaminant depending on the connected industry)
Run-off, retained rainwater	Highly dependent on runoff surface, e.g. - agriculture: pesticides - buildings: biocides, metals like zinc & copper - green areas: nutrients & pathogens - streets: PAC - polyaromatic hydrocarbons)

Water reuse - Options



+ indoor uses

(e.g. toilet flushing)

+ water supply

Source: MULTI-ReUse project

Water reuse – Use types

Water for potable reuse (direct/indirect) vs. non-potable reuse

Unplanned/de facto vs. Planned/targeted

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Water source substantially made up of previously used water (e.g. treated wastewater discharges in rivers for water supply)

Designed to benefit from reusing recycled water (e.g. agricultural/urban irrigation, industrial process water, potable water supplies, groundwater supply management)

Water reuse – Potential stakeholders

- Several departments of public authorities for
  - Human health
  - Water/ wastewater
  - Urban development/ parks
  - Agriculture/ rural development
  - Environment
- Reclaimed water provider: e.g. WWTP operator or other intermediate
- Reclaimed water user
- Civil society

…

➡ **Depending on water use type**

Water reuse – EU history

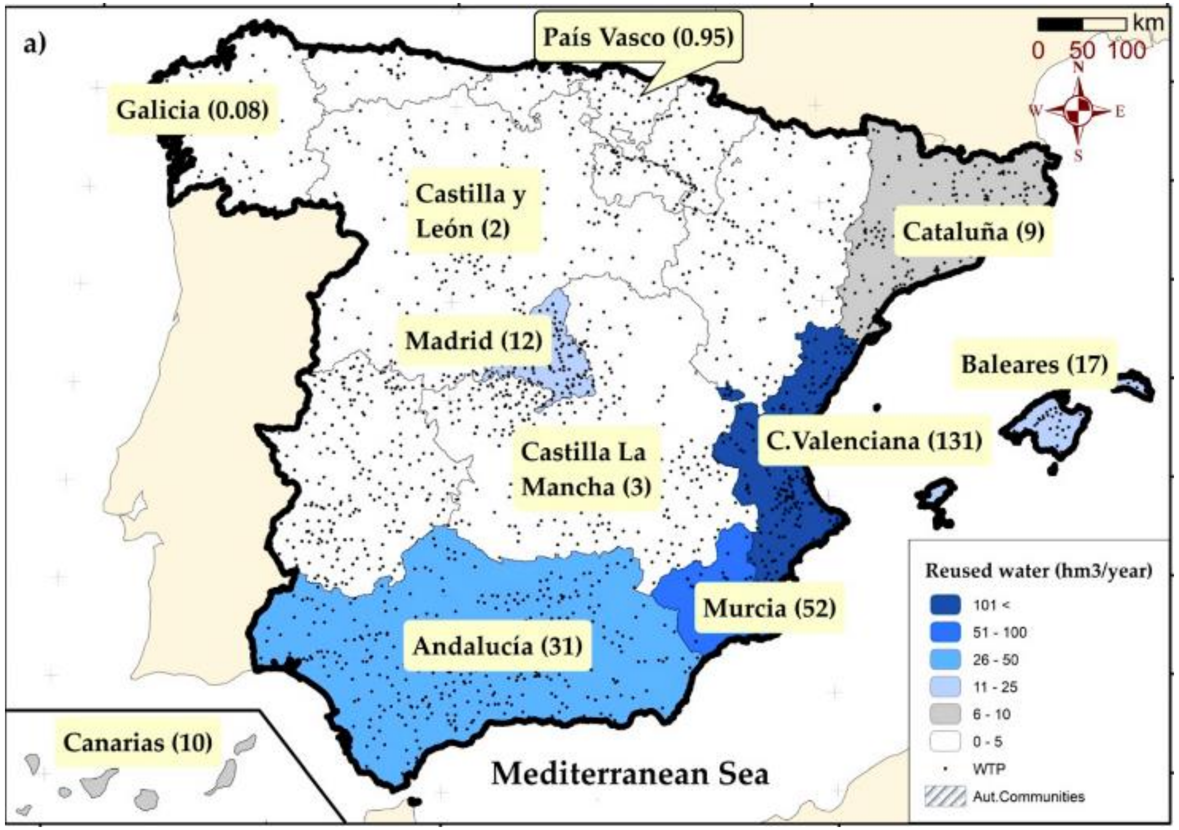
Trickle field around Berlin with ditches (wastewater disposal & reuse on agricultural fields)

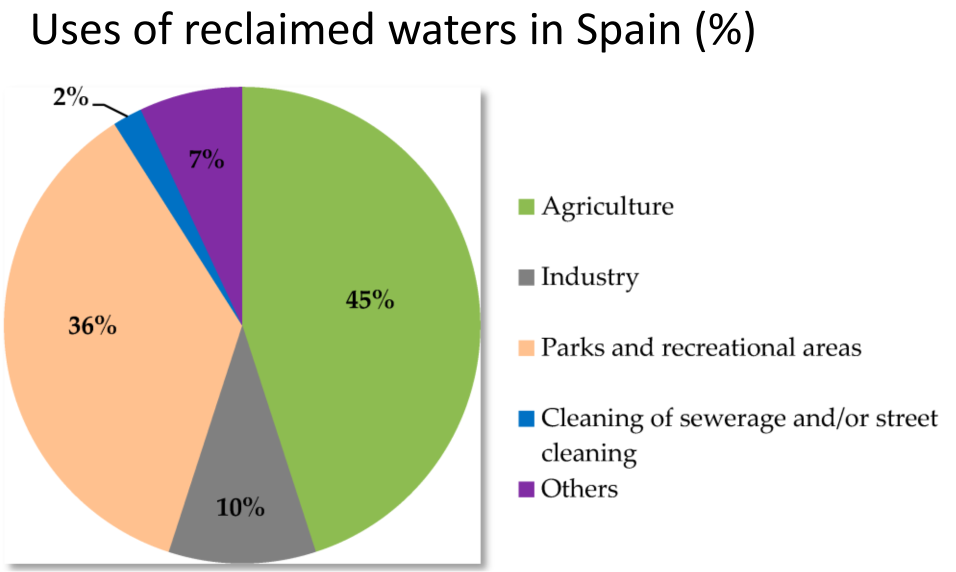
- 3000 BC: Early evidence of agricultural irrigation with wastewater in Greece
- 6 BC-7 AD: Roman systems for harvesting rainwater from rooftops for domestic uses in cities
- 19th century: unintended reuse in countries through “sewage farms” (wastewater with fertilising value applied to land)
- Early 20th century: **planned water reuse** to increase water use efficiency & limit freshwater abstraction (rivers/ aquifers)
- 1960s: crop irrigation with reclaimed wastewater as common practice in Israel & other Mediterranean countries
- Since 1980: many water reuse projects developed

Source: Water Reuse Europe, 2020

Water reuse – EU examples

- Some EU member states, such as Spain, Cyprus & Greece even have their own water reuse legislation
- In Cyprus & in some regions of Spain, almost 90 % of municipal wastewater is reused





Source: Jodar-Abellan et al. Wastewater Treatment and Water Reuse in Spain. Current Situation and Perspectives , 2019.

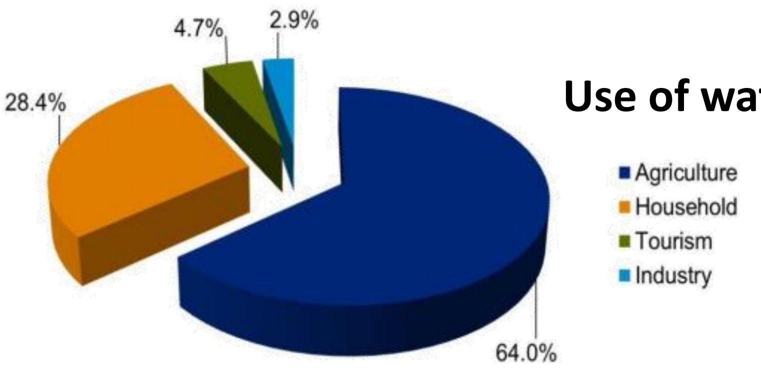
Water reuse – EU example: Cyprus

- Semi-arid climate & prolonged droughts
- Limited water resources
- Unevenly distributed rainfalls (temporally & geographically)
- Reuse mainly for agricultural irrigation

Declining Rainfall in Cyprus

Statistical analysis reveals a stepped drop of 15% in precipitation since the early 70's, resulted in a drop of 40% in river runoff

Use of water



Source: Ministry of Agriculture, Rural Development and Environment of the Republic of Cyprus, 2015.

Desalination for domestic use & WWTP effluent reuse for irrigation

Main crops irrigated in Cyprus

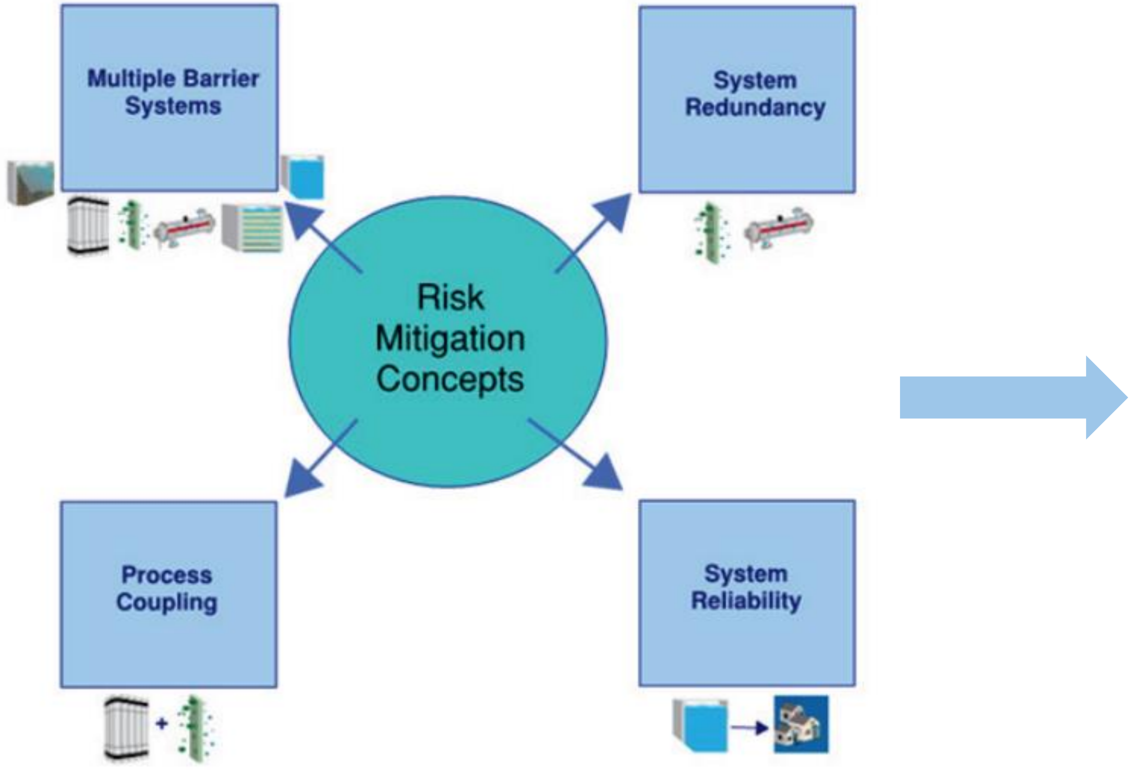
Water reuse - Challenges

General challenges:

- "significant potential to extend water reuse in response to climate change and water scarcity but a lack of **common requirements** prevents widespread uptake." (EC) – except agricultural reuse
- Justified risk management for human & environmental health (Reasonable effort for the benefit)
- Unclear liabilities & responsibilities between stakeholders
- Distances between water reuse supply & water reuse demand
- Conflicting objectives (e.g. groundwater protection & urban irrigation)
- Costs (water, infrastructure, technology,…)
- Social & public acceptance

Fit-for-purpose treatment

- Reclaimed water should be treated to the most appropriate level for a specific use
- Often done using a multi-barrier treatment concept



Overall goals of treatment

- Remove suspended solids
- Reduce concentration of dissolved chemicals
- Disinfection
- Removal of trace organic compounds
- Stabilize water
- Control the aesthetics of water

Source: US EPA Potable Reuse Compendium, 2017.

Treatment technologies for water reuse

Treatment objective	Process	
Removal of suspended solids	• Coagulation • Flocculation • Sedimentation	• Media filtration • Microfiltration (MF) • Ultrafiltration (UF)
Reduce concentrations of dissolved chemicals	• Ion exchange • Biologically active filtration (BAF)	• Reverse osmosis (RO) • Nanofiltration (NF) • Granular activated carbon (GAC)
Disinfection	• Ultraviolet disinfection (UV) • Chlorine/chloramines • Nature based solutions (NbS)	• Peracetic acid (PAA) • Chlorine dioxide • Ozone (O_3)
Removal of trace organic compounds	• O_3 • O_3 + BAF • NF/RO	• GAC • NbS • Advanced oxidation processes (AOP)
Stabilization	• Sodium hydroxide • Lime stabilization	• Calcium chloride • Blending
Aesthetics	• O_3 + BAF	• MF/RO
Salinity	• RO • Ion exchange	• Electrodialysis

Source: US EPA Potable Reuse Compendium, 2017.

Trace organic compound removal

technology		compounds that break through
activated carbon	→	small aliphatic and/or anionic compounds
anion exchange resin	→	cations and neutral compounds
cation exchange resin	→	anions and neutral compounds
reverse osmosis & nanofiltration	→	very small molecules
advanced oxidation processes	→	compounds with unoxidable bonds & unwanted by-products

- **Granular activated carbon (GAC)**
  - Compounds are removed via adsorption to carbon surface
  - Good removal of larger molecular weight, hydrophobic compounds (e.g. benzotriazole)
  - Also found as pulverized activated carbon (PAC) in activated sludge processes

- **Ozone (O_3) with or without biological activated filtration (BAF)**
  - O_3
    - Produced when oxygen splits into atomic oxygen; free radicals (HO_2 and HO•) generated during this process are responsible for the oxidation of other compounds
    - Can degrade more complex, non-biodegradable compounds (e.g. carbamazepine)
    - Can produce disinfection by-products
  - BAF
    - Filter media can be any of the following: slow sand, rapid media, GAC, riverbank or aquifer filtration
    - Media should allow growth of a biologically active layer, which degrades compounds via direct substrate utilization or co-metabolism

Source: Hale et al., 2022. https://doi.org/10.1186/s12302-022-00604-4; US EPA Potable Reuse Compendium, 2017.

Trace organic compound removal

technology	compounds that break through
activated carbon	→ small aliphatic and/or anionic compounds
anion exchange resin	→ cations and neutral compounds
cation exchange resin	→ anions and neutral compounds
reverse osmosis & nanofiltration	→ very small molecules
advanced oxidation processes	→ compounds with unoxidable bonds & unwanted by-products

Generally only used in potable reuse

- **Advanced oxidation processes (AOP)**
  1. UV/H_2O_2
     - Removes compounds via 1) UV photolysis and 2) hydroxyl radicals from UV and H_2O_2 reaction
  2. O_3/H_2O_2
     - Similar to 1, used under low nitrosamine concentrations or if UVT is limiting factor
  3. UV/Cl_2
     - Similar to 1, but suitable only when pH <6.5 & requires a chlorine residual

- **Dense membranes**
  - RO
    - Feed water is forced through a semi-permeable membrane using a pressure gradient to separate permeate from a concentrated reject (concentrate)
    - Used for desalination of seawater and brackish water
  - NF
    - Constructed similar to RO, but allow more monovalent ions to pass through, while rejecting highly charged inorganic ions and larger molecular weight organic constituents
    - Requires lower feed pressure than RO, removes less TDS and nitrate than RO

Source: Hale et al., 2022. https://doi.org/10.1186/s12302-022-00604-4; US EPA Potable Reuse Compendium, 2017.

Disinfection

- **Ultraviolet disinfection (UV) → UV transmittance**
  - Biophysical disinfection method which prevents microorganisms from replicating (light is absorbed by nucleic acids and results in dimerization)
  - At high UV doses, photons can break chemical bonds (lower energy than the photons)

- **Chlorine/chloramines, chlorine dioxide → free or combined chlorine, breakpoint chlorination**
  - Applied as gas (chlorine), liquid (sodium hypochlorite) or solid (calcium hypochlorite)
  - ClO_2: Generates numerous disinfection by-products (chlorate, chlorite)

- **Peracetic acid (PAA)**
  - Delivered as a mixture of acetic acid, hydrogen peroxide, PAA, and water (CH_3CO_3H)
  - No harmful disinfection by-products generated

Source: US EPA Potable Reuse Compendium, 2017.

Salinity

- RO
  - Feed water is forced through a semi-permeable membrane using a pressure gradient to separate permeate from a concentrated reject (concentrate)
  - Used for desalination of seawater and brackish water

- Electrodialysis
  - Uses ion selective membranes to transport mineral salts and other constituents from one solution to another in an electrically driven process
  - Also effective for bromide removal

- Ion exchange
  - Uses a solid phase ion exchange material which replaces an ion in the aqueous phase for an ion in the solid phase (cationic resins replace cations, anionic resins replace anions)
  - Often used to soften water

Source: US EPA Potable Reuse Compendium, 2017.

Membrane filtration

Porous

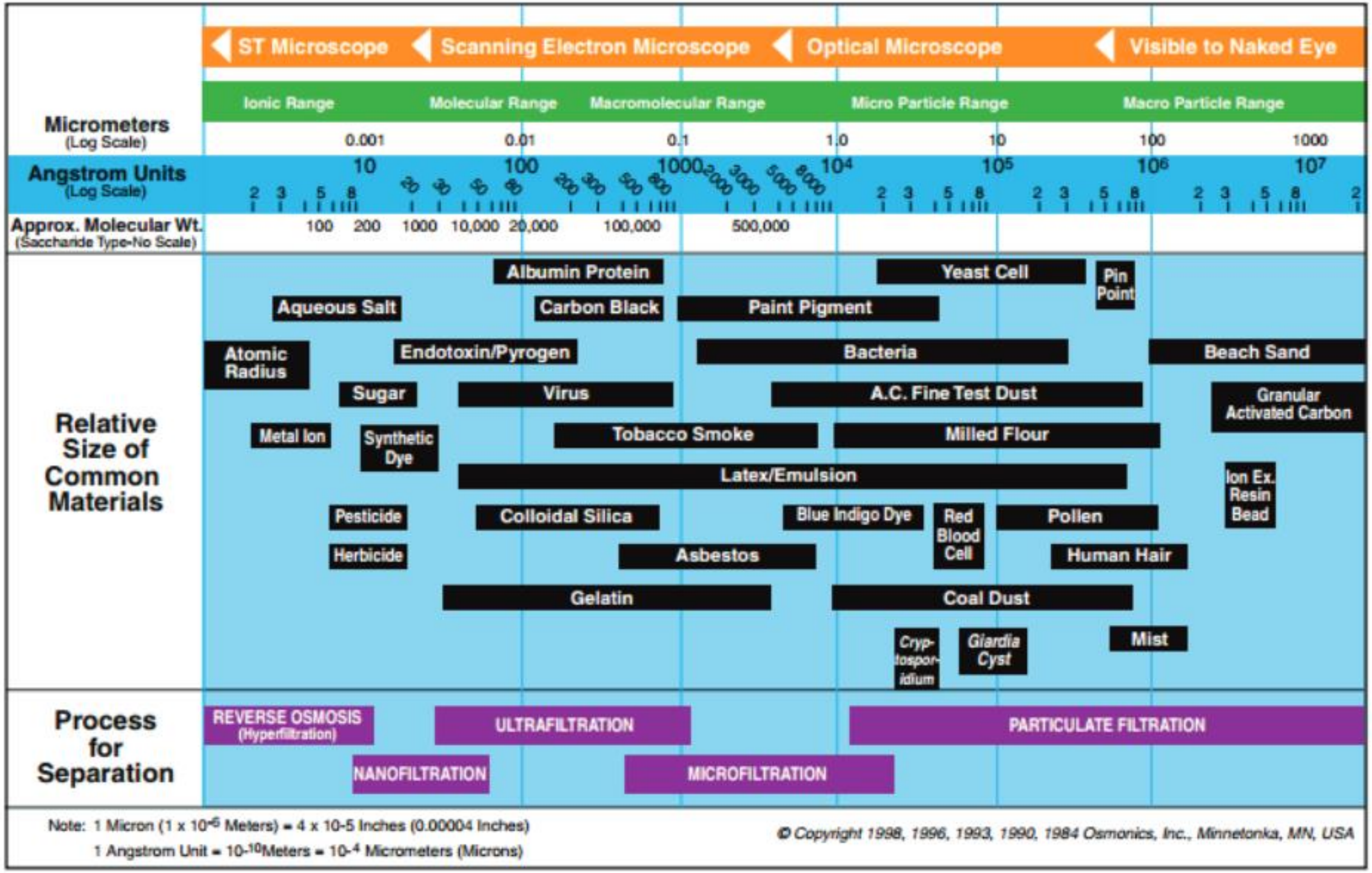
- Microfiltration
- Ultrafiltration

Dense

- Nanofiltration
- Reverse osmosis

Combination

- Membrane bioreactors



Source: US EPA Potable Reuse Compendium, 2017.

Nature based solutions (NbS)

- Often called environmental buffers in potable reuse
- Provides microbial and chemical removal
- Managed aquifer recharge (MAR)
  - Soil-aquifer treatment (SAT)
  - Aquifer storage and recovery (ASR)
  - Riverbank filtration (RBF)
  - Rapid infiltration basins (RIB)
  - Managed surface water recharge
    - Removal due to adsorption and biodegradation

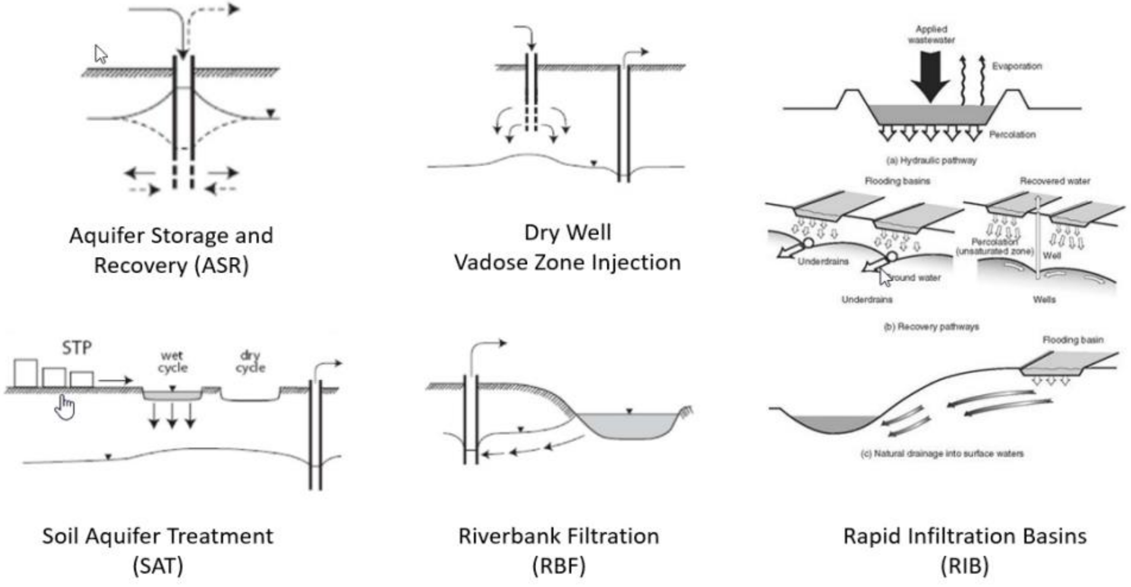


Figure 2-1. Simplified Representation of Different MAR System Types.
Source: Adapted from Page et al. 2018 and Mousavinezhad et al. 2015.

- Constructed wetlands
  - Acts as a biological filter for removal of TOrCs and disinfection by-products

Source: State-of-the-Science Review: Evidence for Pathogen Removal in Managed Aquifer Recharge Systems. WRF #4957.

Treatment technologies for water reuse

Treatment goal	Media filtration	Cloth filter / microsieve	Membrane filtration (UF)	Ozone	GAC	Chlorination (Cl_2 / NaOCl)	UV disinfection
Suspended solids / Turbidity	++	+	+++	o	o	o	o
Disinfection	(+)[1]	(+)[1]	+++	+[2]	o	++[3]	++
Antibiotic resistant bacteria (ARB)	(+)[1]	(+)[1]	+++	+	o	++	++
Trace organic compounds	o	o	o	++	++	o	o
Microplastics	++	+/++[4]	+++	o	o	o	o

Source: Miehe and Wintgens

[1] little reduction possible due to solids removal
[2] at a specific ozone dose of 0,5 – 0,7 mgO_3/mgDOC with the goal of removing trace compounds
[3] high removal of viruses and bacteria, low removal of protozoa
[4] > 50 µm

Non-potable water treatment trains

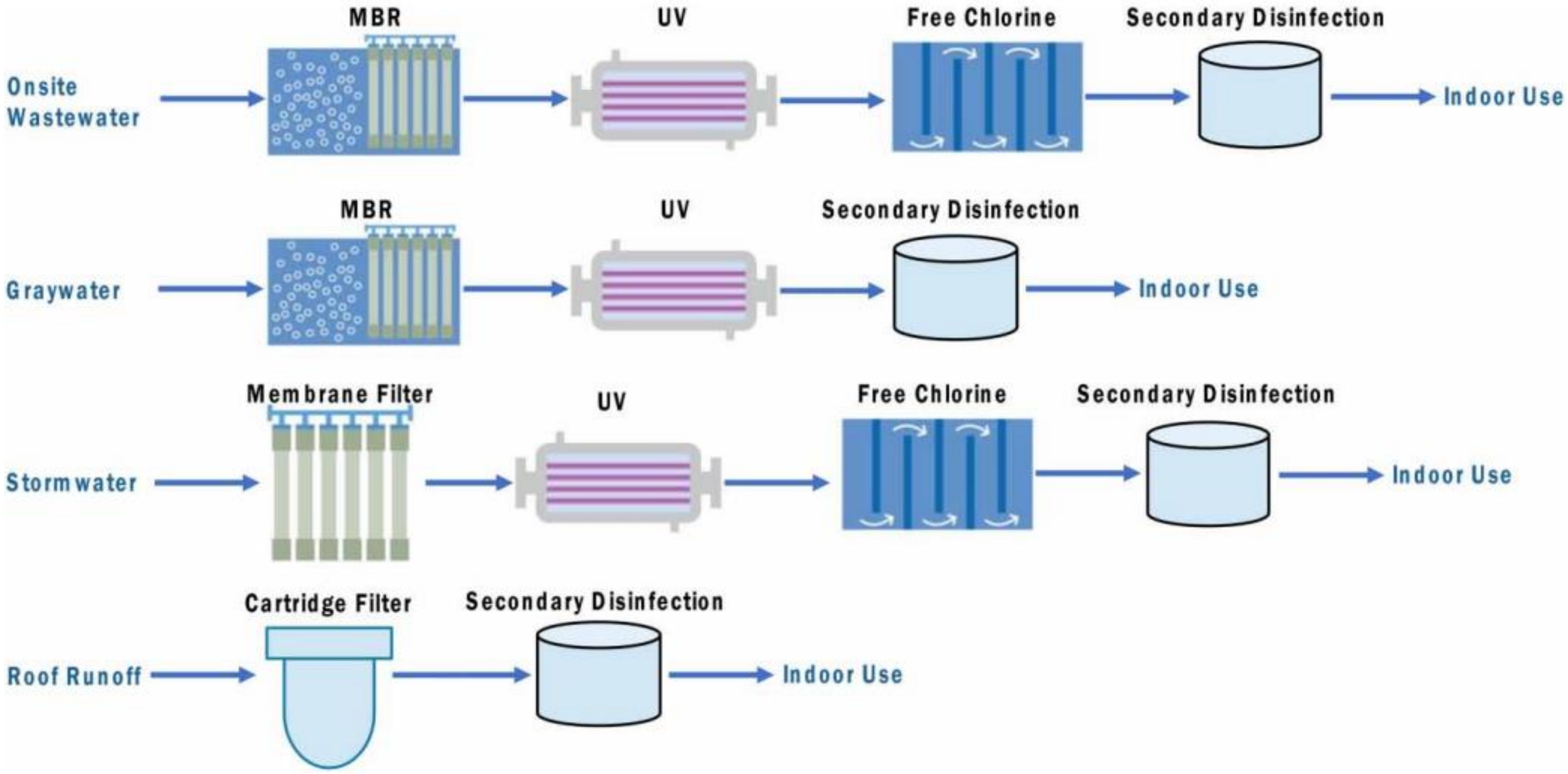
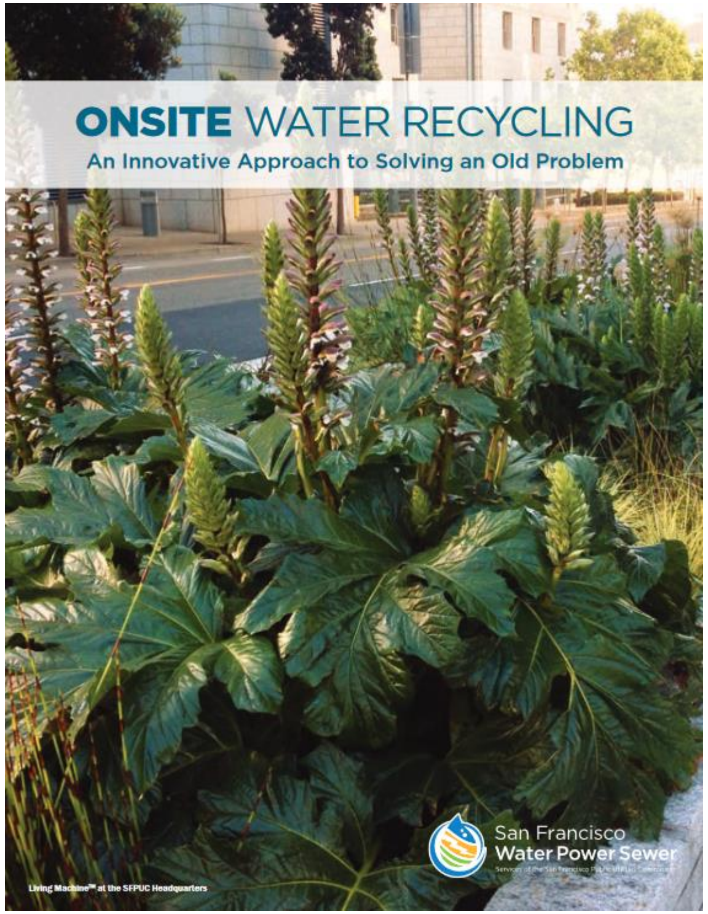


Figure 1 | Summary of model treatment trains capable of meeting LRTs for ONWS source waters.

More information can be found here: US EPA decentralized & centralized non-potable reuse

Source: Pecson et al, 2022. https://doi.org/10.2166/wh.2022.135

Additional sources for non-potable reuse



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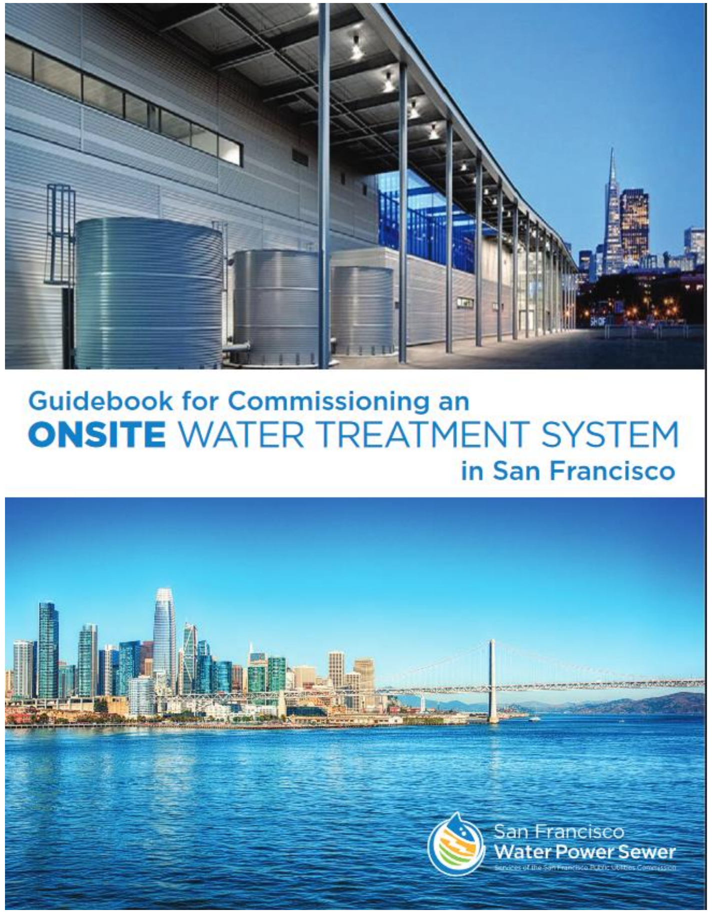

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Water Reuse Resource Hub
by End-use Application

THANK YOU

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