CIRCULAR SANITATION | TOOLBOX

PRACTICAL GUIDES FOR RESOURCE-ORIENTED, DECENTRALIZED SANITATION

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aquatic research

INTRODUCING THE TOOLBOX

BACKGROUND & SCOPE

Circular Sanitation*, as presented in this toolbox, refers to approaches for treating wastewater that focus on recovering valuable resources, such as water, nutrients, and energy, for safe reuse. These solutions also prioritize the protection of human health and the environment. Unlike centralized, sewer-based systems, circular sanitation often works best at smaller, decentralized scales and by separating waste streams at the source.

The Circular Sanitation TOOLBOX was created in response to requests from practitioners looking for know-how on resource-oriented and/or decentralized sanitation. Information in this emerging field is dispersed and difficult to navigate, particularly for newcomers. There is a demand for simplified information curated to stakeholders, beyond the environmental engineer, who play a key role in the planning, construction, and management of sanitation systems.

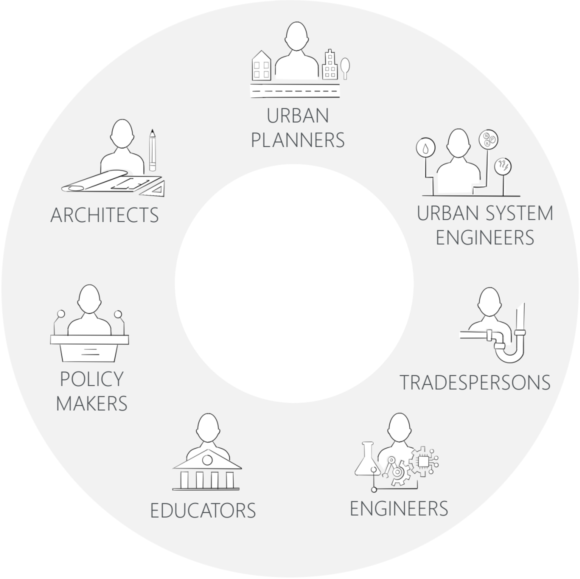
To this end, the toolbox facilitates access to knowledge by presenting information that is brief, structured, and visually engaging. It does so by categorizing information across three levels of guides: goals, strategies, and technologies (see 'What's in the Toolbox'). While each guide functions as a stand-alone document, guides can also be used together to build a narrative that answers to "What goal do I want to achieve? Which strategy can I implement to achieve that goal? And which technology, and/or treatment train, suits my context and needs?"

In addition to general information, the guides present case studies to illustrate strategies and technologies relevant for urban, peri-urban and rural contexts, from single household to neighborhood scales. The case studies also provide examples of relevant metrics, such as space requirements, scale, costs and energy. Typical values for such metrics are beyond the scope of the toolbox because they vary per configuration, context and implementation scale. Rather, the toolbox's success lies in the documents' brevity, structure, and visual appeal as a navigational portfolio to explore possible configurations for circular sanitation.

* Circular Sanitation is also referred to as: Resource-Oriented Sanitation, Decentralized Sanitation, Source-Separated Sanitation, Ecological Sanitation (EcoSan), New Sanitation, New Alternative Sanitation Systems (NASS), Non-sewered Sanitation, Productive Sanitation, Reuse-Oriented Sanitation

TARGET AUDIENCE

The toolbox is useful for architects and planners, that are responsible for including circular sanitation in projects and developments. For this audience it is intended to provide an initial overview of options and to function as a communicative planning tool with project stakeholders. The toolbox is also useful for policy makers, educators, engineers, and tradespersons looking for simplified information.



The Circular Sanitation Toolbox has been created and developed by the Water Hub, a research project on resource-oriented sanitation by Eawag: Swiss Federal Institute of Aquatic Science and Technology (www.eawag.ch). The Water Hub includes a laboratory located in the basement of the NEST building (www.empa.ch/web/nest), which offers a platform for the testing of new technologies for decentralized treatment of greywater, urine and feces, under real conditions. The Water Hub is open to testing and developing these technologies together with external industrial partners and stakeholders to accelerate the uptake of these innovative systems from research to practice. Exchange with external stakeholders during the projects prompted the Water Hub to fill the gap on access to knowledge on resource-oriented, decentralized sanitation.

WHAT'S IN THE TOOLBOX

BOOKLET

The booklet introduces the toolbox and its parts. It positions the broad portfolio of circular sanitation solutions within the boundaries of urban water management.

SUPPORTING DOCUMENTS

An online repository includes reference documents that are complimentary to the toolbox, such as fact-sheets, guidelines, decision support tools, and literature references, as well as a database of case studies.

Available at: www.eawag.ch/en/wh/toolbox

GUIDES

Guides present summarized information per goal, strategy and technology. The chosen categorization aims for detail and clarity, while avoiding repetition of information. Each guide functions as a stand-alone document, though used together they can help practitioners build a story: from identifying their goals, to exploring different implementation strategies, to selecting appropriate technologies.

The guides help users consider the potential of integrating circular sanitation strategies and technologies at a given location, however, do not specify design, space, cost and energy requirements. The many case studies do provide an indication of metrics as well as possible and opportune scales, configurations, and contexts.

New guides can be added to the stack as new goals and strategies arise, or new technologies are developed and established.

IDENTIFY
GOALS

- SAVE WATER
- RECOVER NUTRIENTS & ORGANICS
- SAVE ENERGY
- BUILD RESILIENT CITIES
- TREAT DECENTRALLY

EXPLORE
STRATEGIES

- URINE DIVERSION
- DRY SANITATION
- VACUUM SANITATION
- FLUSH SANITATION
- WATER REUSE
- WATER EFFICIENT FIXTURES
- RAINWATER HARVESTING
- HEAT RECOVERY

SELECT
TECHNOLOGIES

T.1	URINE STORAGE | PASTEURIZATION
T.2	NITRIFICATION ON BIOCHAR
T.3	NITRIFICATION - DISTILLATION
T.4	STRUVITE PRECIPITATION
T.5	AMMONIA STRIPPING
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T.61	HEAT EXCHANGERS | HEAT PUMPS

GOALS FOR CIRCULAR SANITATION

Practitioners are often driven to achieve one or more goals to respond to general, and often context-specific, challenges. A well-defined goal helps to identify context-appropriate solutions, and filter the option space of circular sanitation strategies and technologies. The overarching goals below serve as an entry point to the toolbox.

SAVE WATER

Freshwater resources are under growing pressure from climate change (e.g., heat waves, droughts) and rapid urbanization, leading to increased water scarcity in many parts of the world. Decreased and variable supply, paired with higher demand and greater water use contribute to this issue. Reducing demand, reusing water, and utilizing renewable sources like rainwater can enhance local water availability.

RECOVER NUTRIENTS & ORGANICS

Current linear nutrient flows involve: 1) resource-intensive fertilizer production dependent on fossil fuels and finite ore reserves, 2) farming systems that deplete soil nutrients and organic matter, and 3) waste management practices that lead to nutrient loss to air, water, and landfills, and pollution, like the eutrophication of surface waters. Recovering nutrients and organic matter from human excreta can reduce losses and produce renewable fertilizers.

SAVE ENERGY

Heating of domestic water often relies on fossil fuels. Residual heat from showers, sinks, and appliances quickly dissipates into the receiving sewer system and wastewater treatment plant. Energy savings can be achieved by reducing hot water usage or recovering heat from wastewater near the source. Additionally, organic matter can be valorized to produce biogas.

BUILD RESILIENT CITIES

Urbanization impacts resource flows, concentrating water, nutrient, and energy use and loss. Warmer weather increases cooling and irrigation demand, while heavy rainfall causes more stormwater overflows into sewers. Recovering resources from wastewater and linking urban functions (e.g., domestic wastewater and urban landscaping) can boost self-sufficiency and climate resilience. Sustainable building certifications like BREEAM and LEED* recognize sanitation contributions to meet their criteria. Certified projects often enhance public image and property values.

TREAT DECENTRALLY

In some areas, centralized infrastructure is absent, such as in remote locations or where urbanization outpaces development. In other contexts, existing systems may be at capacity. Decentralized treatment can extend infrastructure capacity to defer costly investments, and provide flexible, autonomous solutions for design and operation. Decentralized treatment can be an alternative or compliment centralized infrastructure.

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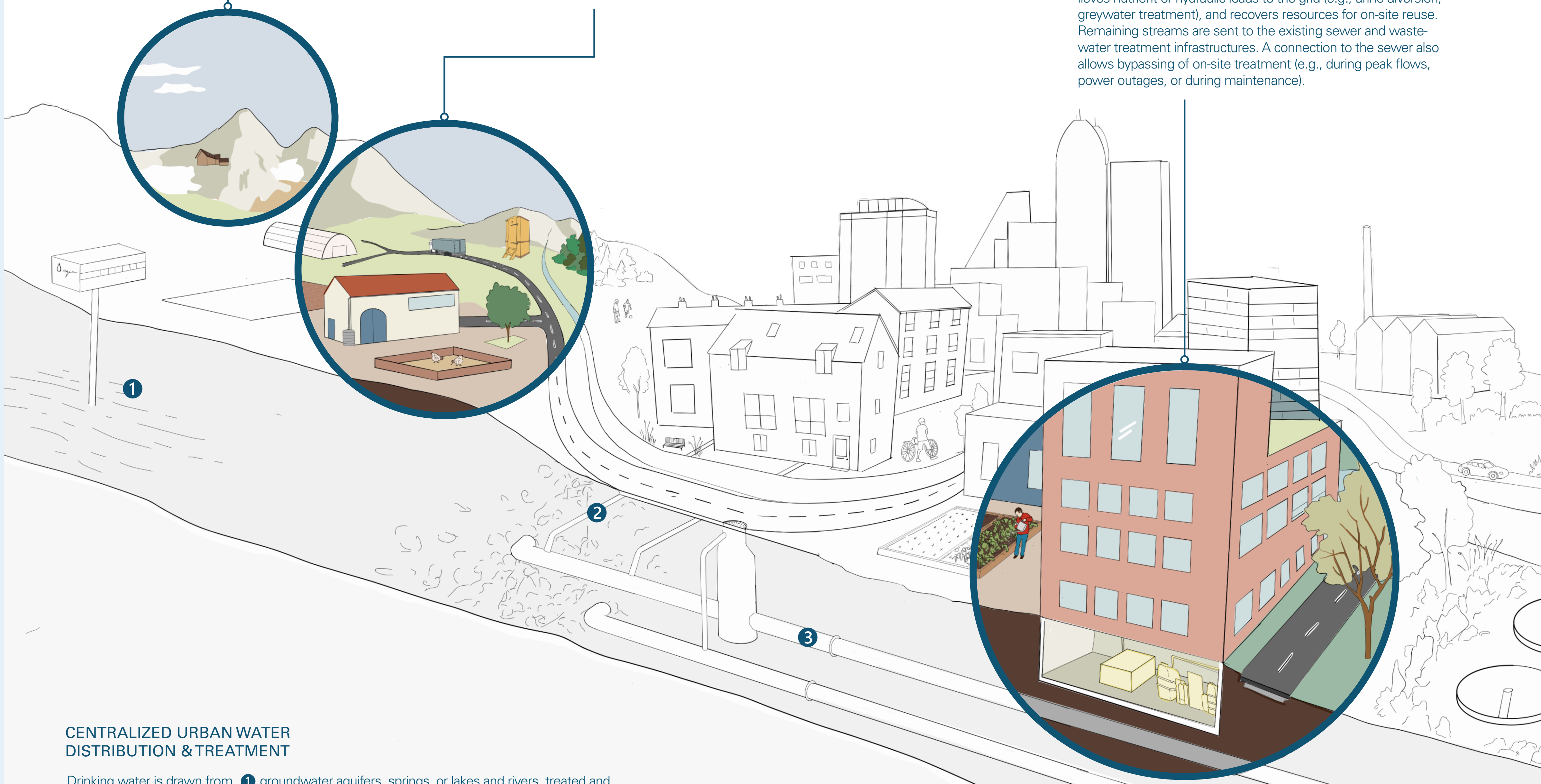
* BREEAM: Building Research Establishment Environmental Assessment Method; LEED: Leadership in Energy and Environmental Design

APPROACHES TO URBAN WATER MANAGEMENT

Urban water management is the practice of managing water resources in the urban environment. Current management, often underpinned by large, centralized infrastructure, has greatly improved public health and protection of the natural and urban environment. In the face of growing global challenges such as resource scarcity, water pollution, climate change, urbanization, and aging infrastructure, it is beneficial to explore a broader range of strategies to achieve urban water management and sanitation. In other words, the coexistence of solutions of different scales and configurations may be considered.

Circular Sanitation focuses on the recovery of water, nutrients and organic matter, and energy from source-separated wastewater streams, to reduce impacts of resource extraction, use and pollution, while maintaining sanitation goals of protecting public health and the environment. In short, circular sanitation is resource-oriented and is underpinned by two guiding principles: decentralization and source separation, as illustrated in the four examples in the figure below.



OFF-GRID TREATMENT OF ALL STREAMS

Remote huts, villages, or settlements, removed from centralized infrastructure, need autonomous solutions for the management of all waste for reuse or safe discharge.

TRANSPORT TO TREATMENT & RECOVERY HUBS

Urine and feces collected from public toilets, mobile units, or buildings are transported to a semi-centralized location for storage, treatment, and recovery of resources.

TREATMENT OF & RECOVERY FROM SOME STREAMS, REST TO SEWER

Separate collection and treatment of one (or more) stream(s) relieves nutrient or hydraulic loads to the grid (e.g., urine diversion, greywater treatment), and recovers resources for on-site reuse. Remaining streams are sent to the existing sewer and wastewater treatment infrastructures. A connection to the sewer also allows bypassing of on-site treatment (e.g., during peak flows, power outages, or during maintenance).

CENTRALIZED URBAN WATER DISTRIBUTION & TREATMENT

Drinking water is drawn from ① groundwater aquifers, springs, or lakes and rivers, treated and distributed via extensive underground pressurized networks for domestic, industrial, commercial, and public use. Wastewater collected from ② households is often mixed with industrial wastewater, and sometimes stormwater, and conveyed through piped ③ sewer networks to centralized wastewater treatment plants. ④ Treatment plants remove solids, organics, nutrients, pathogens, heavy metals, and micropollutants before ⑤ discharging treated water (effluent) into natural bodies of water. ⑥ Resource recovery technologies have been increasingly adopted to enhance these processes, including treatment of effluent for reuse, recovery of nutrients from concentrated streams or incinerated sludge ash, and biogas production from sewage sludge.

DECENTRALIZATION

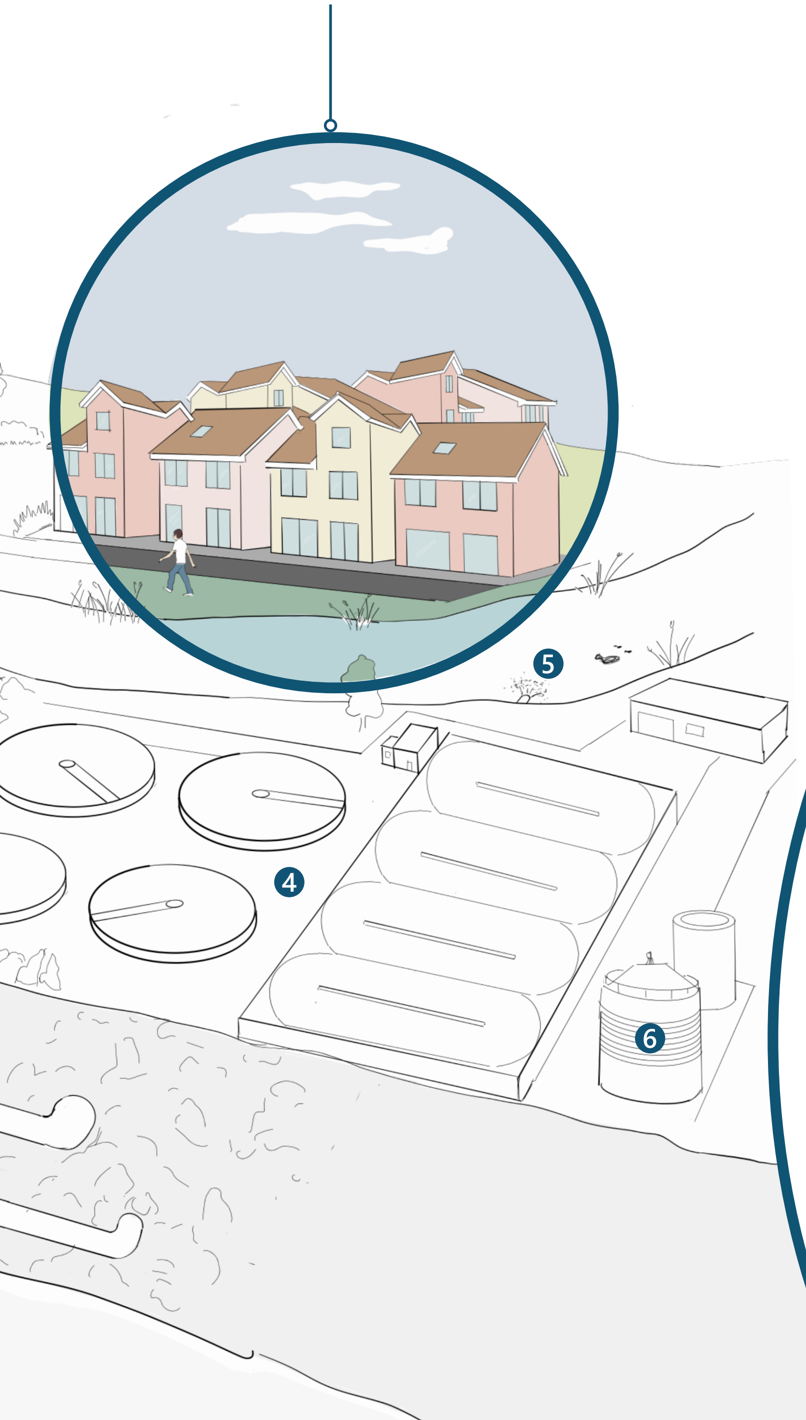
Decentralization refers to the collection, conveyance and treatment of wastewater on a smaller scale than centralized infrastructure. While decentralization is often used to describe sanitation in remote or low-density areas, it can also be applied in or near urban contexts, alongside centralized infrastructure, as hybrid solutions. Importantly, decentralization allows for the collection, conveyance and treatment of separate streams and promotes reuse close to the source (i.e., minimizing losses and often redistribution costs).

SOURCE-SEPARATION

Circular sanitation is based on the premise that resource recovery is more effective from streams with low dilution. Separating streams at the source facilitates treatment and recovery according to the stream properties. Specialized toilets (e.g., low flush, vacuum and urine diversion) and infrastructure modifications (e.g., separate or vacuum piping) enable the collection and conveyance of source-separated streams. Treatment and recovery technologies allow for the targeted recovery of water, nutrients and organics, and energy.

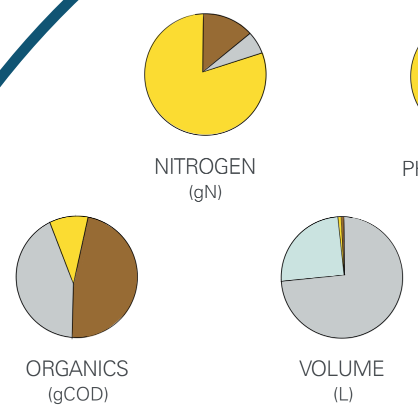
TREATMENT OF & RECOVERY FROM ALL STREAMS

Buildings, neighborhoods or districts can choose to collect and treat all waste streams decentrally to achieve grid autonomy, relieve existing infrastructure, or improve local resource cycles.



WHY SEPARATE STREAMS?

Separation of domestic wastewater streams prevents the dilution and mixing of streams, and allows for targeted recovery of water, nutrient and energy resources.



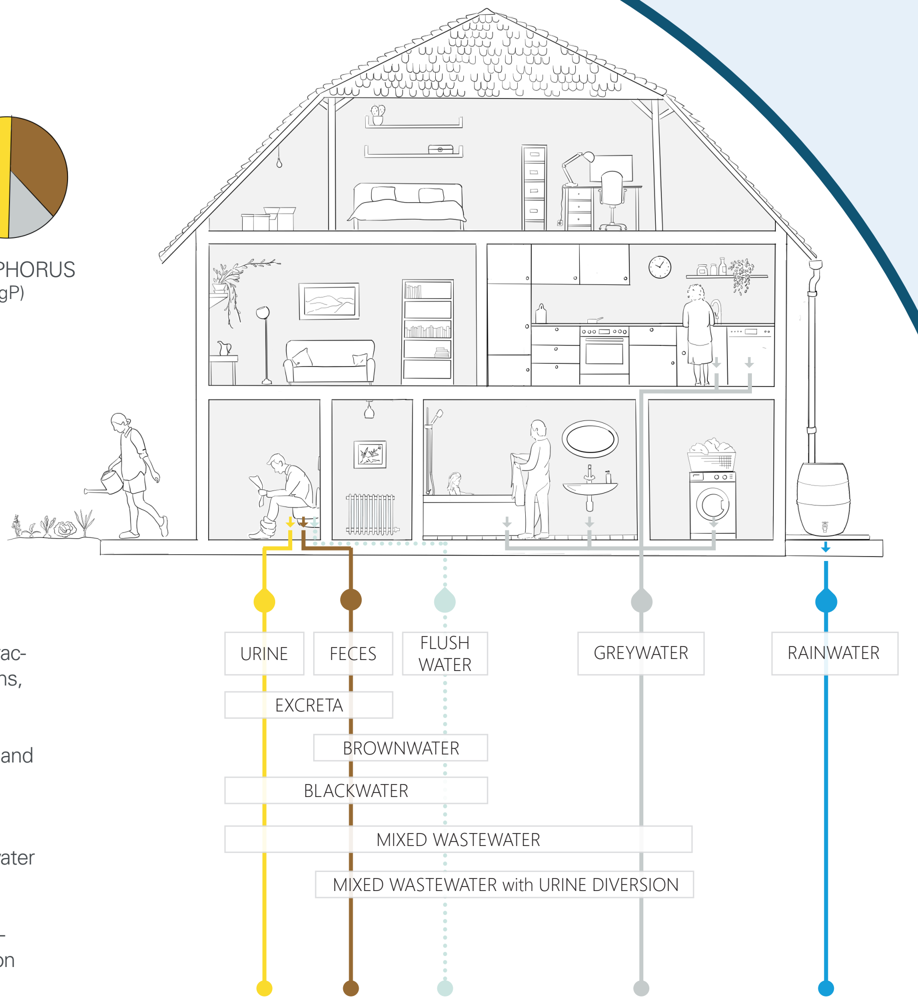
Contribution of separate streams to domestic wastewater.

● Urine and ● feces contribute the majority of nutrients and organic matter to domestic wastewater in a small fraction of the volume. However, they also contain pathogens, pharmaceuticals and hormones.

● Flush water significantly dilutes the nutrients, organics, and contaminants in excreta.

● Greywater includes water from showers, laundry, sinks and dishwashers. It contains the largest proportion of water in domestic wastewater, as well as residual heat.

● Rainwater can be collected from above-ground, impervious surfaces. Its availability depends on local precipitation events and collection surface areas.



IMPLEMENTATION STRATEGIES

Circular sanitation involves strategies for collection, conveyance, treatment, and resource recovery. Many strategies can be combined, while others are mutually exclusive (e.g., dry sanitation and vacuum sanitation). Most strategies can be implemented alongside existing centralized infrastructure. When selecting strategies, it is important to consider goals and context.

URINE DIVERSION

Urine diversion is the separation of urine from the rest of the remaining wastewater streams. This strategy helps divert nutrient loads from exisiting treatment plants and can yield nutrient-rich fertilizers.

DRY SANITATION

Dry sanitation refers to the collection of excreta or feces without flush water, contributing to water savings. Treatment of the excreta or feces yields soil amendments.

VACUUM SANITATION

Vacuum sanitation is the collection of excreta via vacuum piping under negative pressure, with minimal water for flushing. In addition to saving water, liquid and solid fertilizers, as well as soil amendments can be recovered. The organics can be valorized to produce biogas.

FLUSH SANITATION

Flush sanitation refers to the use of standard flush toilets to handle human excreta. Treatment allows for the recovery of water from the liquid fraction, and nutrients and organics from the solid fraction.

WATER REUSE

Water reuse includes the collection and treatment of greywater, or mixed wastewater, for non-potable or potable reuse. Water reuse results in drinking water savings.

WATER-EFFICIENT FIXTURES

Water-efficient fixtures include appliances and fittings that reduce water demand. If fixtures reduce hot water demand, energy demand for heating is also reduced.

RAINWATER HARVESTING

Rainwater harvesting refers to the collection of rainwater from above-ground surfaces (e.g., rooftops) during rainfall events. Rainwater can be used for non-potable and potable applications, replacing drinking water demand.

HEAT RECOVERY

Heat recovery refers to the use of heat exchangers or heat pumps to recover heat from greywater or mixed wastewater to save energy.

TREATMENT & RECOVERY TECHNOLOGIES

Resource treatment and recovery can be achieved using single or combined technologies, depending on the input stream, desired output, and context-specific factors (e.g., space, weather).

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CIRCULAR SANITATION TOOLBOX

PRACTICAL GUIDES FOR RESOURCE-ORIENTED, DECENTRALIZED SANITATION

1ST EDITION

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Disclaimer: The Circular Sanitation Toolbox includes a compilation of case studies that have implemented strategies and technologies for resource-oriented, decentralized sanitation across the world. The technologies and systems were designed, developed, and implemented by engineers, planners and/or technology providers involved in each case study. The inclusion of these case studies does not imply endorsement or authorship of the technical solutions described.

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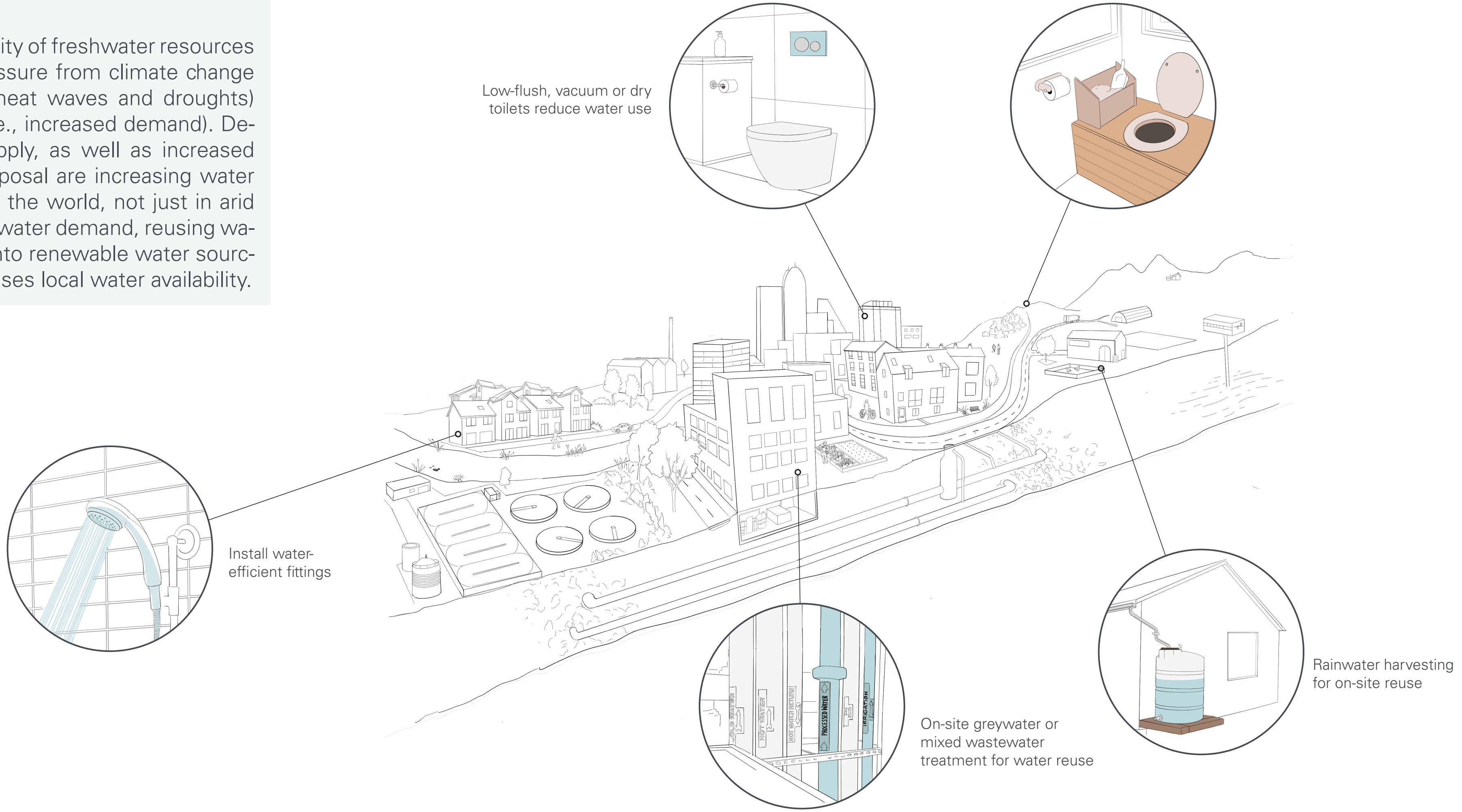
SAVE WATER

GOAL

The availability and reliability of freshwater resources are under increasing pressure from climate change (e.g., warmer weather, heat waves and droughts) and rapid urbanization (i.e., increased demand). Decreased and variable supply, as well as increased abstraction, use, and disposal are increasing water scarcity in many parts of the world, not just in arid environments. Reducing water demand, reusing water on site, and tapping into renewable water sources (e.g., rainwater) increases local water availability.



Low-flush, vacuum or dry toilets reduce water use

Install water-efficient fittings

On-site greywater or mixed wastewater treatment for water reuse

Rainwater harvesting for on-site reuse

REDUCE WATER USE

Swap out water-intensive appliances and toilets, with waterless and water-efficient alternatives. Appliances can be anything from faucet fittings to water recirculating showers to dry or vacuum toilets. Such fixtures minimize water demand, and some also reduce the energy demand needed to heat the water.

REUSE WATER

Treat used water (e.g. greywater, blackwater, mixed water) streams to provide an alternative water supply for non-potable and potable reuse. Depending on the desired end use, water is treated to match end use demand for quality and quantity, to provide reliable and safe water supply. Reusing water minimizes demand for drinking water supply and diverts hydraulic flow to existing sewer infrastructure.

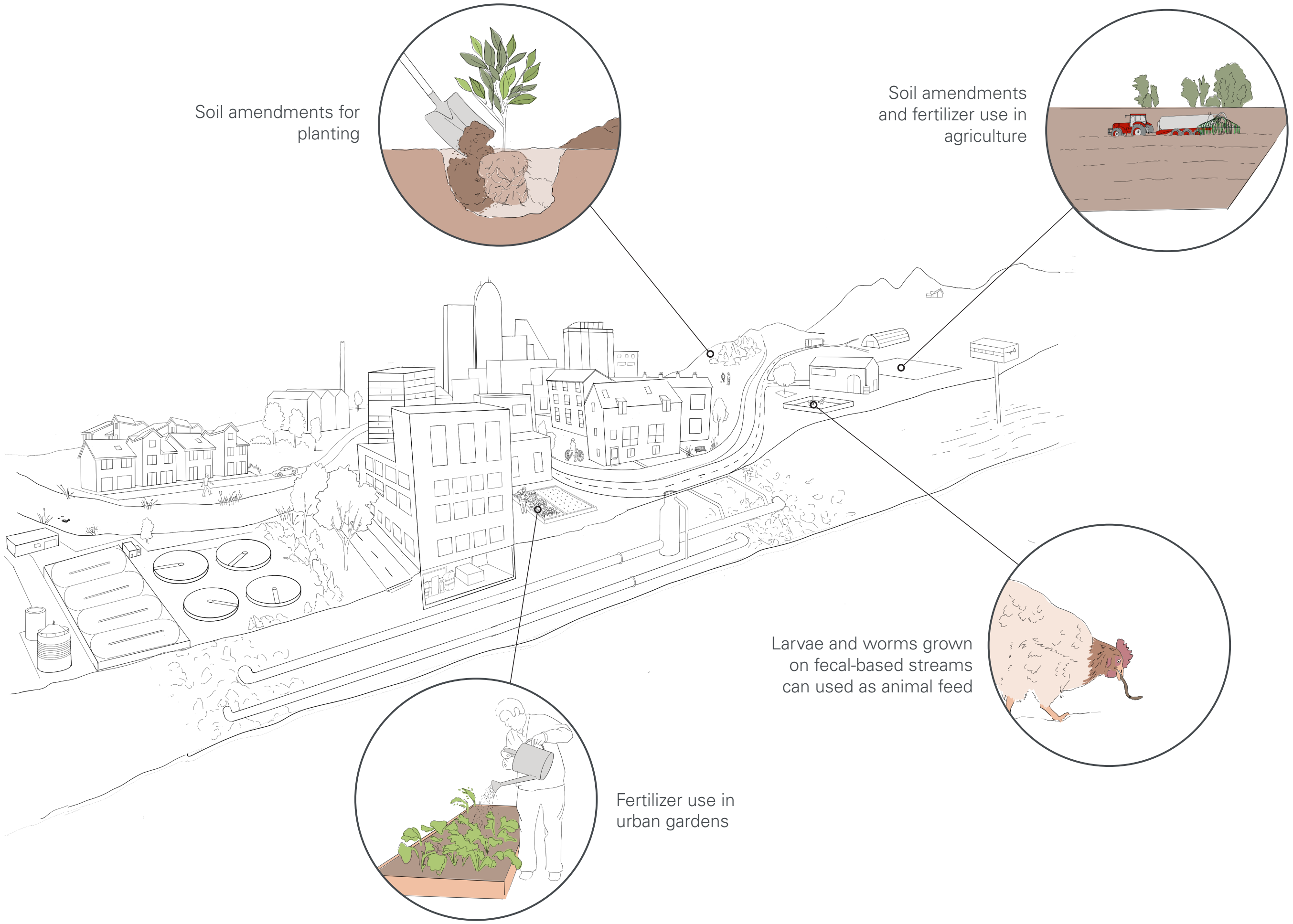
CAPTURE RAINWATER

Harvest rainwater for fit-for-purpose reuse. Depending on the desired end-use, these water sources can be treated to match end-use demand for quality and quantity, including irrigation, non-potable reuse and potable reuse. Using captured water minimizes demand for drinking water supply and diverts hydraulic flow to existing sewer infrastructure.

RECOVER NUTRIENTS & ORGANIC MATTER

GOAL

Current linear nutrient flows are characterized by: 1) cheap and resource-intensive fertilizer production that relies on fossil fuels, and finite, spatially-concentrated ore reserves, 2) food and farming systems that contribute to soil nutrient imbalances and soil organic matter depletion, and 3) and human excreta management practices that result in irretrievable losses of nutrients and organic matter to air, water, and landfills. Nutrients discharged to surface waters can cause eutrophication (algal blooms, dead zones, and fish kills). Recovering nutrients and organic matter from streams containing human excreta diverts nutrients from existing infrastructure, reduces losses, and allows for the production of renewable fertilizers and soil amendments.



Soil amendments for planting

Soil amendments and fertilizer use in agriculture

Larvae and worms grown on fecal-based streams can used as animal feed

Fertilizer use in urban gardens

PRODUCE FERTILIZER

Separate wastewater streams containing urine and/or feces at the source to facilitate the treatment and targeted extraction of nutrients as fertilizers, minimizing pollution and losses. Recovery can target specific nutrients (often one macronutrient) or several nutrients (macro- and micronutrients). The recovered products can be reused as fertilizer in agriculture, horticulture, plant nurseries, and on sport fields.

PRODUCE SOIL AMENDMENT

Separate fecal streams at the source, or after solid-liquid separation of mixed wastewater, to aid nutrient and organic matter recovery. Treatment and recovery processes of the fecal streams, potentially combined with kitchen and/or garden waste, produce soil amendments that increase soil health and supply nutrients. Source separation also lowers pollutants, like heavy metals, compared to sludge from centralized treatment plants.

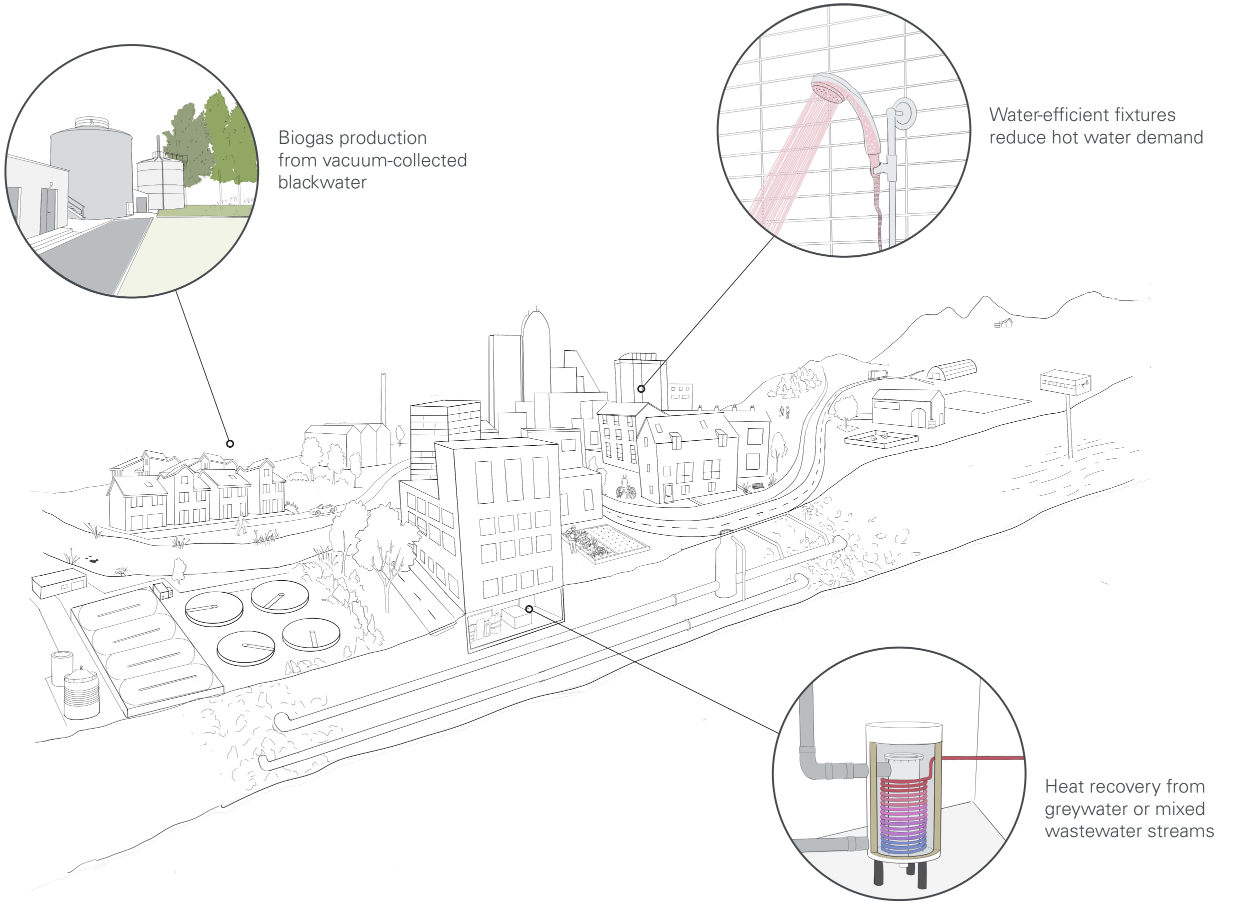
PRODUCE BIOMASS

Use streams containing urine and/or feces to grow or produce algal biomass, worms or insects (e.g., black soldier fly larvae). While algae is often grown on nutrient-rich liquids, such as urine, larvae and worms can be grown on fecal biomass and/or kitchen waste. The products can be used as, or in, animal feed, or used as soil amendments/fertilizer (e.g., algae)

SAVE ENERGY

GOAL

Heating water, for showers, sinks, and appliances, requires energy. Once used, residual heat quickly dissipates into the receiving sewer system and wastewater treatment plant. Energy savings can be achieved by reducing the consumption of hot water or by recovering residual heat from wastewater streams (e.g., greywater) on site. Valorization of organic matter to produce biogas, or heat, helps diversify energy supply and reduce dependence on external power sources.



Biogas production from vacuum-collected blackwater

Water-efficient fixtures reduce hot water demand

Heat recovery from greywater or mixed wastewater streams

REDUCE HEAT DEMAND

Install fixtures that reduce hot water demand, such as shower head fittings and water efficient washing machines, and thus also reduce the energy needed for heating. Showers that recirculate hot water also reduce energy demand.

RECOVER HEAT

Use passive systems to heat up water, or actively recover heat from grey- or mixed wastewater through heat exchangers at different scales. To reduce heat dissipation, recovery should take place close to the source.

PRODUCE ENERGY

Produce gas, pellets, or heat from streams containing feces (and toilet paper). Digesting feces or vacuum-collected blackwater, with or without organic food waste, produces biogas. Combustion or pyrolysis oxidizes dried fecal matter.

BUILD RESILIENT CITIES

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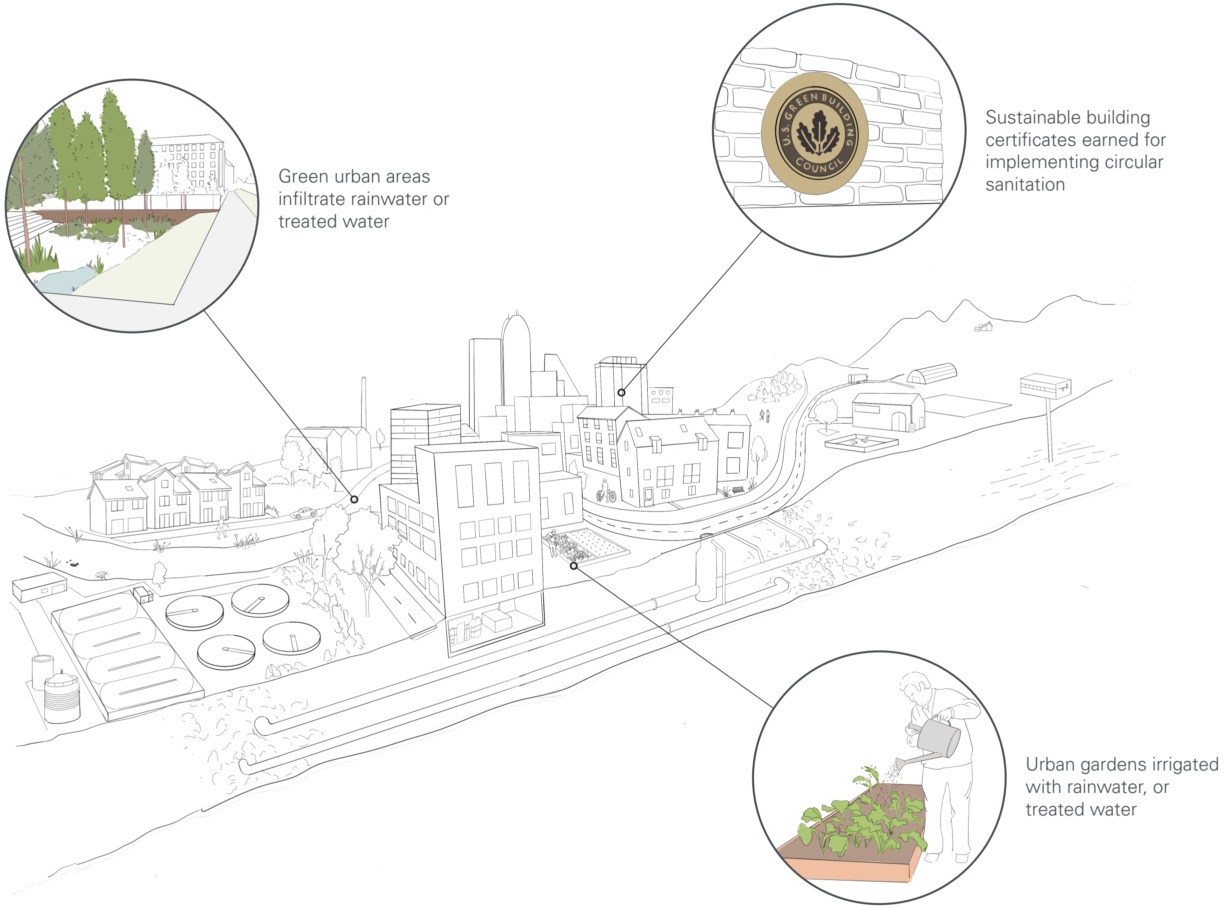
GOAL

Urbanization has significant impact on resource flows, concentrating the use and loss of water, nutrients, and energy. Warmer weather increases demand for cooling and irrigation, while heavy rainfall leads to more frequent stormwater overflows into sewers. Recovering and reusing resources from wastewater, and closing resource cycles between urban activities, can improve local self-sufficiency and climate resilience. Many sustainable building certifications, such as BREEAM and LEED*, recognize the contribution of circular sanitation to meeting their sustainability criteria. Certified projects often enhance public image and property values.

*BREEAM: Building Research Establishment Environmental Assessment Method; LEED: Leadership in Energy and Environmental Design



Green urban areas infiltrate rainwater or treated water

Sustainable building certificates earned for implementing circular sanitation

Urban gardens irrigated with rainwater, or treated water

SUPPORT BLUE-GREEN INFRASTRUCTURE

Use rainwater and/or reuse treated water to support 'blue' urban hydrological functions and provide a water source for the irrigation of 'green' vegetation. Blue-green infrastructure positively impacts the urban environment: increasing biodiversity, mitigating climate change (e.g., urban cooling), and promoting of human health and well-being.

● ●

COMPLY WITH CERTIFICATIONS

Water, nutrient and energy management practices are prerequisites to obtain sustainable building certifications (e.g., BREEAM, LEED, Living Building, Minergie). The impact that circular sanitation implementations have on the final score can vary depending on the type of certification, project, context, etc. Often the labels only indicate targets and principles and leave ample margin for the selection of specific solutions.

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PROMOTE A CIRCULAR ECONOMY

A circular economy aims to decouple economic activity from the consumption of finite resources; it promotes an economy where resources are circulated. The recovery of nutrients, water, and energy from source-separated streams reduces dependencies on external inputs, minimizes waste production, reduces pollution, and enhances local resource availability.

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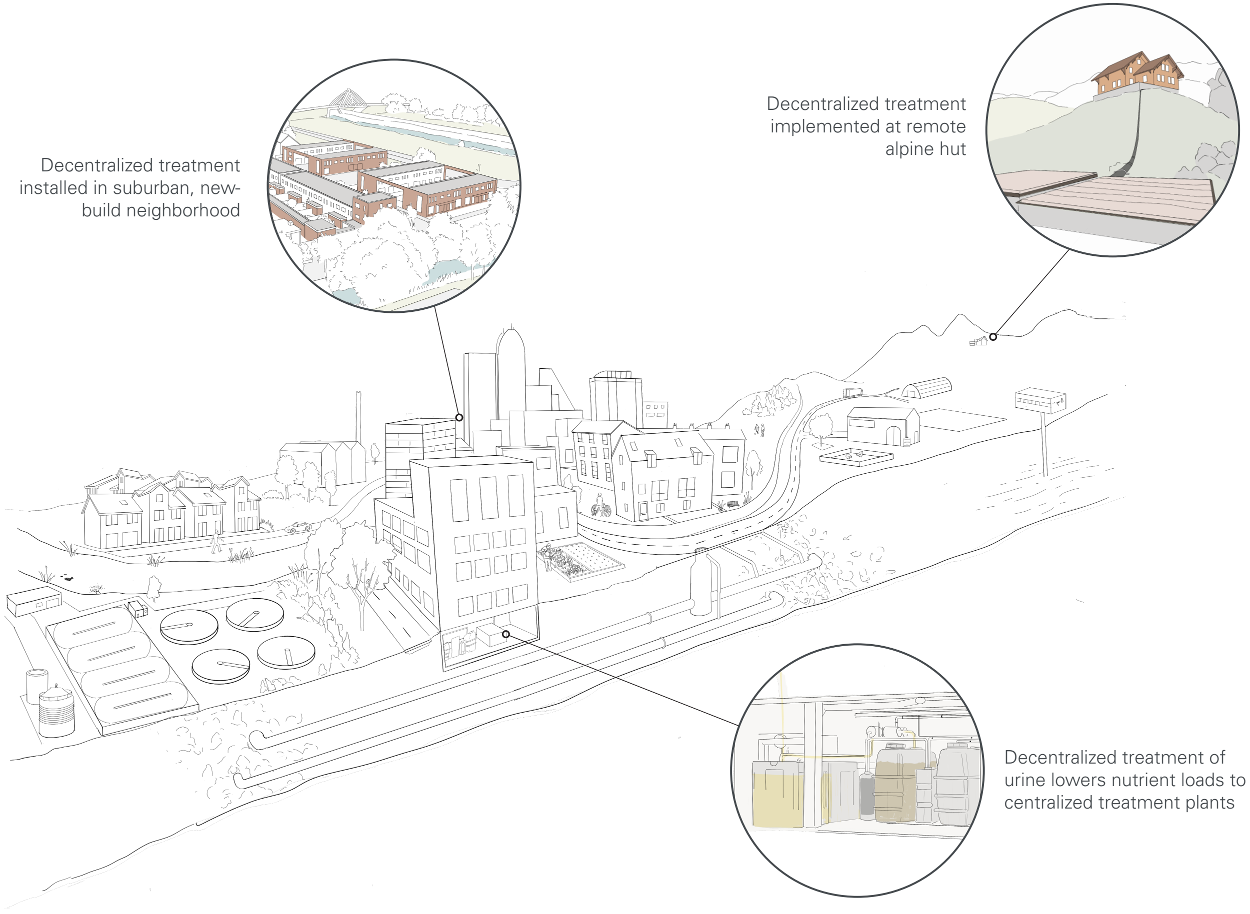
TREAT DECENTRALLY

GOAL

In many contexts, centralized infrastructure is absent, such as in sparsely-populated and remote areas, or in areas where financial burden of centralized systems is too high. Infrastructure may also be absent where urbanization outpaces the implementation of centralized infrastructure. In other cases, existing sewer and/or treatment infrastructure is ageing or is at capacity. Decentralized treatment, of some or all streams can replace or extend the operating capacity of existing infrastructure, deferring expensive investments. Decentralized treatment also allows for autarkic solutions and allows for experimentation and flexibility in design and operation.



Decentralized treatment installed in suburban, new-build neighborhood

Decentralized treatment implemented at remote alpine hut

Decentralized treatment of urine lowers nutrient loads to centralized treatment plants

DEVELOP INDEPENDENT OF THE GRID

In areas where centralized drinking and/or wastewater infrastructure is absent (e.g., remote hut, village or settlement), or when it is desired to exercise grid autonomy, on-site or decentralised sanitation provides water supply and wastewater treatment.

RELIEVE THE GRID

Diverting the total volume (e.g. greywater, flush water, rainwater) and nutrient load (e.g. urine and feces) from existing sewers and treatment plants extends their operating capacity and increases their treatment performance. Such solutions help avoid or postpone costly expansions. Diverted streams need to be treated, reused or discharged (semi-)decentrally.

TAILOR SOLUTIONS PER CONTEXT

Buildings, neighborhoods or cities may face different challenges. Decentralization allows for the implementation of tailored solutions that are flexible and adaptable. These solutions not only address local challenges but also reduce vulnerability during disasters.

URINE DIVERSION

STRATEGY

Urine contains most nutrients and pharmaceuticals excreted, though accounts for less than 1% of the mixed wastewater flow. Diverting urine from other wastewater streams sent to sewer reduces nutrient and micropollutant loads to centralized treatment plants ○ extending their operating capacity and increasing their treatment performance. Recovering nutrients ○ from urine to produce fertilizer can help close nitrogen, phosphorus and other nutrient cycles, and reduce reliance on synthetic fertilizers in agriculture. Urine diversion via urine-diverting flush toilets or dry toilets also enables the separate collection and treatment of blackwater via flush toilets ● or feces via dry toilets ● . Urine diverting dry toilets, as well as waterless urinals are water efficient fixtures ● that reduce water use ○ .

INPUT STREAMS

- ● Urine
- ● Yellow water

TARGET OUTPUTS

- △ Liquid fertilizer
- △ Solid fertilizer

TOILETS

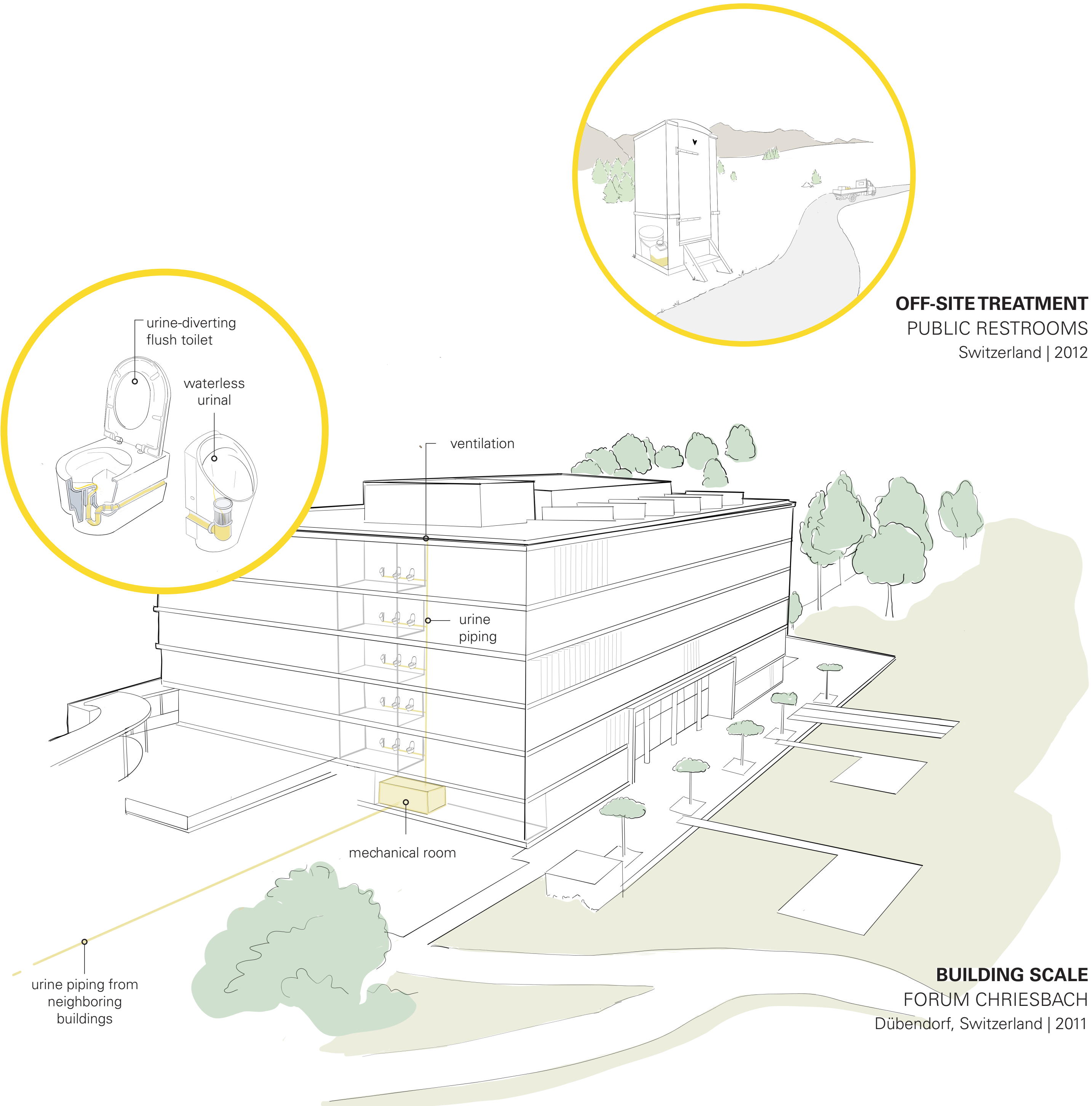
Commercially available urine-diverting toilets, separate urine from feces and most flush water while waterless urinals and urine-diverting dry toilets allow for the undiluted collection of urine. Portable fixtures (e.g., funnel attachment on a jerrycan) are a low-cost urine collection option.

PIPING | TRANSPORT

At building and neighborhood scales, designated urine piping leads urine to a storage tank for collection. Pipes and pumps can lead the urine further through on-site urine treatment, if available. Alternatively, urine can be transported in containers to a centralized treatment point (e.g., by truck). Adequate access points for collection should be considered.

TREATMENT

Treatment of the urine can take place on site or off site. On-site treatment usually takes place close to the urine collection tanks in a mechanical room in the basement. Off-site treatment can require the pumping of urine from smaller containers to larger tanks. Urine treatment integrated into the toilet/bathroom is also possible.



OFF-SITE TREATMENT
PUBLIC RESTROOMS
Switzerland | 2012

BUILDING SCALE
FORUM CHRIESBACH
Dübendorf, Switzerland | 2011

TO CONSIDER

COLLECTED STREAM

Approximately 0.5 m^3 of urine can be collected per person per year. A urine stream collected with flushwater has a significantly larger volume. Spontaneous mineral precipitation in toilets and pipes can lead to deposit build-up and clogging. Flushing with rainwater reduces mineral precipitation compared to flushing with (calcium- and magnesium-rich) tapwater.

SPACE & PLACEMENT

Unless urine collection occurs at bathroom scale, or in portable fixtures (e.g., jerry cans), urine diversion requires designated piping. Space requirements for a mechanical room for storage and treatment depend on the volume of the collected urine and the treatment process of choice. A mechanical room is often placed in the basement.

RESOURCE INTENSITY

There are initial material, planning and installation costs for toilets, pipes, storage and treatment, which vary with the configuration and technology selected. To prevent deposit build-up and clogging of pipes, regular cleaning and maintenance is needed. In the case of urine collection in containers, transport of urine to a treatment hub should be considered. Some treatment processes (e.g., struvite precipitation) require additional chemical dosing.

NEW BUILD VS. RETROFIT

The installation of urine-diversion toilets and designated urine piping is easiest in new build planning and construction where designated piping can be incorporated into the building skeleton. However, urine diversion is possible when retrofitting buildings. The planning process is critical for a coordinated and well-executed implementation.

HYBRID VS. DECENTRALIZED

Urine diversion can be implemented in a hybrid scenario, where other streams are sent to the centralized sewer, or as part of a decentralized solution, in combination with treatment of fecal and greywater streams.

USER EXPERIENCE

Urine-diverting toilets typically require all users to sit while urinating for optimal collection and separation, though urinals are also an option. Awareness among users about appropriate cleaning products is critical for biological treatment processes and fertilizer end use of recovered products.

TREATMENT OPTIONS

Urine treatment aims to degrade organic substances (to prevent malodor and unwanted biological processes), minimize volatilization of ammonia (causing nitrogen losses, air pollution, and bad smell), remove or kill pathogens and micropollutants, and concentrate or extract nutrients. Different treatments yield urine-based fertilizers with different physico-chemical characteristics (e.g., solid/liquid; basic/acidic) and composition, suitable for different agricultural uses (e.g., hydroponics, soil injection, fertigation, broadcasting).

TREATMENT OF THE URINE STREAM	Treatment of the full urine stream yields multinutrient fertilizers. Concentration is not strictly necessary, but reduces the need for storage space and facilitates transport and fertilizer application.
NUTRIENT EXTRACTION	Processes for the targeted extraction of phosphorus and/or nitrogen from urine yield single-nutrient fertilizers which can be used directly or in fertilizer manufacturing.

SAFE END USE

PATHOGENS & PHARMACEUTICALS

Pathogens in urine mainly come from fecal cross-contamination during excretion, while pharmaceuticals, and their metabolites, come from consumed, and subsequently excreted, medication. Treatment of urine inactivates pathogens and removes pharmaceutical compounds to varying degrees depending on the treatment technology applied. It is recommended to follow safety measures during fertilizer application (lag time between last application and harvest and soil application or injection as opposed to foliar application) to further reduce risks arising from the presence of pathogens in urine based fertilizers.

Risks arising from pharmaceuticals include plant take-up of these substances, or dissipation into the environment. Targeted micropollutant removal steps, like the activated carbon filtration, ensure high removal.

PROCESS OBJECTIVES

TECHNOLOGY

PRODUCT(S)

Hygienization involves the reduction of pathogens, via ammonia sanitization or heat. Micropollutant removal is achieved to varying degrees by filtration and sorption.

Stabilization processes (e.g., biological treatment or acid/base addition) limit nitrogen losses during treatment and other steps of the value chain (e.g., field application).

Processes of distillation and evaporation separate out water to concentrate target nutrients and reduce volume.

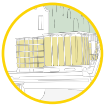
The extraction of one or more nutrients via chemical and physical mechanisms. Additives are often required (e.g., magnesium for precipitation).

VOLUME REDUCTION

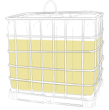
STABILIZATION

HYGIENIZATION

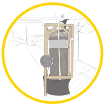
NUTRIENT EXTRACTION



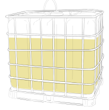
T.1 URINE STORAGE | PASTEURIZATION



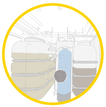
STORED URINE



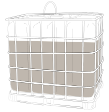
T.2 NITRIFICATION ON BIOCHAR



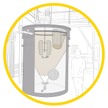
NITRIFIED URINE



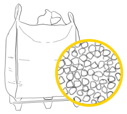
T.3 NITRIFICATION - DISTILLATION



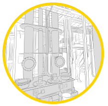
NITRIFIED-CONCENTRATED URINE



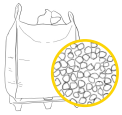
T.4 STRUVITE PRECIPITATION



STRUVITE



T.5 AMMONIA STRIPPING



AMMONIA SALTS

DRY SANITATION

eawag
aquatic research

STRATEGY

Dry sanitation refers to the collection of excreta or feces without flush water . The low-energy and low-tech requirements of dry systems make them suitable for rural, off-grid settings, and areas with water shortages. In multistory buildings, dry collection of excreta or feces is a challenge, yet has been successfully implemented in buildings of up to three stories with straight-drop pipes to the basement, and in larger housing complexes by means of collection of feces at the toilet level and transport to a treatment site. Aside from significant water savings compared to flush sanitation, dry sanitation facilitates the recovery of nutrients and organics and can be an attractive solution for communities in which inhabitants want to manage their own sanitary system off the grid . Dry sanitation is usually combined with urine diversion and often complemented with on-site greywater treatment .

INPUT STREAMS

● Feces

● Excreta

TARGET OUTPUTS

△ Soil amendments

DRY TOILETS

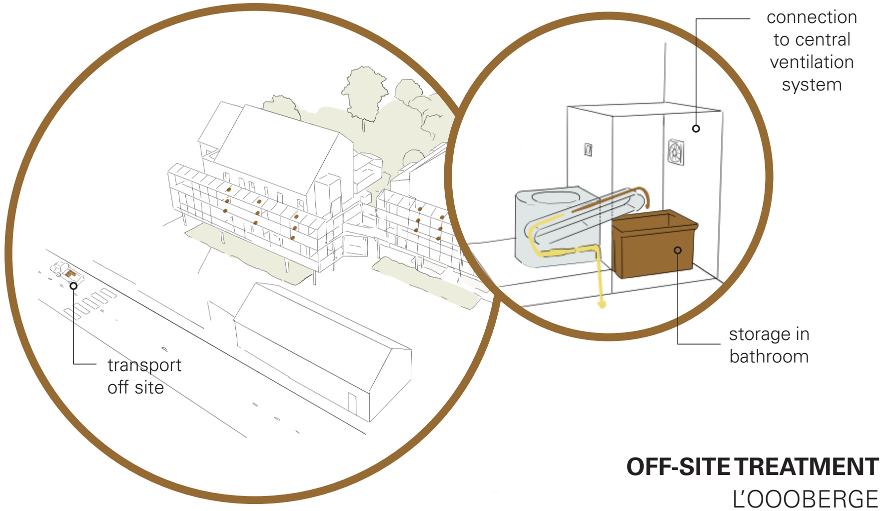
A wide variety of dry toilets are commercially available: from simple models with a "drop hole", to more sophisticated configurations with e.g., conveyor belts. Separation of urine can take place in the toilet itself (e.g., by a separate bowl on the front) or by gravity in the collection and treatment unit. The toilet should be designed to continuously draw air into the toilet bowl, preventing odors.

PIPING

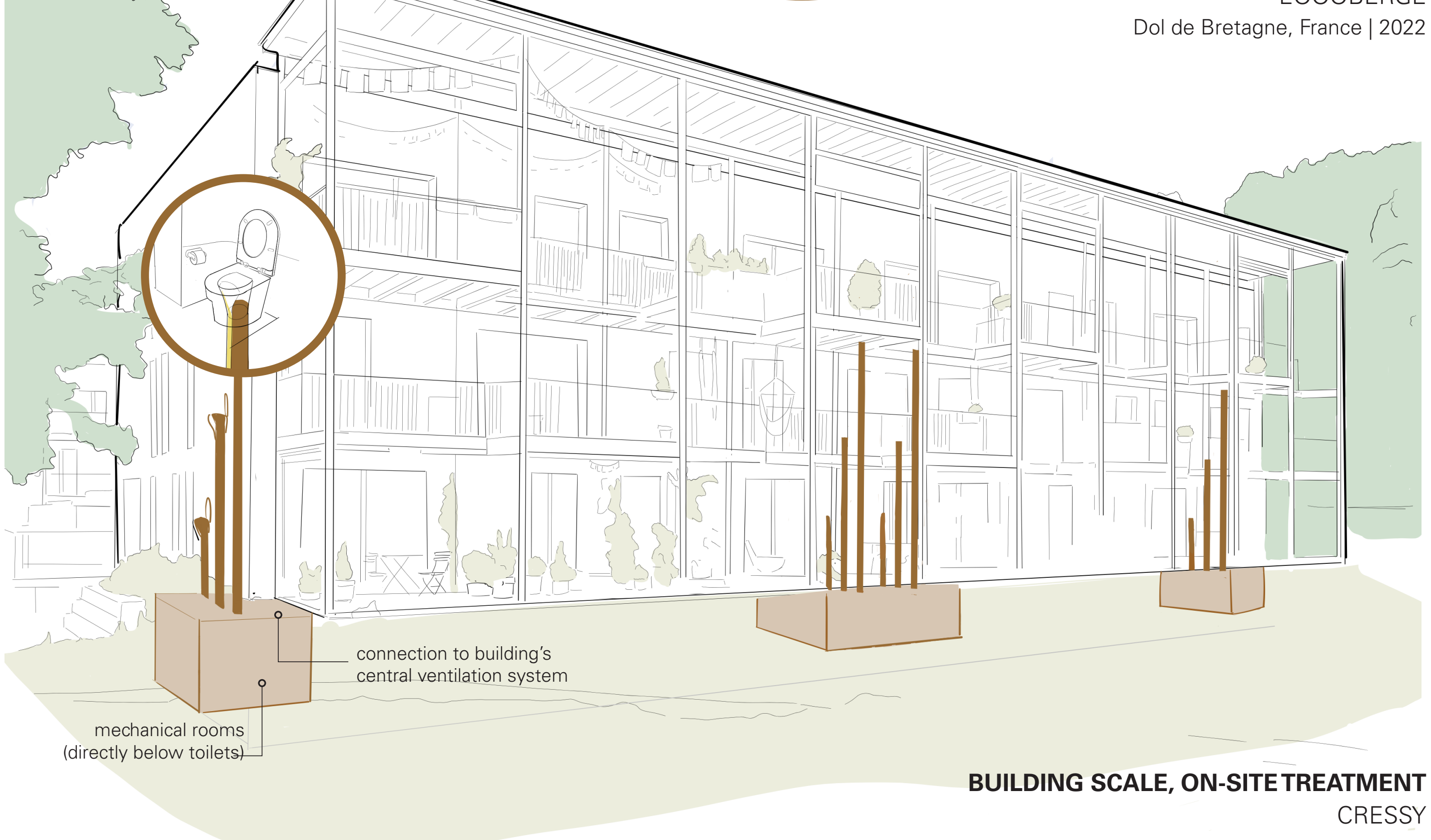
When not collected at the bathroom level (e.g., in containers), feces/excreta can be conveyed one to three stories down via large diameter, straight-drop pipes.

TRANSPORT | TREATMENT

Excreta or feces can be treated on site at building level or can be simply contained/stored on site (at bathroom or toilet level) before transport, often via truck, to an off-site treatment location.



OFF-SITE TREATMENT
L'OOOBERGE
Dol de Bretagne, France | 2022



BUILDING SCALE, ON-SITE TREATMENT
CRESSY
Geneva, Switzerland | 2011

TO CONSIDER

COLLECTED STREAM

Dry toilets collect excreta, or feces with separate collection of urine. When urine and feces are treated together, a bulking agent (e.g., sawdust) is usually added to the stream. Dry sanitation yields relatively small volumes (e.g., 0.15 m³ of fresh feces per person per year, plus toilet paper) with a high solids content of ~25% dry matter. The volume is reduced further during collection and treatment due to evaporation.

SPACE & PLACEMENT

Collection at bathroom level requires space in the bathroom for storage and adequate access for collection. In buildings, straight-drop pipes are needed with collection/mechanical rooms placed directly below the pipes. This poses a limitation on the amount of stories the building can have, and takes up a considerable amount of space in the building. Ventilation is key for dry sanitation: pipes, chambers and mechanical rooms can be connected to the building’s central ventilation system.

RESOURCE INTENSITY

Dry sanitation systems are usually low-tech solutions, requiring little energy consumption, and little-to-no water demand. Passive or active ventilation is required. Maintenance of more sophisticated dry toilet models (e.g., conveyor belt dry toilet) should be carried out periodically.

NEW BUILD VS. RETROFIT

Given the architectural considerations imposed by dry sanitation (i.e., piping constraints, ventilation needs, collection space) implementation is easiest in new builds. Collection at toilet and bathroom scale is more accessible for retrofits.

HYBRID VS. DECENTRALIZED

Dry sanitation is usually implemented together with treatment of the remaining streams (i.e., urine and greywater) for holistic and off-grid solutions. Excreta or feces collected in containers (e.g., via dry porta pottys), are often transported to a semi-centralized treatment hub.

USER EXPERIENCE

When designed properly, odor nuisances from dry toilets can be less than for conventional flush toilets, with the added advantage that no aerosols are produced. Bathroom lighting can be adjusted to avoid lighting the inside of the toilet directly. Users may be required to add bulking materials (e.g., sawdust) after toilet use, and to adjust toilet cleaning practices.

TREATMENT OPTIONS

Treatment of feces or excreta is often includes a single treatment step to either stabilize the organic matter, via aerobic decomposition (i.e., composting) or via thermal decomposition (i.e., incineration or pyrolysis).

VALORIZATION OF ORGANICS & NUTRIENTS

Biological treatment, like composting, and thermal treatment, like pyrolysis, converts feces, or excreta, into soil amendments. These soil amendments contribute to long term fertilization, humus reproduction, carbon binding and carbon storage in the soil.

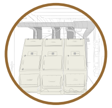
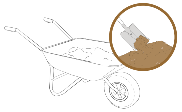
VALORIZATION OF NUTRIENTS

Incineration is a thermal treatment process that combusts organic matter and evaportates water, rendering an inorganic ash rich in nutrients, such as phosphorus and potassium.

SAFE END USE

PATHOGENS & PHARMACEUTICALS

Fecal streams contain human pathogens, posing significant health risks. The collection and handling of feces (e.g., transport for off-site treatment) is the primary disease transmission pathway, with guidelines in place to minimize these risks. Treatment, whether on site or off site, should ensure pathogen inactivation. Pharmaceuticals and other micropollutants will mostly remain in the compost, though health risks from their accumulation in plants using feces-based soil amendments are considered low. The environmental risks from pharmaceuticals or antibiotic resistance genes in soil remain unclear, though are likely lower than those from applying animal manure. Similarly, the risks of heavy metals and micropollutants in feces-based soil amendments are lower compared to sewage sludge because of the exclusion of industrial wastewater and stromwater from the fecal stream.

PROCESS OBJECTIVE		TECHNOLOGY	PRODUCT(S)
Aerobic biological treatment stabilizes the organic matter (and nitrogen), reduces the volume of the stream, and generates heat, which contributes to hygienization.	BIOLOGICAL TREATMENT	 T.21 ON-SITE COMPOSTING	 COMPOST
		 T.22 OFF-SITE COMPOSTING	 COMPOST

VACUUM SANITATION

STRATEGY

Vacuum sanitation systems are based on suction for the removal of excreta with minimal water for flushing, which results in important water savings compared to flush sanitation systems. The concentration of the vacuum-collected blackwater facilitates the recovery of nutrients and valorization of organics from the stream. Compared to conventional gravity sewerage systems, vacuum sewers enable flexible piping installations regardless of topography. A growing number of neighborhoods combine vacuum sanitation with food waste management strategies for biogas production, and with water reuse and heat recovery from greywater for a holistic, off-grid solution. Implementing vacuum sanitation can help projects attain green building certificates.

INPUT STREAMS

- Vacuum-collected blackwater

TARGET OUTPUTS

- Biogas
- Soil amendments & fertilizers
- Treated water

TOILETS

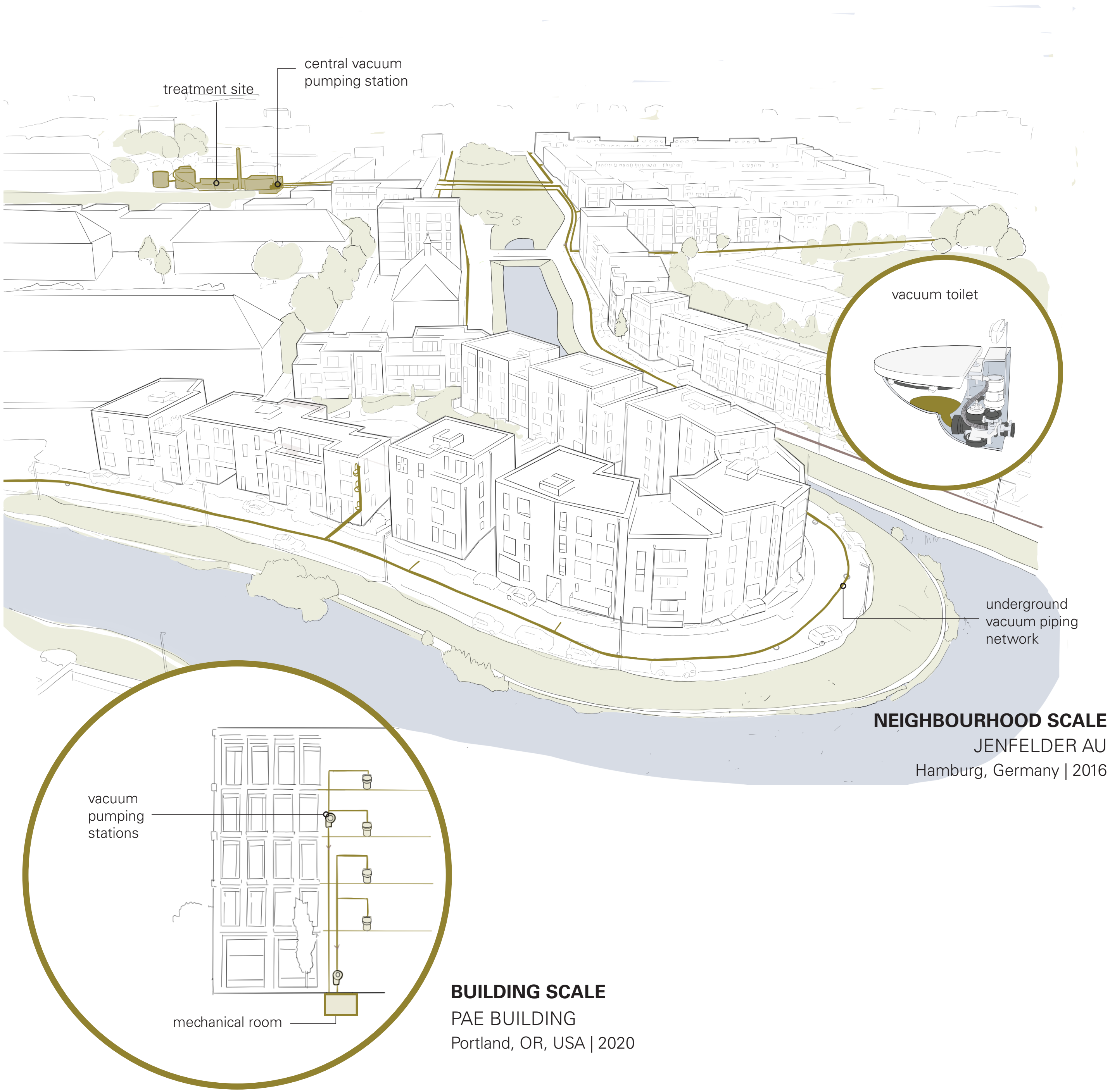
Commercially available vacuum toilets are similar in appearance and user experience to conventional flush toilets. When flushing, a small diameter opening at the base of the toilet bowl opens, and the vacuum in the pipes "sucks" out the excreta, toilet paper, and a small amount of water used to rinse the bowl.

PIPING

Vacuum systems require pumps that generate a vacuum, or negative pressure, in the vacuum piping system. Carefully planned vacuum piping systems can cover whole neighborhoods, with central underground pumping stations keeping the pipes under constant vacuum. At a building or household scale, vacuum pumps can be located close to the toilet or within the building and can operate on demand.

TREATMENT

Treatment and recovery sites can be integrated into a building structure or in a separate treatment location. Alternatively vacuum-collected blackwater can be sent to sewer for centralized treatment.



NEIGHBOURHOOD SCALE
JENFELDER AU
Hamburg, Germany | 2016

BUILDING SCALE
PAE BUILDING
Portland, OR, USA | 2020

TO CONSIDER

COLLECTED STREAM

The low water requirement of vacuum toilets (< 1 L, compared to 3-6L in conventional flush toilets) yields a concentrated blackwater from which organics and nutrients can be more effectively recovered. Solids in vacuum-collected blackwater are "macerated," due to shearing forces in the pipes.

SPACE & PLACEMENT

Vacuum pipes require a smaller pipe diameter than gravity systems, making them lighter and more compact. Independence from gravity offers additional layout flexibility (e.g., pipes can be installed vertically or laid in ceilings). Soundproofing measures should be considered during floorplan design and construction (guidelines exist), as well as the inclusion of inspection points.

RESOURCE INTENSITY

Vacuum sanitation requires more sophisticated technology and more regular maintenance than conventional toilets and gravity drainage. Spontaneous mineral precipitation in pipes can lead to deposit build-up and clogging which require preventative maintenance. Additionally, a constant, though small, energy source is needed to keep vacuum in the pipes. Contingency plans and careful design are thus necessary for power shortages and during maintenance.

NEW BUILD VS. RETROFIT

The installation of vacuum toilets and sewerage is easiest in new build planning and construction as it requires good coordination between all stakeholders. However, vacuum sanitation can also be retrofitted into buildings, which is facilitated by its high flexibility in piping layout.

HYBRID VS. DECENTRALIZED

Vacuum sanitation is implemented in combination with greywater reuse for a holistic, off the grid, solution. When reducing water demand is the primary driver, or in cases where the scale of recovery is not efficient, sending vacuum-collected blackwater to the sewer may be preferred.

USER EXPERIENCE

There is no significant change in user experience with respect to conventional flush toilets apart from a change in flush sound, which is slightly louder. However, vacuum toilet systems also provide certain advantages from the user perspective including lower risk of user exposure to pathogens (no aerosols are generated during flushing), better ventilation (a large volume of air is flushed with the vacuum), and lower water bills.

TREATMENT OPTIONS

Treatment trains for vacuum-collected blackwater typically consist of a biological treatment step for valorization of the organics (e.g., as biogas or compost) followed by nutrient extraction from the digestate or leachate, and sometimes water recovery.

VALORIZATION OF ORGANICS & NUTRIENTS	Biological anaerobic or aerobic treatment of vacuum-collected blackwater yields biogas and/or a soil amendment (e.g., compost, anaerobic sludge).
NUTRIENT EXTRACTION	Processes for the targeted extraction of phosphorus and/or nitrogen from digestate or leachate yield single-nutrient fertilizers (e.g., struvite, ammonia salts) which can be used directly or in fertilizer manufacturing.
WATER REUSE	Biological treatment, filtration and disinfection technologies can treat the remaining water stream, though the volume of the remaining effluent is usually small and thus, it often makes sense to treat it together with greywater (see 💧 for water reuse treatment options).

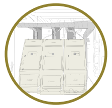
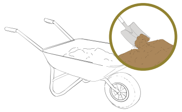
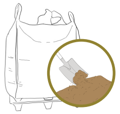
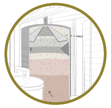
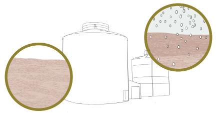
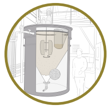
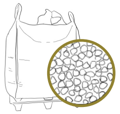
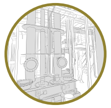
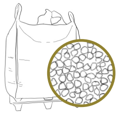
SAFE END USE

SAFE HANDLING OF BIOGAS

Biogas can be converted into heat via a burner or used in combined heat and power (CHP) systems for electricity and heat (often also used to heat the anaerobic reactor). Biogas is flammable and a greenhouse gas 28 times more potent than carbon dioxide (CO_2). Safety measures should be considered for storage and use, and to avoid release of biogas to the atmosphere.

PATHOGENS & PHARMACEUTICALS

Risks from pathogens in blackwater-derived soil amendments and fertilizers can be reduced through additional treatment (e.g., compost maturation, struvite drying) or application measures (e.g., lag time between last application and harvest). Micropollutant removal varies per treatment. Risks are likely lower compared to sewage sludge or animal manure application.

PROCESS OBJECTIVE		TECHNOLOGY		PRODUCT(S)
Anaerobic or aerobic biological treatment converts organics into biogas or compost. While vacuum-collected blackwater can be directly composted, more often composting (of the digestate) follows anaerobic digestion.	BIOLOGICAL TREATMENT		T21 ON-SITE COMPOSTING	 COMPOST
			T22 OFF-SITE COMPOSTING	 COMPOST
			T23 ANAEROBIC DIGESTION	 SLUDGE BIOGAS
The extraction of one or more nutrients via chemical and physical mechanisms. Additives are often required (e.g., magnesium for precipitation, sulfuric acid for stripping).	NUTRIENT EXTRACTION		T4 STRUVITE PRECIPITATION	 STRUVITE
			T5 AMMONIA STRIPPING	 AMMONIA SALTS

FLUSH SANITATION

STRATEGY

Flush sanitation refers to the standard practice of using flush toilets to handle human excreta. A separately-piped flush stream is called blackwater, which contains urine, feces and flush water. When mixed and piped together with greywater it is referred to as mixed wastewater. Like water reuse from greywater, blackwater or mixed wastewater can also be treated for fit-for-purpose water reuse ● to save water 💧. Recovery of nutrients and organics from these streams remains a challenge due to their strong dilution and the lack of simple and efficient solid-liquid separation technologies that enable recovery from the solid fraction. Flush sanitation can be combined with urine diversion ●, via urine diverting flush toilets, to enable nutrient recovery from urine 🌱. This strategy allows for resource recovery where a flush toilet already exists or is desired ▦ 🏠.

INPUT STREAMS

- ● Blackwater
- ● Mixed wastewater

TARGET OUTPUTS

- 💧 Treated water for non-potable water reuse (see ●)
- △ Soil amendments & fertilizers

FLUSH TOILETS

Flush toilets are the standard fixture in contexts with centralized, water-based sanitation, though they can also be installed in decentralized systems. Flush toilets often use 3 -13 L/flush depending on the toilet type. Variations include: dual flush, low flush, pour flush, and pressure flush. Commercially available urine diversion flush toilets further separate urine from the blackwater stream (see ●).

PIPING

Flush water can be piped separately (blackwater with or without urine diversion), which requires designated piping, or together with other streams (mixed wastewater). The latter requires only one pipe, as is conventionally installed for sewered systems.

MECHANICAL ROOM

Treatment of the collected stream(s) typically takes place in a mechanical room, integrated within a building, in underground tanks, or in a neighboring building for a semi-centralized treatment solution. Proper ventilation of mechanical rooms is crucial.

NEIGHBORHOOD SCALE
LA BISTOQUETTE
Geneva, Switzerland | 2025

BUILDING SCALE
ALPINE HUT
Rossinière, Switzerland | 2022

TO CONSIDER

COLLECTED STREAM

Flush water often contributes 20 - 40% of total domestic water use. Flush toilets mix urine and feces, and toilet paper, with large volumes of water resulting in a diluted stream. The flush stream can be collected separately, or together with greywater. The addition of greywater further dilutes the stream.

SPACE & PLACEMENT

No additional space is required for piping when flush water is mixed with other wastewaters; for blackwater collection designated piping is needed in parallel to greywater, and/or urine piping. Space requirements for a mechanical room for treatment depend on volumes collected and treatment technologies selected. While technologies can be quite compact (e.g., MBR), the series of technologies together do require space.

RESOURCE INTENSITY

Operational costs for treatment of streams containing flushwater are generally higher than for cleaner streams, such as greywater. When considering treatment options, the costs of advanced systems (e.g., membrane bioreactors) should be compared to real estate costs of space-intensive systems (e.g., nature-based solutions). Energy use varies by technology. Separate blackwater piping adds capital costs.

NEW BUILD VS. RETROFIT

Flush sanitation lends itself to building retrofits, where flush toilets are already installed in existing buildings, as well as to new build where flush toilets are preferred. Mixed wastewater requires single piping (e.g., existing piping). Blackwater, collection requires separate designated piping, next to other collected streams, and is therefore easiest in new build planning and construction.

HYBRID VS. DECENTRALIZED

Treatment of and recovery from collected blackwater or mixed wastewater can be implemented in hybrid or decentralized scenarios. Where a connection to the sewer is available, remaining streams or byproducts (e.g., from a liquid-solid separation step) can be discharged to sewer for a hybrid configuration.

USER EXPERIENCE

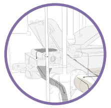
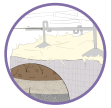
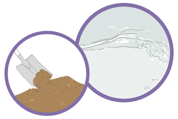
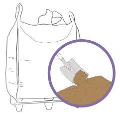
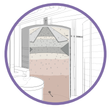
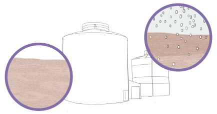
In many contexts, flush toilets are already installed, or are preferred. Implementing flush sanitation does not change the user experience at the user interface. Awareness among users about appropriate cleaning products is critical for biological treatment processes and fertilizer use of recovered products.

TREATMENT OPTIONS

A typical treatment train for blackwater or mixed wastewater begins with a solid-liquid separation step, followed by technologies that valorize the organics and nutrients from the solids fraction or treat the liquid fraction for water reuse. In remote areas, where treatment is needed independent of the grid, infiltration or discharge are also possible solutions.

WATER REUSE	Treatment of the liquid fraction for fit-for-purpose reuse via biological treatment, filtration and disinfection technologies (see ◗ for water reuse treatment options).
WATER INFILTRATION & DISCHARGE	Treatment (e.g., septic tanks or aerobic treatment of mixed wastewater, or after a solid-liquid separation step) that produces an effluent that can be discharged to the environment or infiltrated on site.
VALORIZATION OF ORGANICS & NUTRIENTS	Biological anaerobic or aerobic treatment of the solid fraction after solid-liquid separation that yields a soil amendment (e.g., compost, anaerobic sludge) or biogas.

BELOW: Treatment options for valorization of nutrients and organics from the solids fraction. For water reuse treatment options see ◗ *.*

PROCESS OBJECTIVE		TECHNOLOGY		PRODUCT(S)
Solid-liquid separation removes grit, debris, and grease, and/or separates suspended solids (toilet paper, feces) from the liquid fraction.	S-L SEPARATION		T.42 SETTLING TANKS | SCREENS	 LIQUID FRACTION
	BIOLOGICAL TREATMENT		T.43 VERMIFILTERS	 COMPOST LIQUID FRACTION
Anaerobic or aerobic biological processes, driven by microorganisms, convert organics into biogas or compost. Limited pathogen and micropollutant removal is achieved.			T.22 OFF-SITE COMPOSTING	 COMPOST
			T.23 ANAEROBIC DIGESTION	 SLUDGE BIOGAS

SAFE REUSE

SAFE WATER REUSE

See ◗ for details on pathogen removal and inactivation, preventing microbial regrowth, and dealing with micropollutants for safe water reuse.

PATHOGENS & PHARMACEUTICALS

Pathogen risks in fecal-derived soil amendments can be reduced by combining treatment steps (e.g., compost maturation following vermifiltration or digestion) or by application measures (e.g., lag time between last application and harvest). Pharmaceutical and micropollutant removal varies per treatment. Their environmental risks in soil remain unclear, though are likely lower than those from applying animal manure or municipal sewage sludge (which also includes industrial wastewater and stromwater).

WATER REUSE

eawag
aquatic research

STRATEGY

Collecting and treating greywater or mixed wastewater for reuse in irrigation, non-potable building uses, or even potable reuse, results in significant drinking water savings. Reuse can also alleviate pressure on existing sewage infrastructures by reducing the volume of wastewater produced. Implementing water reuse can contribute credits, via water savings and supporting blue-green infrastructure, to attain green building certificates. For holistic water management solutions, water reuse is best integrated with water efficient fixtures, rainwater harvesting, and heat recovery. Cities like Melbourne, San Francisco, and Barcelona are pioneering legislative frameworks enabling widespread on-site water reuse at different scales.

INPUT STREAMS

- Greywater
- Mixed wastewater

TARGET OUTPUTS

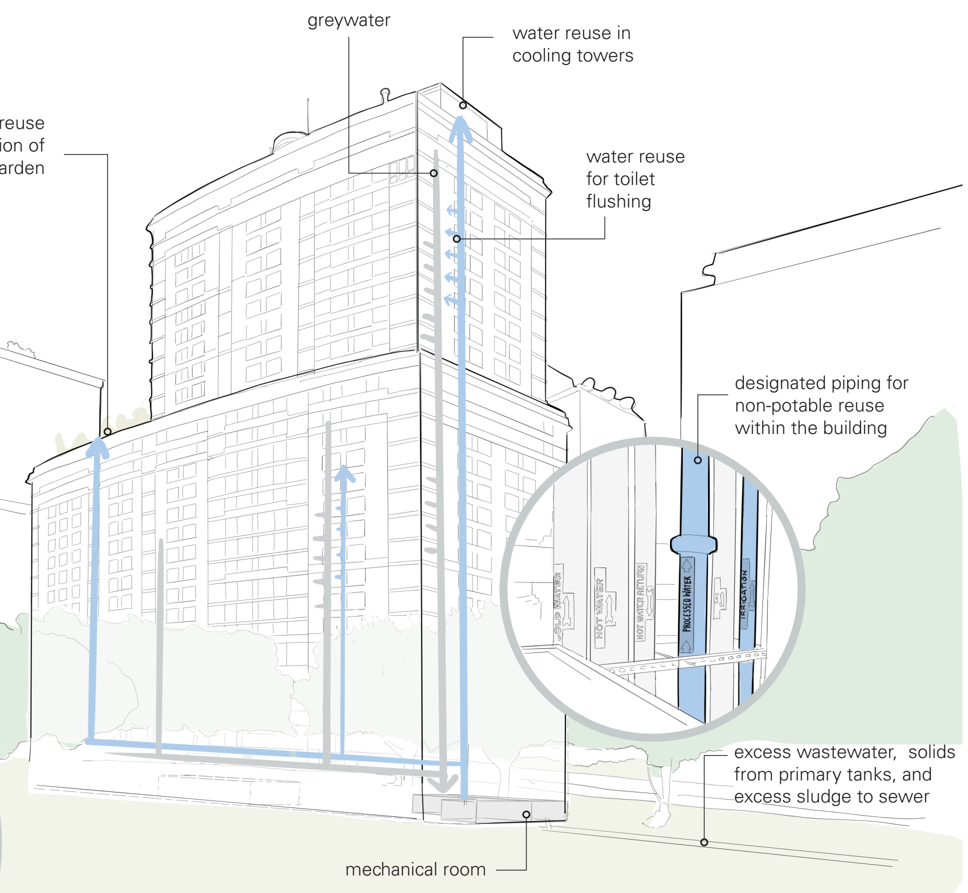
- Treated water for non-potable reuse (toilet flushing, irrigation, infiltration, laundry)
- Treated water for potable reuse

PIPING

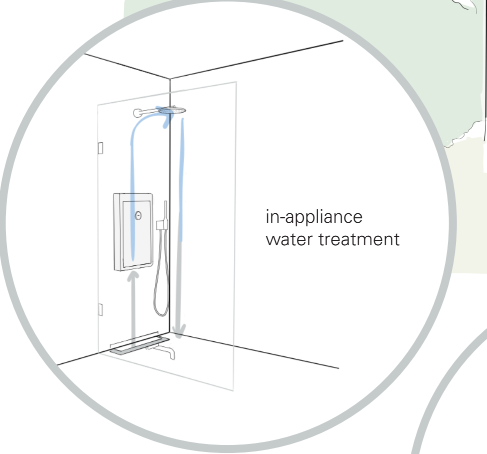
Building scale water reuse must consider needs for additional piping for collecting greywater (if implemented) and/or for distributing treated water to the point of use. For non-potable, in-building reuse, adequate measures should be taken to prevent cross connections and backflow between treated water pipes and drinking water pipes and to minimize microbial regrowth in storage tanks and pipes.

TREATMENT

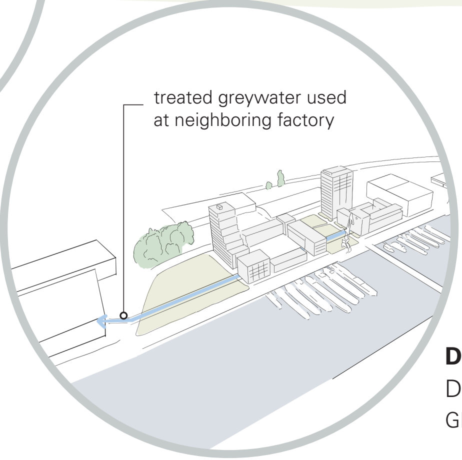
Mechanical rooms for water treatment and recovery are typically placed in the basement for building scale reuse or at a neighboring treatment facility in larger district-scale projects. Some treatment technologies can be placed outdoors, either underground or integrated in the (urban) landscape (e.g., constructed wetlands).



BUILDING SCALE
THE SOLAIRE
New York City, NY, USA | 2004



APPLIANCE SCALE
GULDSMEDEN AXEL
Copenhagen, Denmark | 2018



DISTRICT SCALE
DE NIEUWE DOKKEN
Ghent, Belgium | 2020

TO CONSIDER

COLLECTED STREAM

Both greywater or mixed wastewater can be reused. Greywater collection requires designated piping, though keeps the greywater from mixing with streams containing urine and feces, often requiring less intensive treatment than for mixed wastewater. Treating greywater yields smaller volumes than mixed wastewater, especially in non-residential buildings.

SPACE & PLACEMENT

The space required for treatment varies greatly depending on the technologies selected: higher tech solutions (e.g membrane bioreactors) can be very compact, while lower tech or nature-based solutions (e.g., constructed wetlands) require more space. Collection and storage tanks also require space.

RESOURCE INTENSITY

Operational costs for mixed wastewater treatment are generally higher than for greywater treatment. Separate greywater piping adds capital costs. When considering treatment options, the costs of advanced systems (e.g., membrane bioreactors) should be compared to real estate costs of space-intensive systems (e.g., constructed wetlands). Energy use varies by technology.

NEW BUILD VS. RETROFIT

Reusing treated mixed wastewater is easier to integrate into existing buildings, where greywater separation is not implemented. It is easier to plan for and implement separate greywater collection in new construction, although retrofitting existing buildings is possible.

HYBRID VS. DECENTRALIZED

If connected to the sewer, excess wastewater, solids from separation, or excess sludge can be discharged, ideally during low-flow periods to reduce strain on sewer and treatment infrastructure. A connection to the drinking water network provides backup if treated water volumes are insufficient.

USER EXPERIENCE

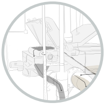
Nature-based treatment technologies may bring added value to the user by improving biodiversity, air quality, and aesthetics. For all water reuse scenarios, willingness of users to use lower than drinking water quality for applications where high quality is not necessary is important.

TREATMENT OPTIONS

A typical water reuse treatment train combines technologies from four process groups. Treatment trains do not need to include technologies from all process groups and can include more than one technology from the same process group.

S-L SEPARATION

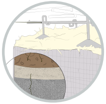
Solid-liquid separation removes grit, debris, and grease, and/or separates suspended solids (from toilet paper, feces) from the liquid fraction.



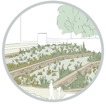
T42 SETTLING TANKS | SCREENS

BIOLOGICAL TREATMENT

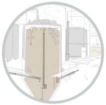
Biological processes, driven by microorganisms, remove organic compounds and can be designed to remove nitrogen as well as phosphorus. Limited pathogen and micropollutant removal is achieved.



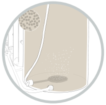
T43 VERMIFILTERS



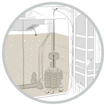
T44 CONSTRUCTED WETLANDS



T45 TRICKLING FILTERS



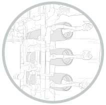
T46 AERATED BIOREACTORS



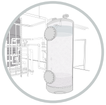
T47 MEMBRANE BIOREACTORS

FILTRATION

Filtration is the removal of particles and colloids using membranes or granular media. Pathogen and micropollutant removal is achieved to varying degrees.



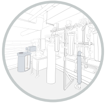
T48 MEMBRANE FILTERS



T49 GRANULAR MEDIA FILTERS

DISINFECT. & ADV. OX.

Disinfection is the inactivation or removal of pathogens to ensure microbial safety for reuse. Advanced oxidation processes also provide targeted removal of micropollutants.



T50 UV & CHLORINE DISINFECTION

T51 OZONATION & ADVANCED OXIDATION

SAFE REUSE

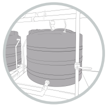
PATHOGEN REMOVAL & INACTIVATION

Enteric viruses, protozoa, and bacteria pose health risks, and their removal or inactivation, measured by log reduction, is essential for safe reuse. The required treatment level depends on 1) the source water (e.g., mixed wastewater will require higher log reductions than greywater), 2) the reuse application (e.g., irrigation has lower pathogen risk than indoor use), and 3) acceptable risk or regulatory standards. Water reuse treatment trains should be designed using a multi-barrier approach, which includes redundancies against pathogenic risks.

PREVENTING MICROBIAL REGROWTH

Trace levels of biodegradable organic matter and nutrients can cause microbial regrowth in storage tanks and pipes, affecting water color, odor, and system maintenance. Growth of opportunistic pathogenic microorganisms, like *Legionella pneumophila* or *Legionella spp.*, is a major concern for water reuse.

To minimize microbial regrowth, measures include: 1) filtration to remove organics and nutrients, 2) disinfection (e.g., with residual disinfection) 3) reducing treated water temperature, and 4) regular cleaning of tanks and pipes.



T41 WATER TANKS | CISTERNS

DEALING WITH MICROPOLLUTANTS

Treated water may contain organic micropollutants from cleaning products, pesticides, pharmaceuticals, and personal care products. While exposure is low for most non-potable uses, it poses a concern for potable and agricultural applications, as well as irrigation or infiltration where water enters the environment without further treatment.

Micropollutant removal depends on the sequence of technologies in the treatment train. Targeted removal (e.g., with activated carbon or advanced oxidation) can achieve desired removal for specific pollutants.

WATER-EFFICIENT FIXTURES

STRATEGY

Water-efficient fixtures are products designed to reduce overall water consumption ● in buildings without compromising performance. These fixtures replace typical fittings and appliances with, for example, low-flow shower heads and faucets, low-flush, dual-flush or waterless urinals ● and toilets ●, and/or water-efficient household appliances. Implementing water-efficient fixtures often does not require large infrastructural changes, yet reduces water consumption by 20-60%, depending on the type and usage. Water savings also reduce energy demand for hot water ● and contributes credits to attain green building certificates ●. Together with rainwater harvesting ● and water reuse ●, water-efficient fixtures can contibute to an overall water saving and reuse strategy.

INPUT STREAMS

- ● Drinking water
- ● Treated water

SHOWERS & FAUCETS

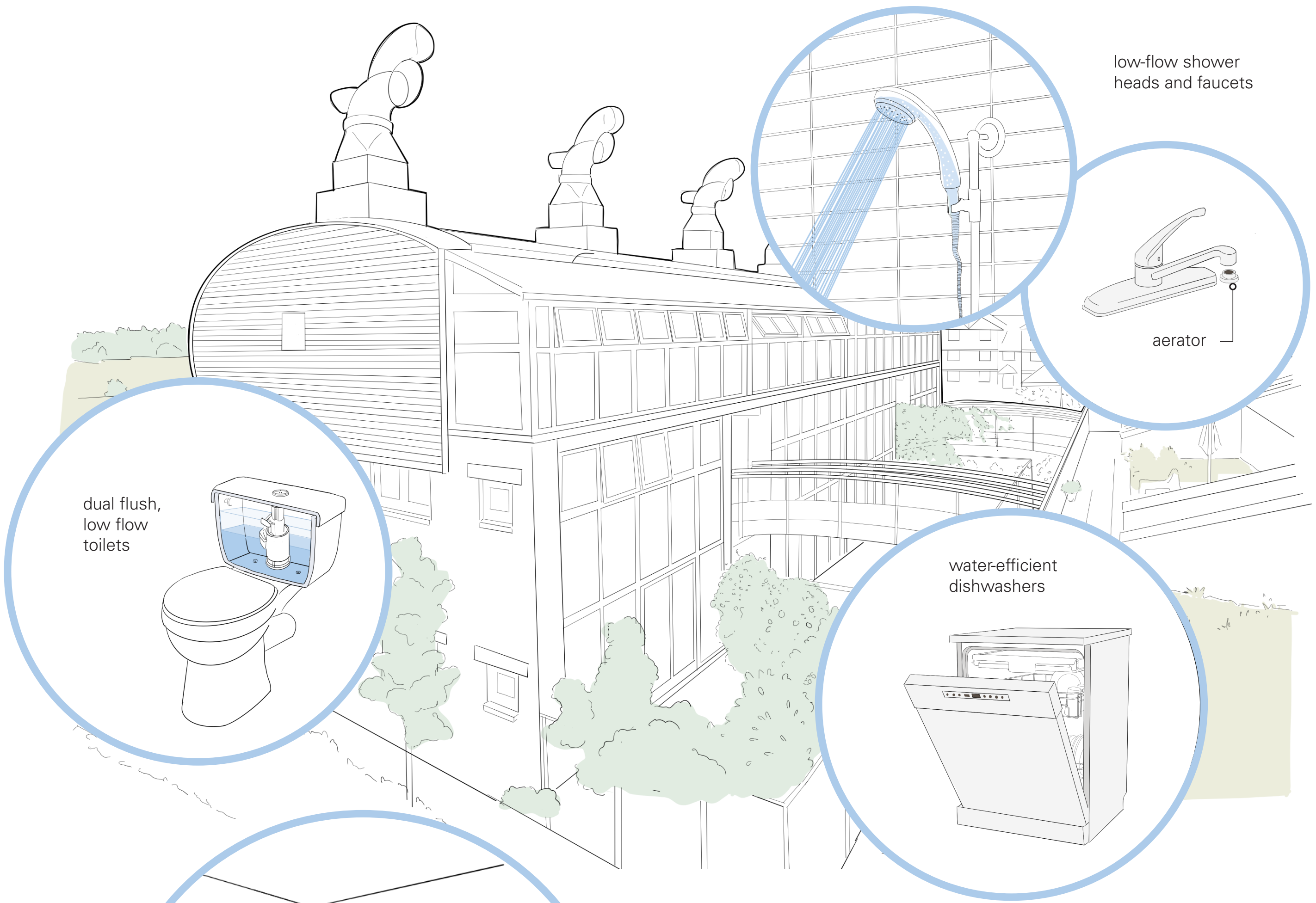
Watersaving flow restrictors (e.g., aerators) in shower and faucet fittings can be installed to reduce water consumption at the tap. Some bathtubs are sculpted to lower the volume of water they can hold. Showers that recirculate water, via in-appliance treatment also reduce water use.

APPLIANCES

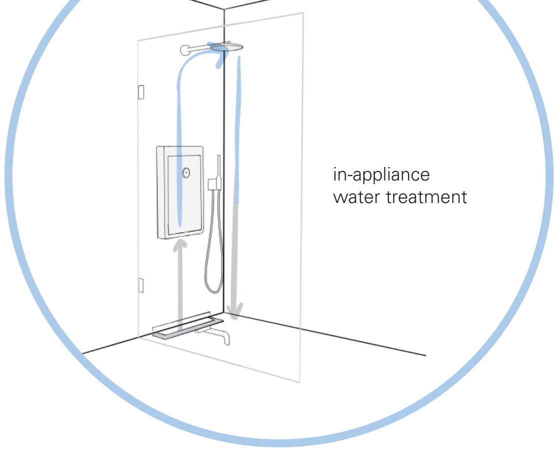
Water efficient washing machines and dishwashers are examples of appliances that reduce water use. For washing machines, front-loaders generally save more water in comparison to top-loaders.

TOILETS

Flush toilets use large quantities of water per flush (~9 liters). Dual flush toilets allow users to control the amount of water per flush. Waterless urinals, vacuum toilets and dry toilets significantly reduce overall water use. However, their implementation may require additional planning of and infrastructure for the collected streams if they are not sent to sewer. See ● ● ●



APPLIANCE SCALE
BedZED
London, United Kingdom | 2000



APPLIANCE SCALE
GULDSMEDEN AXEL
Copenhagen, Denmark | 2018

TO CONSIDER

COLLECTED STREAM

Water-efficient fittings and fixtures use the same source water as regular ones. Faucet and shower aerators mix small air bubbles into the water to maintain water pressure, while using less water. Reduced water consumption reduces the volume of greywater or mixed wastewater produced, which can impact other water reuse strategies.

SPACE & PLACEMENT

Water-efficient fixtures can replace or be attached to conventional ones, occupying the same amount of space. Usually they are compatible with existing hardware.

RESOURCE INTENSITY

Installing water-efficient faucets and shower heads is often cheap and simple. Dishwashers and washing machines account for higher initial costs, although through the long-term water (and often energy) savings, water-efficient appliances can be a better investment over time. Upfront costs for water-saving toilets are often also higher than conventional ones. Installing dry/vacuum toilets may require a larger infrastructural change.

NEW BUILD VS. RETROFIT

Most fixtures are easily placed in both existing and new build infrastructure. Replacing toilets in existing buildings can require some additional construction, especially for the installation of vacuum and dry sanitation.

HYBRID VS. DECENTRALIZED

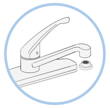
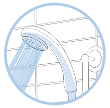
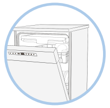
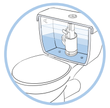
Water saving typically makes sense in all contexts, particularly water-scarce areas.

USER EXPERIENCE

Most water-efficient fittings and fixtures do not compromise their performance or the user experience. Dry toilets are the only fixture that may require a few behavioral changes (e.g., users may be required to add bulking materials, like saw dust after toilet use, and to adjust toilet cleaning practices).

FIXTURE OPTIONS

There are several types of water-efficient fixtures designed to reduce water consumption without compromising performance and user experience. Common fixtures, together with their water use, are listed below.

		FIXTURE	WATER USE
FAUCETS		REGULAR FAUCETS	10 - 15 L/min
		LOW-FLOW FAUCETS	5 - 8 L/min
SHOWERS		REGULAR SHOWERS HEADS	12 - 20 L/min
		LOW-FLOW SHOWER HEADS	6 - 9 L/min
		RECIRCULATING SHOWER	60 - 90% reduction
APPLIANCES		REGULAR DISHWASHERS	~20 L/load
		WATER EFFICIENT DISHWASHERS	9 - 12 L/load
		REGULAR WASHING MACHINES	~150 L/load
		WATER-EFFICIENT WASHING MACHINES	50 - 80 L/load
TOILETS		FLUSH TOILET	6 - 13 L/flush
		LOW-FLUSH TOILET	4 - 6 L/flush
		DUAL-FLUSH TOILET	3 - 6 L/flush
		VACUUM TOILET	<1 L/flush
		WATERLESS/LOW-FLUSH URINAL	0 - 1 L/flush
		DRY TOILET	0 L

USE

WATER & ENERGY SAVINGS

Water-efficient fixtures reduce overall water consumption, conserving valuable resources, especially in drought-prone areas. These fixtures often also reduce energy consumption by reducing the amount of hot water used; less water means less energy required to heat it up.

Water and energy reductions can lead to savings in utility bills over time. Calculated savings vary depending on 1) type and number of fixtures installed, 2) household size, 3) water usage, and 4) local water and energy rates.

RAINWATER HARVESTING

STRATEGY

Rainwater harvesting is the collection of rainwater from rooftops, balconies and/or other (above grade) surfaces during rainfall events. Collection is dependent on precipitation intensity, and by means of storage, collected rainwater can be used at a later point in time. Using rainwater for non-potable, even potable uses, results in drinking water savings 💧. In off-grid ▦ locations, rainwater can be an important primary water source. Rainwater harvesting can be key to supporting urban blue-green infrastructure and is often included in sustainable building certification criteria ♲ . Rainwater harvesting can be part of a larger water saving and reuse strategy in combination with water efficient fixtures ◗ , and the reuse of greywater or mixed wastewater ◗ .

INPUT STREAMS

- Rainwater (from roofs, balconies)
- Rainwater from green roofs
- Stormwater (from lawns, pavement, roadways, etc.)

TARGET OUTPUTS

- Treated water for non-potable reuse (toilet flushing, irrigation, infiltration, laundry)
- Treated water for potable reuse

COLLECTION & STORAGE

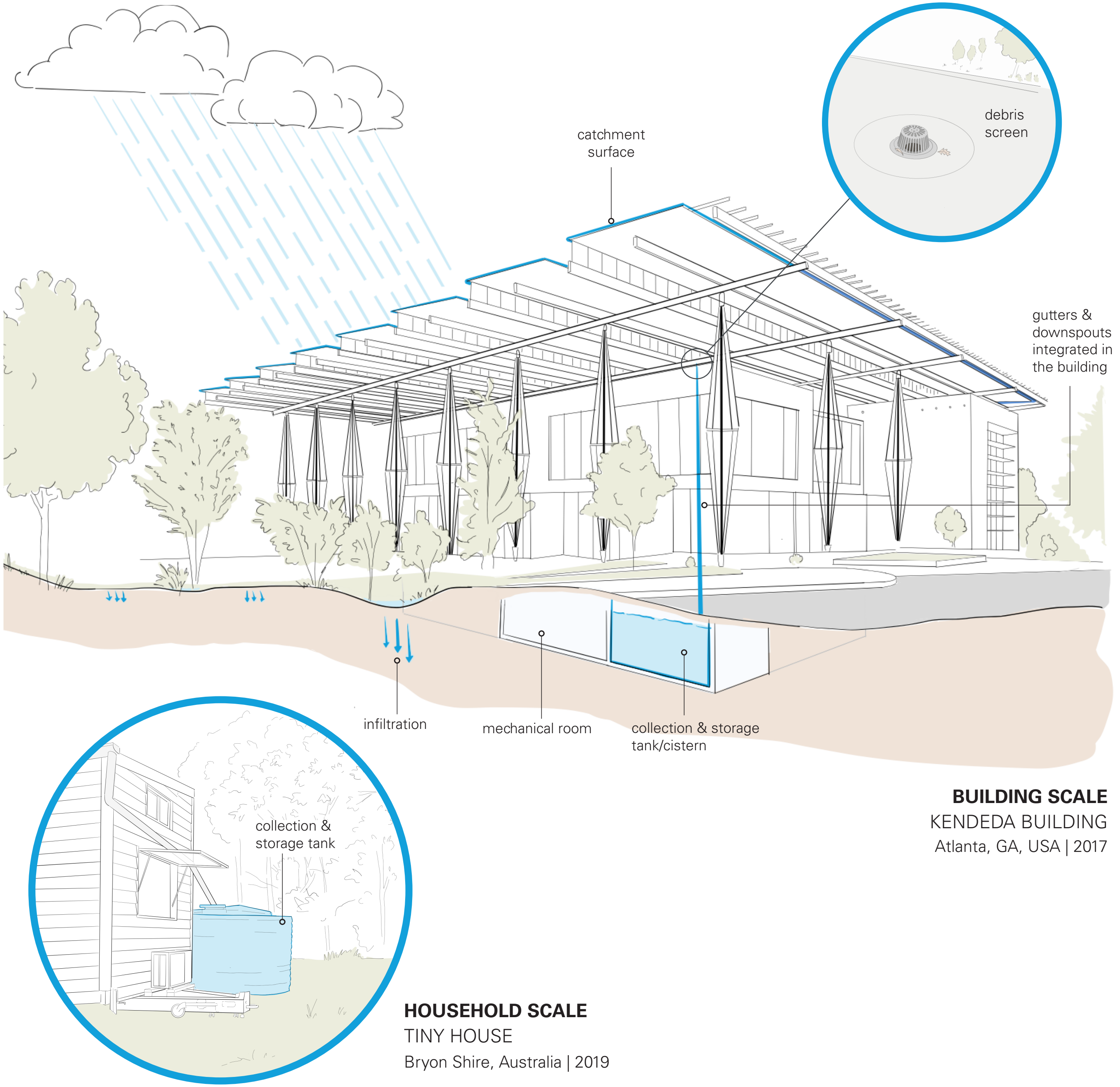
Gutters and downspouts direct rainwater from catchment surfaces to storage tanks or ponds. Ponds additionally support local biodiversity and cooling. Pre-storage measures include debris screens, filters, and first-flush diversion. Storage helps bridge the gap between wet and dry weather, and between collection, treatment, and reuse.

TREATMENT

Rainwater can be directly reused for non-potable purposes like toilet flushing and irrigation, though treatment expands safe reuse, especially indoors. Treatment is typically done in a basement for building-scale projects or at a decentralized facility for neighborhood or district-scale systems.

PIPING & REUSE

A separate piping network distributes treated rainwater to reuse applications. For in-building non-potable reuse, precautions must prevent cross-connections and backflow between treated and drinking water pipes, and minimize microbial regrowth in tanks and pipes.



BUILDING SCALE
KENDEDA BUILDING
Atlanta, GA, USA | 2017

HOUSEHOLD SCALE
TINY HOUSE
Bryon Shire, Australia | 2019

TO CONSIDER

COLLECTED STREAM

Rainwater is a relatively clean stream, though its quality can be reduced by deposition and leaching of metals, nutrients and microbial pathogens from dust, debris, animal droppings and from collection surfaces themselves. The quantity of rainwater available for collection depends of local precipitation, and catchment surface area. Rainwater can also be collected (and treated) together with other water sources (see ●).

SPACE & PLACEMENT

Catchment surface area is an important determining factor in rainwater harvesting potential. Space requirement is most demanding for the storage tank(s), which can be located aboveground (e.g., rain barrels) or belowground (e.g., cisterns). Tank volume depends on rainwater supply and reuse demand balances. Water mass balance models and control units can help users monitor rainwater storage levels, automatically discharging water from the tank before a next rainfall event.

RESOURCE INTENSITY

Most buildings already account for initial material and installation costs for gutters and pipes. Above ground rain barrels are a cheaper add-on than underground storage tanks. Regular, though low, maintenance is required to clean filters. Energy is required to pump rainwater to place of reuse, when gravity-driven distribution is not feasible.

NEW BUILD VS. RETROFIT

Catchment surface materials need to be appropriate to prevent leaching of pollutants into the water (e.g., copper) in both existing and new build construction. Indoor reuse of rainwater requires an additional piping network, which lends itself better to new build construction.

HYBRID VS. DECENTRALIZED

In off-grid, decentralized settings, rainwater can be an important water source. In urban and suburban contexts, harvested rainwater can be used in parallel to other water sources (e.g., drinking water from distribution network), and the harvesting system can benefit from a sewer connection (e.g. to receive first-flush diversion water).

USER EXPERIENCE

Rainwater is generally accepted as a non-potable water source, and often also as a potable water source after sufficient treatment.

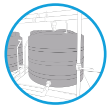
TREATMENT OPTIONS

Rainwater can be directly reused or treated for non-potable, and even potable, reuse. Treatment typically includes filtration and/or disinfection processes. Treatment of stormwater may require additional steps for pollutant removal (see Water Reuse ●).

DIRECT REUSE	Rainwater reuse without treatment is common at the household level, typically for garden irrigation, cleaning, and toilet flushing. The water may have a yellow tint due to tannin staining from organic material like leaves, seeds, and pollen.
TREATMENT BEFORE REUSE	Treatment technologies for rainwater reuse target the removal of heavy metal, nutrient and microbial pollutants. Treatment trains are typically more complex for high-quality reuse and less complex for non-potable applications.

Storage tanks and cisterns store water before treatment and/or reuse.

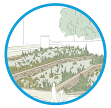
STORAGE



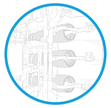
T.41 WATER TANKS & CISTERNS

Filtration is the removal of particles and colloids, as well as microbial and chemical contaminants, using membranes or granular media. Biological degradation also occurs where microorganisms in a biofilm are present.

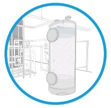
FILTRATION



T.44 CONSTRUCTED WETLANDS



T.48 MEMBRANE FILTERS



T.49 GRANULAR MEDIA FILTERS

Disinfection is the inactivation or removal of pathogens to ensure microbial safety for reuse. Advanced oxidation processes also provide targeted removal of micropollutants.

DISINFECT. & ADV. OX.

T.50 UV & CHLORINE DISINFECTION

T.51 OZONATION & ADVANCED OXIDATION

SAFE REUSE

POLLUTANTS

The removal of pollutants, originating from dust and debris, or from collection surfaces themselves, depends on treatment steps and sequence. User exposure to these pollutants is considered small for most non-potable applications but is a concern for potable applications. A treatment step for targeted micropollutant removal (e.g., activated carbon or advanced oxidation) can be included.

Stormwater, collected from roads and terraces, typically contains more pollutants (e.g., organic and chemical pollutants and heavy metals) than rooftop-collected rainwater. Treatment may require additional steps for pollutant removal (see Water Reuse ●).

SAFE STORAGE

Trace levels of pathogens (e.g., from animal feces), organic matter and nutrients can lead to microbial regrowth in storage tanks and pipes. Growth of opportunistic pathogenic microorganisms, like *Legionella pneumophila* or *Legionella spp.*, is a major concern for human health. Additionally, for potable reuse, tank liners and coatings need to be food grade.

Measures for safe storage include: 1) removing organics and nutrients from water before storage, 2) ensuring tanks are opaque to prevent algal growth, 3) including a disinfection step (e.g., with residual disinfection) 5) regular cleaning of tanks and pipes.

BLUE-GREEN INFRASTRUCTURE

Rainwater harvesting, treatment, and reuse can be combined with blue-green infrastructure (BGI) to support local biodiversity, increase urban cooling, irrigate green areas and add aesthetic value. Examples of synergies between rainwater harvesting and BGI include: collection via green roofs, treatment with constructed wetlands, water storage in open retention ponds, and irrigation of public areas.

HEAT RECOVERY

STRATEGY

Residual heat in greywater or mixed wastewater, from showers, laundry and dishwashers, can be passively recovered via heat exchangers to heat a building's hot water supply. Heat can also be actively recovered via heat pumps and added to a building or district's heat network. The recovery of this residual heat can reduce the energy demand of a building or district by roughly 30%. Heat recovery can be implemented in single- and multi-family homes and residential buildings, as well as in non-residential buildings with high hot water consumption (e.g., sports complexes, commercial washing facilities, hotels). Heat recovery can be coupled to on-site water reuse. The resulting lowered water temperature also helps reduce microbial regrowth in storage tanks.

INPUT STREAMS

- Greywater
- Mixed wastewater

TARGET OUTPUTS

- Recovered heat

IN-APPLIANCE RECOVERY

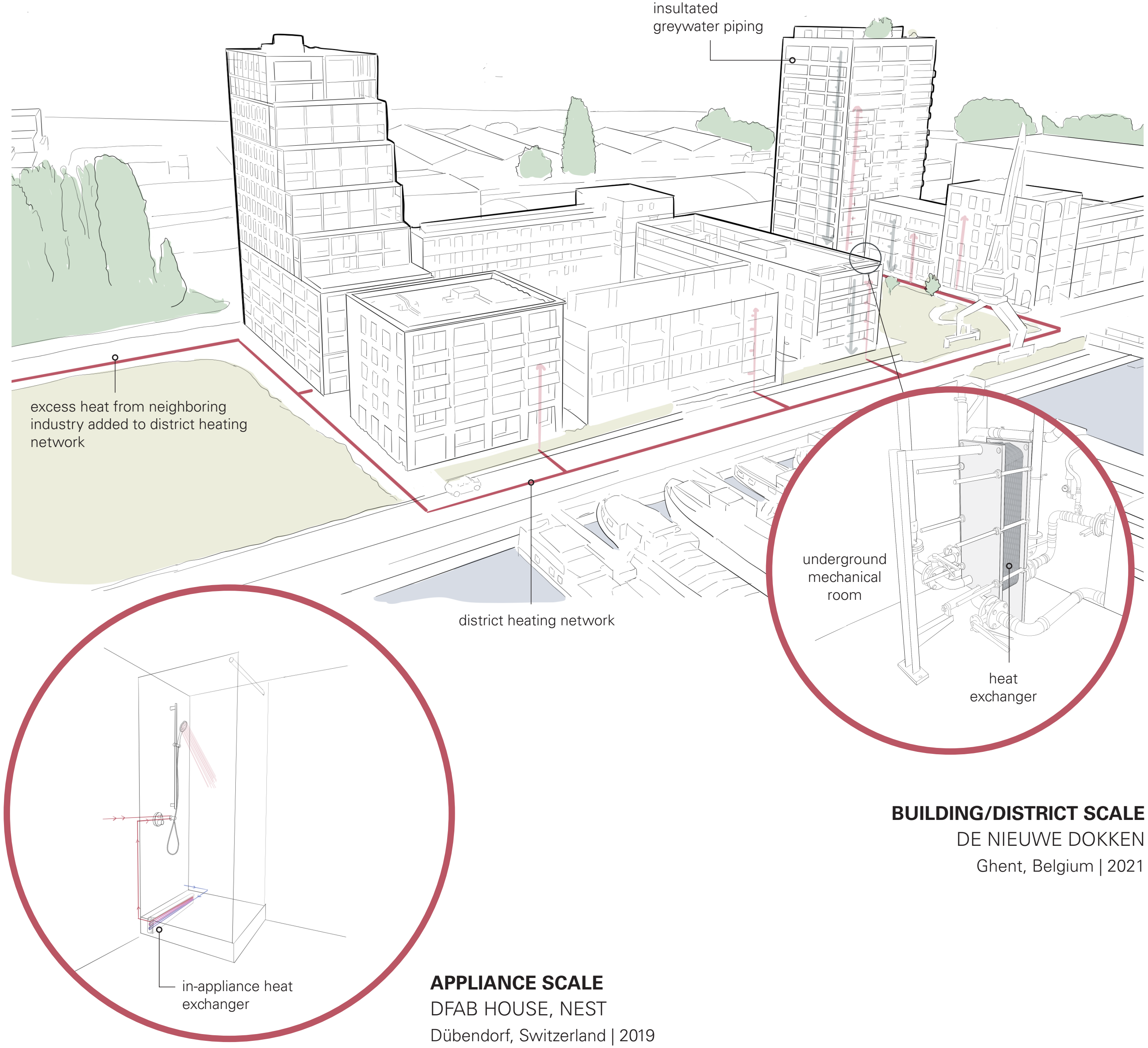
Heat exchangers implemented in or close to a shower, recover heat from the draining greywater to pre-heat the incoming water (by ~15 °C) before the mixing valve. Recirculating showers, that reuse shower water after in-appliance treatment, directly recirculate heat.

INSULATION

Greywater or mixed wastewater piping should ideally be insulated to avoid heat dissipation before reaching the heat exchanger or heat pump. Thermal storage tanks, also known as hot water storage tanks or buffer tanks, are commonly used to store heat between intermittent heat recovery and use. Storage tanks should also be insulated.

MECHANICAL ROOM

Heat exchangers or pumps, as well as storage/buffer tanks, are typically placed in a mechanical room, for example, in a basement. The closer the heat exchanger or pump is to the source, the lower the dissipation of heat during conveyance and the higher the heat recovery potential. Ventilation of the mechanical room is important to allow excess heat to dissipate and prevent overheating of the heat exchangers and pumps, and for humidity control.



BUILDING/DISTRICT SCALE
DE NIEUWE DOKKEN
Ghent, Belgium | 2021

APPLIANCE SCALE
DFAB HOUSE, NEST
Dübendorf, Switzerland | 2019

TO CONSIDER

COLLECTED STREAM

Most of the heat is present in streams including greywater from showers, washing machines, and dishwashers. Heat recovery is therefore implemented from greywater (if separated) or mixed wastewater. Greywater (temp. range: 25 - 38 °C) contains more thermal energy than mixed wastwater (15 - 30 °C). It is important to consider that recovering heat can impact further performance of treatment and recovery technologies.

SPACE & PLACEMENT

Unless appliance scale recovery is implemented, a mechanical room is used to house the heat exchangers and/or pumps, as well as heat storage/buffer tanks. Heat exchangers are often designed for modularity; depending on the volume of the collected stream and heat demand, the setup can expand.The insulation of pipes requires a bit more space between/behind walls. If integration in district heating network is desired, proximity to the network is essential.

RESOURCE INTENSITY

The initial investment for a heat exchanger or pump can be significant, although the long-term energy savings often justify the expenditure. Heat pumps are often most financially suitable at larger scales with high wastewater volumes. Heat recovery requires little additional resources, and minimal operation and maintenance.

NEW BUILD VS. RETROFIT

Heat recovery is suitable for both new constructions and retrofitted buildings. In existing buildings, implementing heat exchangers or pumps may require modifications to plumbing. New build contexts lend themselves for integration of onsite heat recovery into a networking heating distribution model.

HYBRID VS. DECENTRALIZED

Heat can be recovered at a centralized location, for example in conventional sewers and wastewater treatment plants. However, recovery close to the source reduces heat losses (i.e., dissipation) and increases recovery potential. Heat recovery can be part of a larger water saving strategy, however it can also be implemented for wastewater streams sent to sewer.

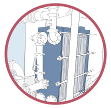
USER EXPERIENCE

Properly designed and maintained systems operate quietly and without odor, ensuring a positive user experiene. Lower heating bills are often a welcome result of heat recovery.

RECOVERY OPTIONS

Heat recovery passively transfers (via a heat exchanger) or actively transfers (via a heat pump) residual heat, which would otherwise be lost, to either preheat or heat a cold water stream. Heat recovery reduces the energy required for heating the stream.

RECOVERY VIA HEAT EXCHANGERS	In a heat exchanger, the greywater or mixed wastewater passively transfers its thermal energy via conduction through metal plates or coils to a separate secondary stream, often colder water. This preheated water is then directed to the building's heating system or storage tank.
RECOVERY VIA HEAT PUMPS	A water-source heat pump can elevate the temperature of the cold water stream (also after heat recovery via heat exchanger) by actively extracting heat from the greywater or mixed wastewater stream via a vapor compression cycle that moves heat from one place to another.



T.61 HEAT EXCHANGERS & HEAT PUMPS

REUSE

STORAGE TO BUFFER SUPPLY & DEMAND

Heat in greywater and wastewater streams varies in depending on user behavior - of showers, dishwashers and washing machines. Not only does the volume and temperature of the flow vary, but the thermal energy in the flow is intermittent. Storing recovered heat is crucial to bridge supply (of recovered heat) and demand (for hot water or heating). Storing heat effectively ensures that it can be used when needed, such as during periods of low wastewater flow or high demand for hot water.

REUSE IN HEATING NETWORK

At scales beyond in-appliance recovery, the heat transferred to the secondary stream, can be used and distributed on site, for space heating or hot water, or into a larger heating network, via another heat exchanger. The heat can then be distributed to other users.

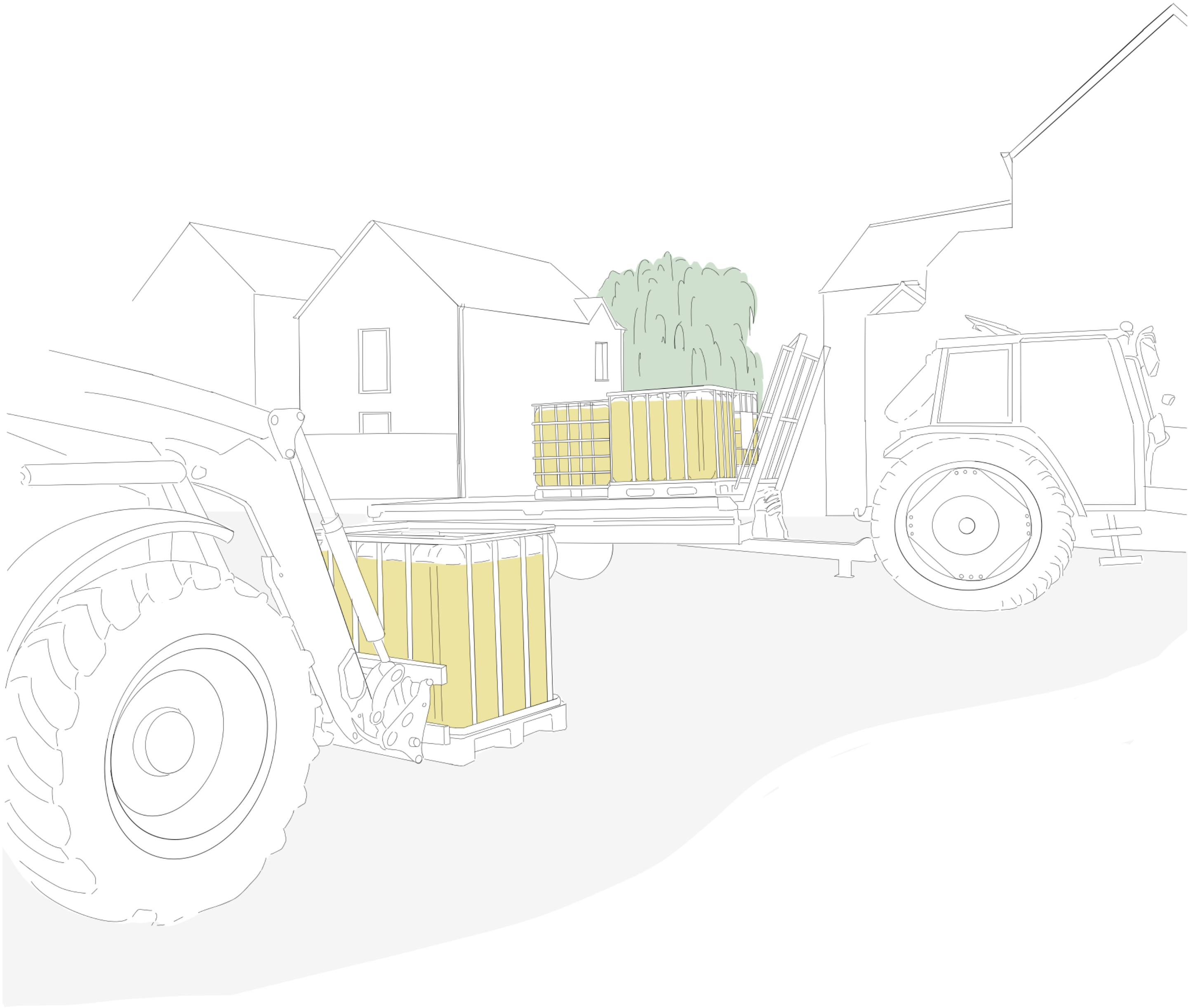
ENERGY SAVINGS

Energy reductions can lead to savings in utility bills over time and pay off initial investments. Calculated savings vary depending on 1) heat recovery efficiency and capacity of the heat exchanger and/or pump installed, 2) household size, 3) hot water usage, and 4) local energy rates.

T.1

URINE STORAGE | PASTEURIZATION

TECHNOLOGY



Extended storage of urine is the simplest, cheapest and most common method to hygienize urine. Urine storage achieves pathogen inactivation due to the combination of increased pH, temperature and time. Recommended storage time is at least six months. During storage, urea hydrolyses and decomposes into ammonium and ammonia, changing the organic composition of the urine and causing the pH of the solution to rise. The alkaline urine solution is a hostile environment for bacteria, protozoa, and viruses, which die off over time. Pathogen removal is variable, however. Hormones and organic micropollutants are not removed. To enhance pathogen inactivation and reduce treatment time, the temperature of stored urine can be raised (e.g., at 80 °C for 30 minutes). This process is called pasteurization. Adding a base (e.g., calcium hydroxide) or an acid to stored urine can also help control ammonia emissions, microbial growth and the stability of the urine during storage. Urine storage requires a lot of space.

Stored urine can be applied as a multi-nutrient liquid fertilizer in agriculture. It has a high nitrogen to phosphorus (N:P) ratio. However, pharmaceuticals and some pathogens are not sufficiently removed and can incur risks.

INPUT STREAMS	TARGET OUTPUT(S)
U Urine	Liquid Fertilizer
YW Yellow water	

L'ÔÔÔBERGE

Dol de Bretagne, France | 2023

Urine from residential complex collected for offsite treatment

L'Ôôôberge is a participatory social housing complex with 23 apartments equipped with dry sanitation. Urine, collected via a conveyor belt dry toilet, flows by gravity piping into three $5m^3$ underground cisterns. The pipes and tanks have ventilation and inspection manholes, and are connected to the sewer in case of overflow. Every six months, the urine is pumped into IBC tanks and trucked to a nearby farm for storage. The urine is reused in agriculture.

U — COLLECTION TANK — TRANSPORT — T.1 URINE STORAGE —

SPECIFICATIONS

INFRASTRUCTURE

After separate collection (via urine diversion toilet, urinal or jerrycan), urine can be piped directly to or manually carried to a storage tank onsite. For offsite treatment, urine can be trucked to a storage facility or farm. Urine storage requires space to accommodate the large volumes of collected urine (~ 0.25 m^3/person). Collection of yellow water (urine with flushwater) increases collection volumes, and can reduce treatment performance. For onsite storage, it is recommended to have more than one storage tank to alternate collection and storage between tanks. Some losses of volatile ammonia can occur with ventilation air during collection, causing unpleasant odor. Urine tanks should not be ventilated to prevent nitrogen losses. Since urine is highly corrosive, pipes and storage tanks should be made of resistant materials such as high-quality plastic or concrete; metals should be avoided.

Urine storage is a simple and cheap on-site treatment solution for off-grid contexts, and lends itself to contexts where urine collection is near to gardens or agricultural lands. In urban contexts, urine is often collected in a basement, however urine storage occurs off site, often in rural areas.

OPERATION & MAINTENANCE

Urine storage is a relatively cheap treatment, though storage space can be costly depending on availability and location. Maintenance requirements primarily concern the prevention or removal of precipitates in the pipes to prevent clogging and blockage. For off-site storage, periodic collection is required. Transport of large volumes can be difficult and costly for large distances. Often arrangements for storage and reuse are made with nearby farms. Use protective gear when handling fresh and stored urine to reduce pathogen risks.

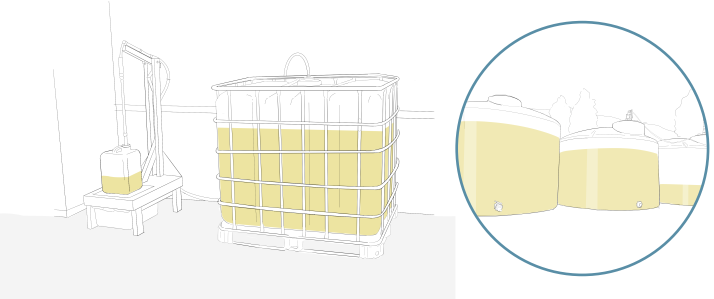
TARGET OUTPUT

Stored urine can be used as a multi-nutrient liquid fertilizer. Precipitates that settled in the tank can be mixed into the liquid fraction before application, or separated out from the liquid fraction (this increases the N:P ratio and removes essential compounds like magnesium and calcium from the liquid fraction). Urine can be applied directly to the soil or diluted before application. During application, nitrogen losses will occur and unpleasant odor is to be expected. Further inactivation of pathogens are likely to occur in the soil after application. Stored urine still contains hormones and pharmaceutical residues.

SELECTED CASE STUDIES

RICH EARTH INSTITUTE

Brattelboro, VT, USA | 2012



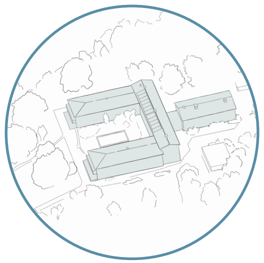
Community-scale urine collection and off-site pasteurization

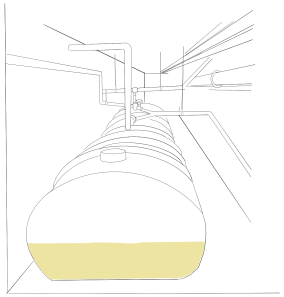
The Institute's Urine Nutrients Reclamation Program collects 45 m^3 of urine each year from home and business installations and via a portable toilet service. Some households bring their urine (in portable jerrycans) to a urine depot, while others have onsite plumbed collection tanks. Urine from both depots and tanks are periodically pumped out by truck and transported to the operations facility for treatment and storage, using an automated pasteurizer. The pasteurizer heats the urine to 80 °C for 1.5 minutes (energy = 20Wh/L). The treated urine is used at local farms to fertilize hay, nursery trees, sweet corn, flowers, and others.

U — COLLECTION TANK — TRANSPORT — T.1 PASTEURIZATION — TRANSPORT

GEBERS

Stockholm, Sweden | 1998





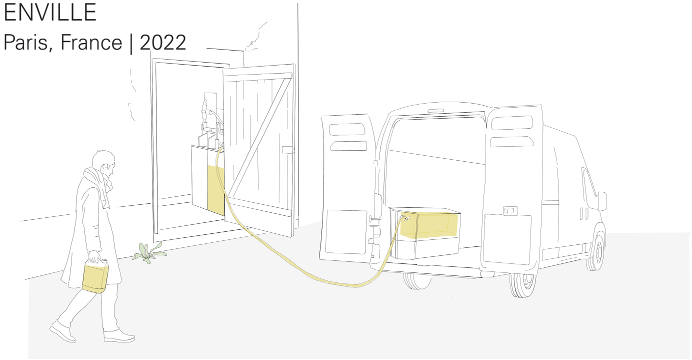
Urine collection and storage for fertilizer use on barley fields

Gebers is a two-story cooperative housing project of 80 inhabitants and 32 apartments located in Stockholm. Urine is collected via urine diverting low-flush toilet (0.1 L per flush) with dry collection of feces. Urine is led to three urine collection tanks (10-15 m^3) in the basement via polypropylene pipes. The tanks are emptied by tanker truck with a vacuum system two to three times per year, and stored off-site before use in agriculture.

YW — COLLECTION TANK — TRANSPORT — T.1 URINE STORAGE

ENVILLE

Paris, France | 2022



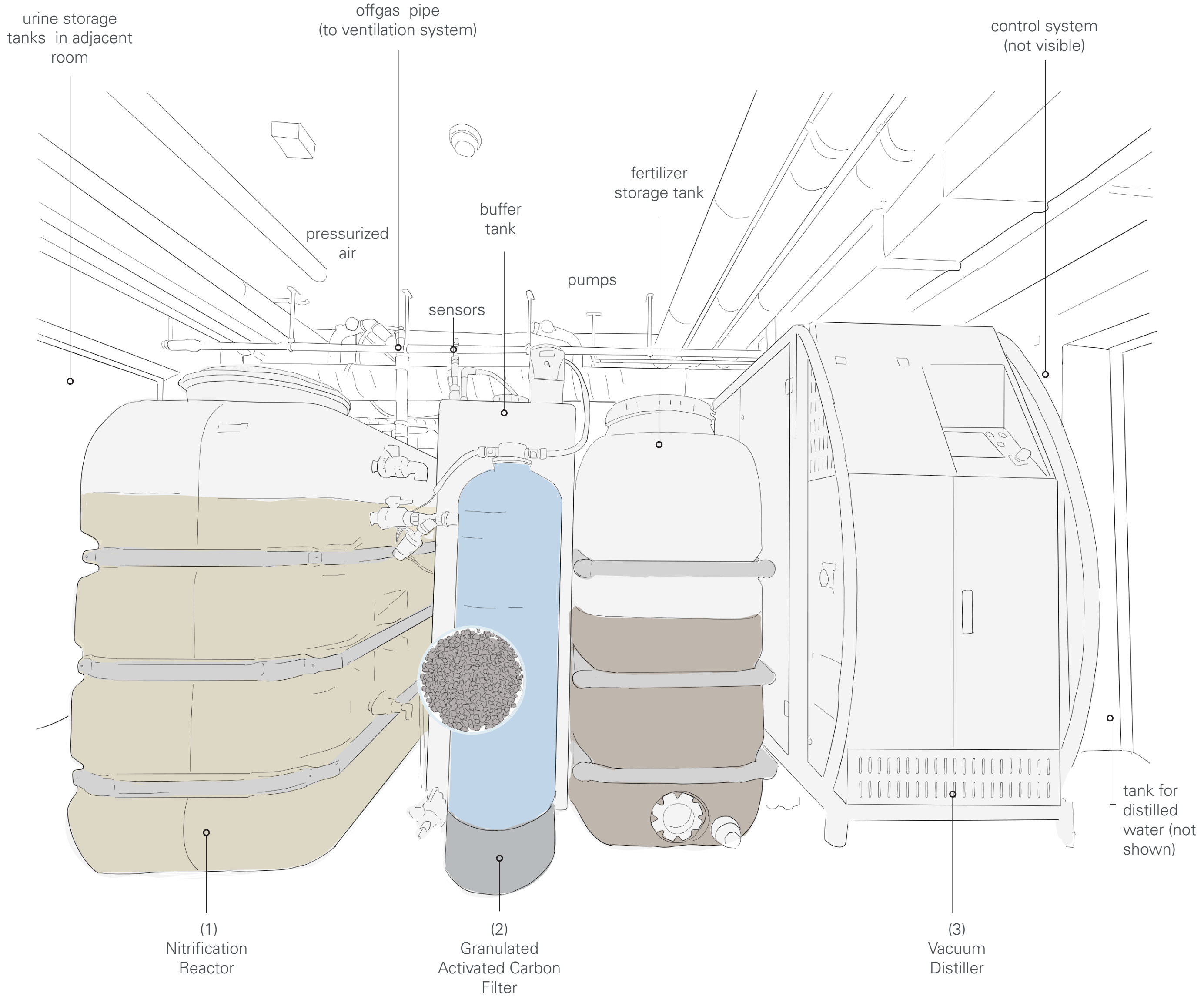
Citizen urine collection, stored and transported by partner farms

Enville, led by the OCAPI research and action program, is a project that enables community-scale collection of urine in cities, paired with transport, storage and reuse of urine at nearby farms. Individuals collect urine using funnel fixtures on jerrycans and periodically empty them at a urine "decanting" station equipped with two 130L tanks and an electric pump, appropriate ventilation and an overflow pipe to the sewer. The urine is transported by farmers that deliver food to the city, collect and transport urine in their vans equipped with 140L tanks (originally water tanks for camper vans) and bring the urine to the farm for storage and reuse as fertilizer.

U — JERRYCAN COLLECTION — COLLECTION DEPOT — TRANSPORT — T.1 URINE STORAGE

T.3 NITRIFICATION-DISTILLATION

TECHNOLOGY



YW — COLLECTION TANK — T.3 NITRIFICATION - DISTILLATION — distilled water

Nitrification-distillation of urine, also referred to as the VUNA process, is a treatment and complete nutrient recovery technology that converts urine into a liquid nutrient fertilizer through (1) biological treatment in an aerated reactor for the stabilization of carbon and nitrogen compounds, (2) activated carbon filtration for the removal of micropollutants and (3) vacuum distillation for the concentration (down to 5-10% of the original volume) and hygienization of the stream. It is a relatively high tech solution, best suited to treat urine flows of at least 500L/day (roughly 350 p.e.). The core of the treatment is the aerated bioreactor in which microorganisms aerobically degrade organics and convert ammonium to nitrate (a process known as nitrification), with residence times between 5-10 days.

The technology can be implemented in (and potentially retrofitted into) large "nutrient hotspot" buildings to alleviate the burden of N & P removal on municipal wastewater treatment. The produced fertilizer solution contains macro- and micronutrients that can be used in agriculture.

INPUT STREAMS	TARGET OUTPUT(S)
U Urine	Liquid Fertilizer
YW Yellow water	

FORUM CHRIESBACH

Dübendorf, Switzerland | 2006

Treatment of urine from three neighboring buildings

Forum Chriesbach includes urine-diverting flush toilets, urine piping, and a storage and treatment room at the underground level, where the VUNA process was developed and optimized. In 2021, two additional campus buildings with urine-diverting flush toilets were connected via piping to the treatment room. In 2022 the treatment system was renewed and scaled to treat the increased volumes of urine. The system treats ~400L/d in a mechanical room of ~50 m².

SPECIFICATIONS

INFRASTRUCTURE

Nitrification - distillation can treat large volumes of urine in a relatively small space, usually in a dedicated technical room at ground or underground level so that the storage tanks can be fed by gravity piping. The system can also be placed in a technical building. If multiple buildings are connected to a single treatment station, gravity piping can be used if sufficient slope can be granted (2 - 3% slope). Alternatively, intermediate tanks and lifting pumps are needed to convey the urine to the treatment station (see ●).

Potential incentives for the implementation of urine diversion coupled with treatment by nitrification-distillation include (1) savings at wastewater treatment plants, particularly those operating at capacity, (2) returns on investment through sales of the fertilizer produced, and (3) water recovery from the distillation process.

OPERATION & MAINTENANCE

Operation and maintenance is carried out by the service provider or trained personnel. The process is automated, with a control system and a series of sensors, and can be monitored remotely.

Energy: Energy is required mainly for the distillation process, and a small amount is needed for aeration and for pumps (to pump solutions between processes).
Consumables: The granular activated carbon filter for micropollutant removal is designed to be exchanged 1-2 times/year.
Byproducts: Distilled water is the main byproduct of the treatment and can either be disposed of to sewer (it contains traces of ammonia) or treated further for water reuse.

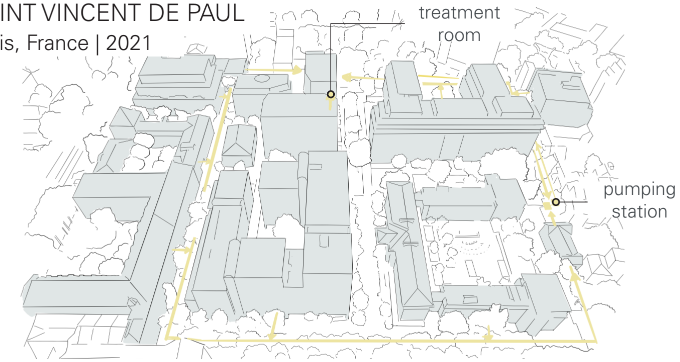
TARGET OUTPUTS

Nitrification-distillation produces a complete liquid fertilizer, with nitrogen (ammonium nitrate) phosphorus and potassium, and a broad range of micronutrients (e.g., iron, boron, zinc). The distillation step enables reuse in agriculture by hygienizing the solution and reducing its volume, facilitating its transport and application on field. Risk of ammonia volatilization during application is low thanks to the low pH (~4) and high solubility of ammonium nitrate. Fertigation, after dilution with water, is possible. The fertilizer has been authorized for sale in Switzerland, Lichtenstein, Austria and France.

SELECTED CASE STUDIES

SAINT VINCENT DE PAUL

Paris, France | 2021



Urine diversion and treatment at neighborhood scale

The renovated "eco-district" of Saint Vincent de Paul will include urine diversion on a neighbourhood scale to reduce the pressure on the municipal wastewater treatment plants discharging to the Seine. The urine piping system, consisting of three gravity pipes (spanning 500m) and one pressurized pipe with a pumping station, was built in 2021, before renovations and new construction. A treatment room in the basement will treat the collected urine from the urine diverting flush toilets and urinals. The fertiliser produced will be used by the parks and gardens services of the City of Paris.

YW — COLLECTION TANK — T3 NITRIFICATION - DISTILLATION — distilled water

KREISWERKE BARNIM (ZIRKULIERBAR)

Eberswalde, Germany | 2023

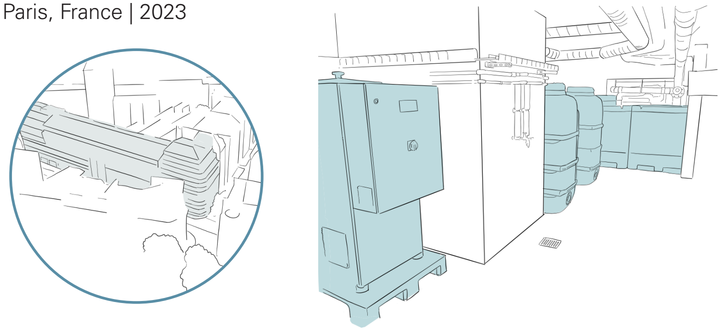
Nitrification-distillation of collected urine in centralized location

Urine collected from public composting toilets and waterless urinals is transported to a recycling center. The urine is stored in IBC tanks next to a shipping container which houses the technology. The produced liquid fertilizer will be used in field tests in nearby agriculture.

U — COLLECTION TANK — T3 NITRIFICATION - DISTILLATION — distilled water

EUROPEAN SPACE AGENCY

Paris, France | 2023



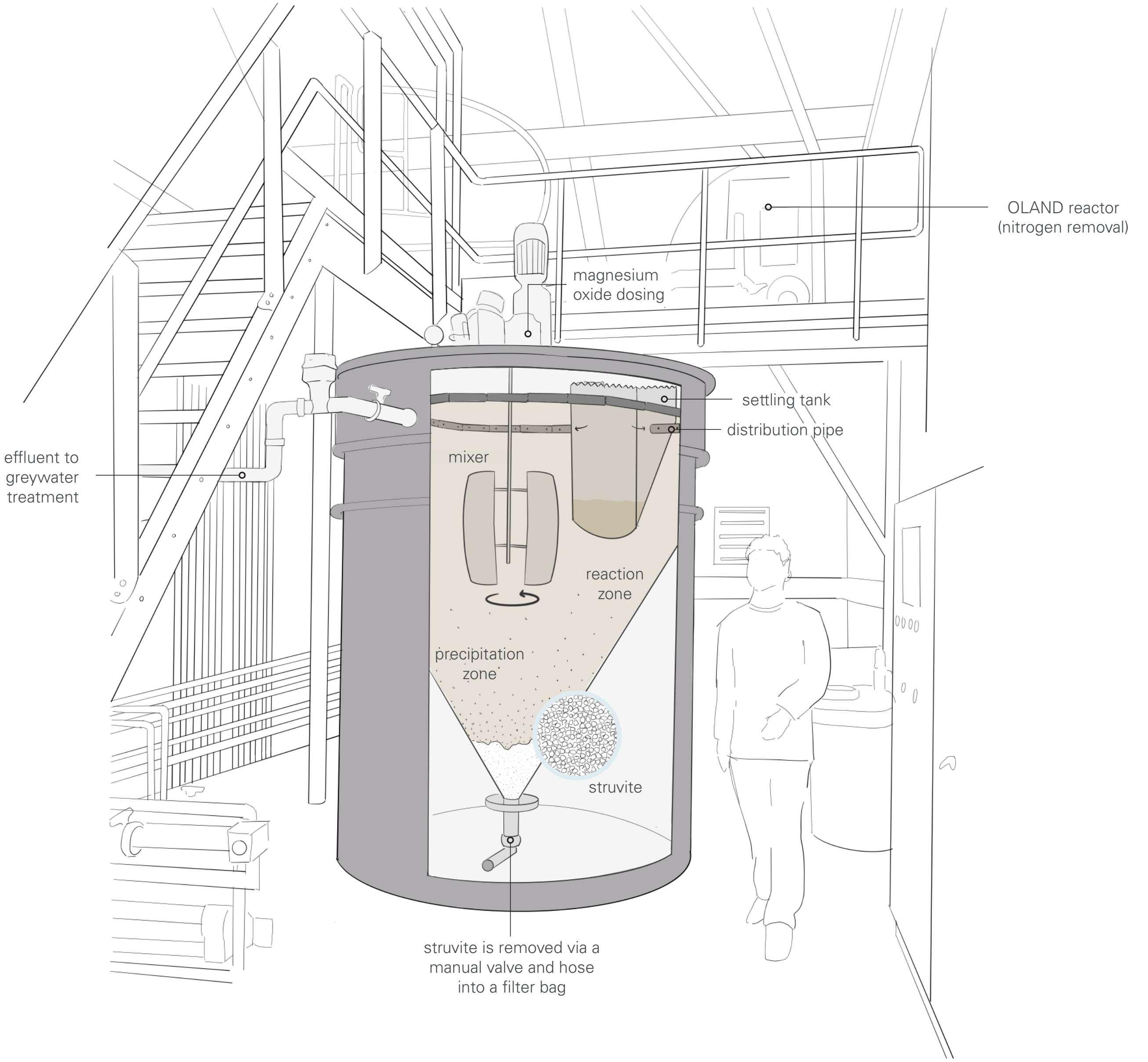
Nitrification-distillation fit into newly refurbished office building

During the complete renovation of ESA's headquarters in 2023, urine diverting toilets and a dedicated urine piping system were installed. A nitrification-distillation system, set up in a technical room in the basement of the building, treats the yellow water from the building's 72 toilets and converts it into the liquid fertilizer known as "Aurin". The system is designed to process 200L/d.

YW — COLLECTION TANK — T3 NITRIFICATION - DISTILLATION — distilled water

T.4 STRUVITE PRECIPITATION

TECHNOLOGY



Struvite precipitation is a nutrient recovery technology that uses a chemical reaction to form magnesium ammonium phosphate hexahydrate ($MgNH_4PO_4 \cdot 6H_2O$), or MAP. To induce and increase precipitation in a nutrient-rich solution, such as urine or wastewater, magnesium is added to the reactor. Mixing inside the tank provides contact between the solution and magnesium. Struvite can be removed from the tank after settling or via sieving. High recovery of phosphorus (90%) can be achieved in many applications. The solid struvite crystals can be easily separated from the solution and dried, to render an odorless powder. Struvite is a bioavailable, slow release fertilizer that can be stored, transported and easily applied to fields. Alternatively it can be an input for the production of conventional NPK fertilizers.

> The precipitation of MAP is chemically favored. However, in the absence of ammonium, magnesium potassium phosphate $MgKPO_4 \cdot 6H_2O$, or MPP, is formed. Both can be reused as fertilizer; MPP is more soluble than MAP.

INPUT STREAMS

- U Urine
- BW Blackwater, effluent
- MW Mixed wastewater, effluent

TARGET OUTPUT(S)

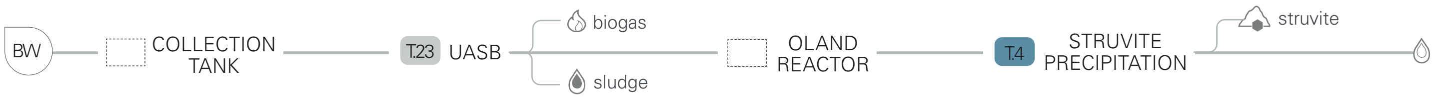
- Struvite

NOORDERHOEK

Sneek, the Netherlands | 2008

Struvite recovery from blackwater and kitchen waste

In a neighborhood of 232 households (~400 residents), vacuum-collected blackwater and kitchen waste are transported together via a vacuum sewer to a treatment facility. The concentrated stream is anaerobically treated in a UASB followed by an OLAND (Oxygen Limited Autotrophic Nitrification Denitrification) reactor for nitrogen removal. Lastly, phosphorus is recovered via struvite precipitation, in a semi-batch struvite reactor with magnesium oxide dosing.



SPECIFICATIONS

INFRASTRUCTURE

Struvite precipitation requires pipes, tanks and storage systems that are resistant to scaling and corrosion. The reactors are usually placed in a mechanical room and need to be equipped with magnesium dosing, mixing mechanisms and struvite harvesters or settlers. To optimize precipitation, pumps, valves, and monitoring instruments help to adjust the flow rate, pH, temperature and chemical dosing.

OPERATION & MAINTENANCE

Operation of struvite precipitation includes the monitoring of optimal conditions for precipitation, including monitoring pH, magnesium dosing, and flow rates. The relevant pumps and control units also need periodic maintenance. Handling and storage of magnesium salts need to be ensured. Struvite can cause scaling and blockages in pipes and equipment if not well maintained, especially caused by spontaneous precipitation upstream of precipitation reactors. Periodic inspection and cleaning is required.

TARGET OUTPUTS

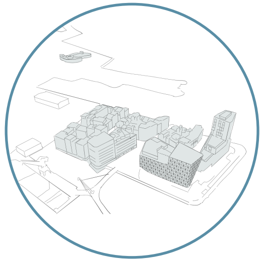
Struvite precipitation is the targeted recovery of phosphorus, which under optimal conditions can result in more than 90% recovery. Struvite can be used for crop fertilization. It provides phosphorus, magnesium, and ammonium in a slow-release form. Struvite can contain pathogens and heavy metals that were present in the input stream. Further treatment of struvite (e.g., washing, drying) can further remove pathogens. Heavy metal levels are usually low, especially when struvite is precipitated from source-separated streams, like urine or blackwater. Farmer acceptance is generally positive if product quality is consistent, granulated and easy to apply, however, market development and regulatory readiness are needed for broader struvite adoption.

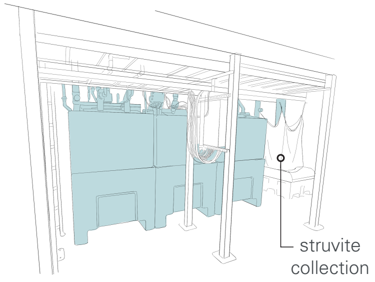
Struvite can be directly used in agriculture as a slow release fertilizer, though the low nutrient solubility and nutrient ratios may not meet full crop nutrient requirements. Struvite application rates may need to be adjusted compared to conventional phosphate fertilizers. Alternatively, struvite can be used in industrial fertilizer manufacturing to produce standard NPK fertilizers.

SELECTED CASE STUDIES

OCEANHAMNEN

Helsingborg, Sweden | 2021



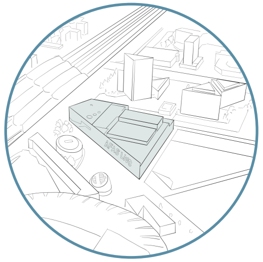


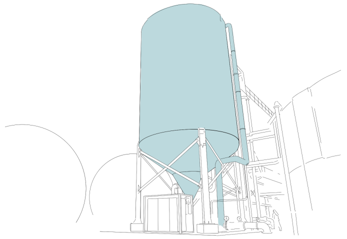
Struvite recovery from effluent from two anaerobic digesters

Oceanhamnen is a waterfront development that has a "three-pipes out" collection of greywater, vacuum-collected blackwater and kitchen waste scaled for 2100 p.e., treated at the Recolab building. The blackwater is digested in a UASB, the kitchen waste in an anaerobic CSTR. The effluent undergoes struvite precipitation and ammonia stripping for nutrient recovery. The struvite will be used together with hygienized sludge to produce fertilizer pellets. The Swedish national sludge certifications and EU end-of-waste regulations have facilitated the production and use of such pellets.

AFAS LIVE

Amsterdam, the Netherlands | 2013



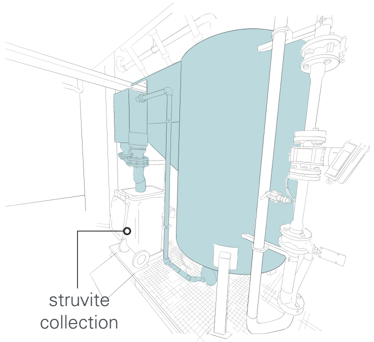


Struvite recovery from urine at centralized location

At an event complex, 54 waterless urinals divert urine to a collection tank (13 m³) in the parking garage. When the tank is full, it is transported to the centralized wastewater treatment plant for struvite recovery, used in fertilizer production.

NIEUWE DOKKEN

Ghent, Belgium | 2012



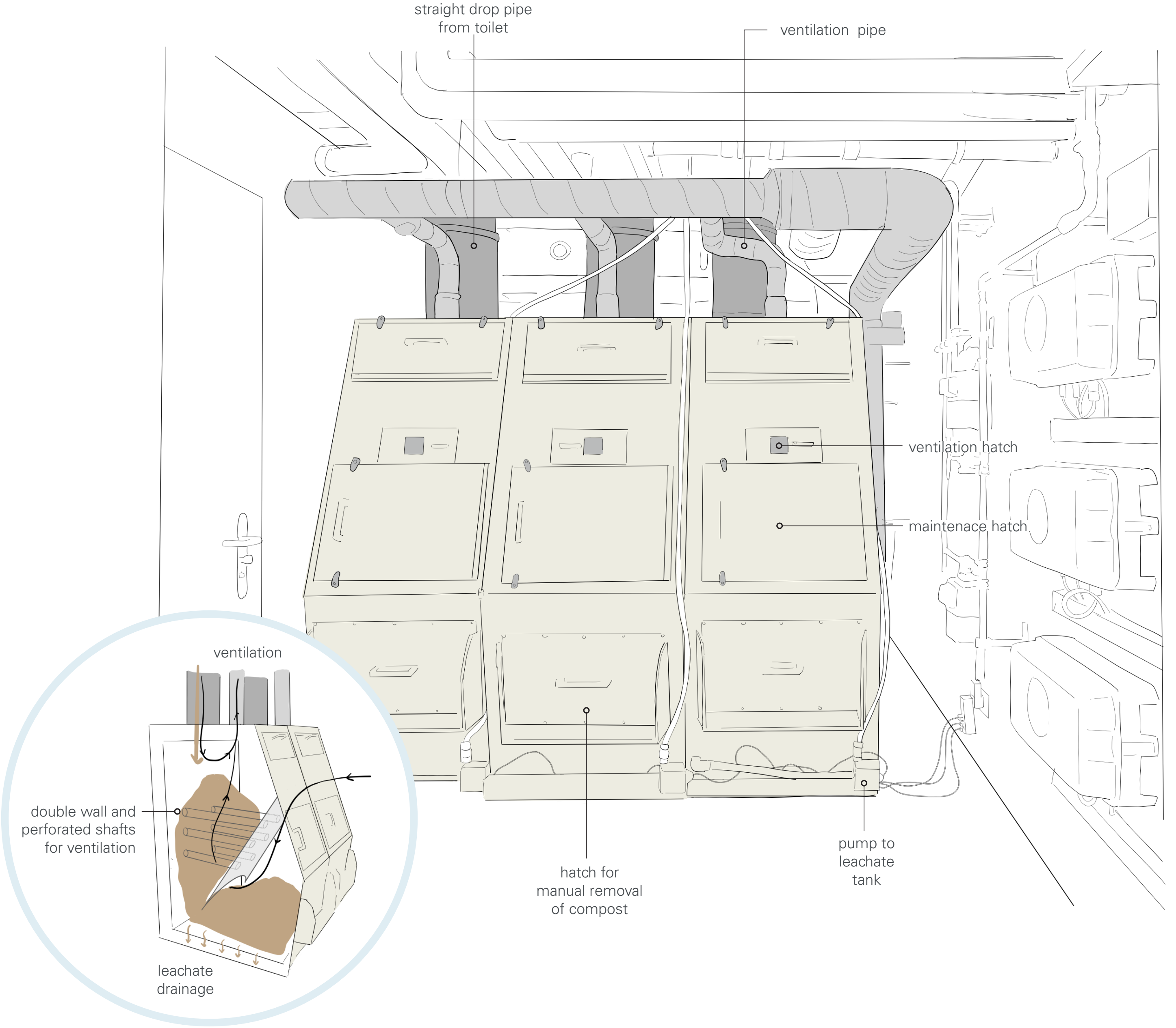
Struvite precipitation after anaerobic treatment

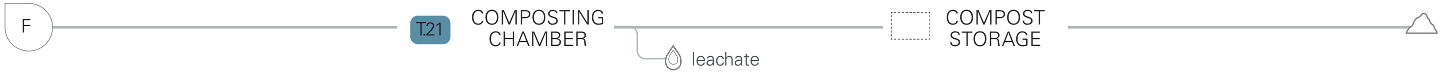
The residential and commercial district is situated in a former industrial area. The vacuum-collected blackwater is treated in an underground mechanical room in several UASB reactors, together with ground kitchen waste. The aerobic sludge from the greywater treatment also goes into the digester. The produced biogas is converted to energy (~600 MWh/year) via a combined heat and power (CHP) unit and fed into the district heating network. The effluent from the digester undergoes struvite precipitation, for struvite recovery (~ 1.2 tons/y).

T.21

ON-SITE COMPOSTING

TECHNOLOGY

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T21 COMPOSTING CHAMBER

leachate

COMPOST STORAGE

Composting is the microbial degradation of organic matter under aerobic conditions to a humus-like product: compost. Composting requires a specific carbon to nitrogen (C:N) ratio, moisture content, and oxygen flow to reach temperatures for optimal degradation and sanitization. On-site composting, often in chambers or containers, achieves mesophilic conditions (20-45 °C), but not thermophilic conditions (45-70 °C). Composting in chambers can be designed to facilitate passive and active aeration and to separate excess leachate from the pile. Often manual turning/watering is required for operation. Vermicomposting, relies on both earthworms and microorganisms for the degradation of organic matter. The worms provide aeration of the compost pile, via borrowing, and reduce the volume of the compost significantly. Volume reduction achieved during composting and vermicomposting allows for long residence times (months to years).

Compost and vermicompost are rich in organic matter and nutrients and can be used as soil amendments in agriculture. Sufficient stabilisation and sanitization need to be considered to prevent human and environmental health risks.

INPUT STREAMS

- F Feces
- Ex Excreta
- BW Blackwater, vacuum-collected

TARGET OUTPUT(S)

- Soil amendment, compost

CRESSY

Geneva, Switzerland | 2011

One composting chamber per apartment

Each of the 13 apartments in this cooperative building (~ 45 residents) is connected to a composting chamber in the basement via a 32 cm diameter straight drop pipe directly below the toilet. A ventilation pipe connects each of the chambers to the building's central ventilation system. Residents manage the chambers themselves. Compost is used in the garden after further maturation, while excess leachate is sent to the sewer.

SPECIFICATIONS

INFRASTRUCTURE

Composting chambers are typically placed indoors (sheltered from low temperatures) in treatment rooms directly below toilets and drop pipes. This limits the amount of stories the building can have, and takes up a considerable amount of space in the building. Composting chambers are made of durable, moisture-resistant materials (e.g., reinforced plastic, stainless steel, concrete). Ventilation is key: pipes, chambers and mechanical rooms can be connected to the building's central ventilation system. To reach and maintain higher temperatures, chambers can be insulated. Backyard composting in dedicated bins requires a safe conveyance plan for the transport of feces from the dry toilet to the outdoor container, a base platform to prevent groundwater contamination, a roof to prevent rainwater infitration, and coverings or screens to prevent pest entry. For both indoor and outdoor composting, adequate drainage for and management of leachate should be considered.

> Simple vermicomposting is often implemented in alpine huts as a robust and low-maintenance solution.

OPERATION & MAINTENANCE

Operation and maintenance of decentralized composting or vermicomposting is relatively simple and can be carried out by the users/residents themselves. Depending on the chamber or container design and stream treated, varying operational measures may be required, for example, the addition of a bulking material (e.g., wood chips, saw dust) to adjust the carbon to nitrogen (C:N) ratio, the manual turning of the fresh compost to increase oxygen supply, or the watering of the compost (with water or leachate) to increase moisture. Energy use is small depending on the configuration and design selected (i.e., energy may be used for active ventilation, mixing, temperature control or pumps. Mature compost must be removed manually (usually no more than twice per year, in some cases after many years).

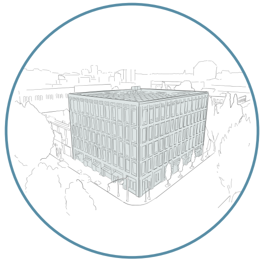
TARGET OUTPUTS

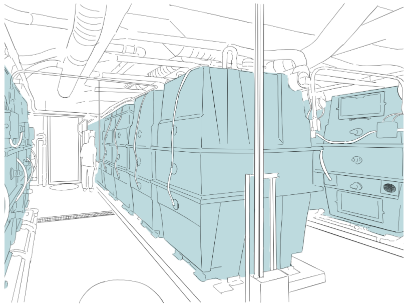
Feces-derived compost is a product rich in organics and nutrients that can be used as a soil amendment with a low nitrogen to phosphorus (N:P) ratio. In practice, optimal conditions for the composting process (e.g., C:N ratio, moisture, temperature, oxygen) are difficult to maintain in decentralized configurations. Moreover, in vermicomposting, the high temperatures considered necessary to obtain a safe compost product (50 °C over a period of a week) are not reached to not harm the worms. As a result, the output products are often not sufficiently stabilized and sanitized, and require safe handling and further treatment/maturation (e.g., via prolonged storage or secondary composting – see T.22).

SELECTED CASE STUDIES

PAE BUILDING

Portland, OR, USA | 2020





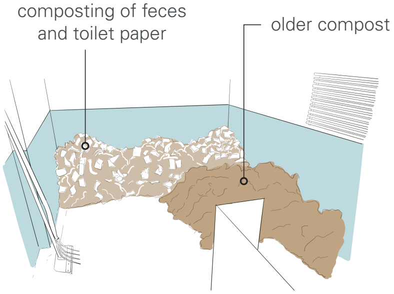
On-site composting from vacuum-collected blackwater

Vacuum-collected blackwater from the toilets of the five-story office building is first collected in an underground tank. It is then equally distributed by means of a manifold, pump, and control system over the 20 composting chambers in a mechanical room on the ground floor. The whole system (including the mixing of the chambers) is run automatically but requires consistent maintenance and monitoring. The compost is used on-site. Leachate from the chambers, as well as urine from male urinals, is collected in tanks for further nitrogen and phosphorus recovery.

BW — T.21 COMPOSTING CHAMBERS — leachate

GRIALETSCH HUT

Zernez, Switzerland| 2021



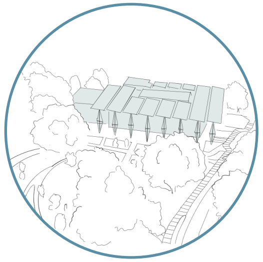
Vermicomposting of feces in alpine hut

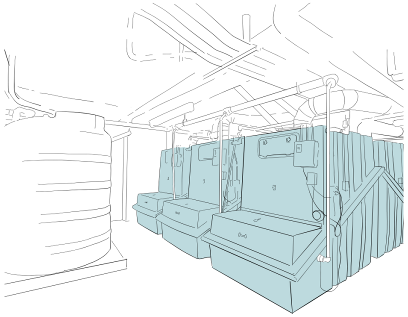
Located at 2542 m above sea level in the Swiss alps, this mountain hut hosts circa 6000 overnight-guests per year. The renovations in 2021 included urine-diverting dry toilets and onsite greywater treatment. Feces are collected via urine-diverting, conveyor-belt toilets and fall directly into a dedicated composting room below forming vermicomposting heaps on the floor. Maintenance includes sporadic watering, and turning once or twice a year. The compost is retained for several years and used onsite for landscaping. The urine is led to a trickling filter together with greywater for treatment before infiltration.

F — T.21 VERMICOMPOSTING HEAPS

KENDEDA BUILDING

Atlanta, GA, USA | 2017





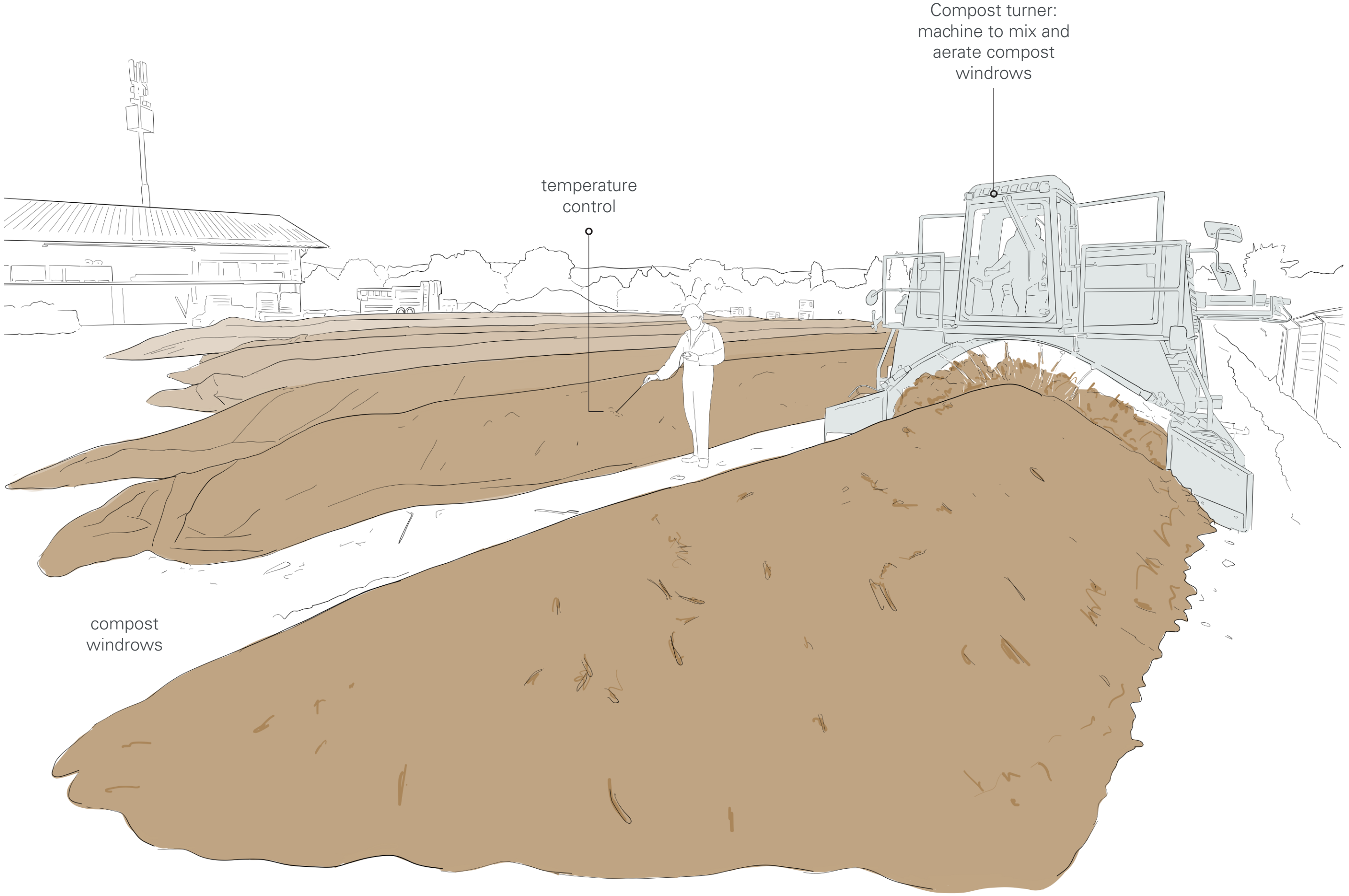
University building with foam flushing toilets

In this two-story building, excreta from 12 foam-flush toilets is treated in six mesophilic composting chambers in the basement. The toilets use biodegradable foam and < 90 mL of water per flush. Bulking materials (such as pine shavings) are added and manually mixed via the access hatch at the top. In the composting chamber, microrganisms, fungi, insects, and earthworms stabilize the excreta. Leachate from the composters is pumped to two adjacent $3\ m^3$ tanks, and transported offsite for use as fertilizer in drip irrigation. The compost is removed every few years for use as a soil amendment.

Ex — T.21 COMPOSTING CHAMBERS — leachate

T.22 OFF-SITE COMPOSTING

TECHNOLOGY



Composting is the microbiologial degradation of organic matter to a humus-like stable product. Composting requires a specific carbon to nitrogen (C:N) ratio, moisture content, and oxygen flow to reach temperatures for optimal degradation and sanitization. Off-site composting, where waste is collected and transported to a dedicated facility, is often larger and more controlled compared to on-site setups. Controlled mixing, aeration and moisture levels, along with adequate retention of the heat generated in the compost matrix to transition from mesophilic conditions to thermophilic conditions (45-70 °C), ensure a well-managed compost process. Microorganisms that tolerate high temperatures, break down organic matter, reducing the volume of the waste. High temperatures kill pathogens. Off-site composting often occurs in aerated static piles, windrows (tuned regularly), or in-vessel systems (containers with precise control). Additional waste feedstocks or bulking agents, such as food scraps, garden waste, animal manure, sawdust, straw, can be added to the fecal waste to improved feedstock characteristics. This is referred to as co-composting.

INPUT STREAMS

- F Feces
- Ex Excreta
- BW Blackwater, sludge

TARGET OUTPUT(S)

- Soil amendment, compost

VALOO IMPACT PROJECT | KOMPOTOI

Uster, Switzerland | 2022

Co-composting of excreta from public dry toilets

During this pilot project, contents from dry toilets (i.e., urine, feces, toilet paper and sawdust) were composted together with green waste, soil, and mature compost. The dry toilet contents accounted for 13-16% of the total feedstock. The quality of the compost was analyzed for pathogens and pharmaceuticals. In collaboration with local authorities, this project contributed to a Swiss regulatory framework for the composting of fecal-based materials.

Ex — COLLECTION — TRANSPORT — T22 WINDROW COMPOSTING —

SPECIFICATIONS

INFRASTRUCTURE

Off-site composting at a dedicated facility generally requires access roads suitable for trucks transporting waste and compost. A weighbridge can be useful to weigh incoming and outgoing materials. To prevent leachate infiltration, an impermeable surface and drainage and collection mechanisms for leachate should be included in the site layout. Composting often requires enough space to prepare (shred/grind) the incoming material, compost, mature, and screen the compost. Plastic coverings are often used to provide insulation and maintain high temperatures. Access to water for moisture adjustments and access to power to operate blowers and machinery is needed.

OPERATION & MAINTENANCE

To achieve thermophilic conditions, composting relies on precise process control including: feedstock management to maintain optimal carbon-nitrogen ratio and moisture levels, temperature management and control to achieve high temperatures for thermal sanitization, and aeration to ensure aerobic degradation, and reduce odors. Periodically measuring temperature and moisture content, as well as taking samples for lab analysis should be carried out by personnel. Equipment should be serviced and cleaned periodically, and drainage channels cleared.

TARGET OUTPUTS

Under optimal conditions, off-site composting produces a pathogen free, stable, and mature, soil amendment rich in organics and nutrients. The nutrient content of compost varies depending on the feedstock (e.g., urine inclusion), and the composting process (e.g., addition of bulking agents, composting duration). Compost is typically characterized by a low nitrogen to phosphorus (N:P) ratio and as a slow-release fertilizer, meaning that the nutrients mineralize slowly for plant availability. Compost use in agriculture should comply with local regulations.

Compost, while rich in organic matter and nutrients requires sufficient stabilisation and sanitization before soil application to prevent human and environmental health risks.

SELECTED CASE STUDIES

LA FUMAINERIE

Bordeaux, France | 2019

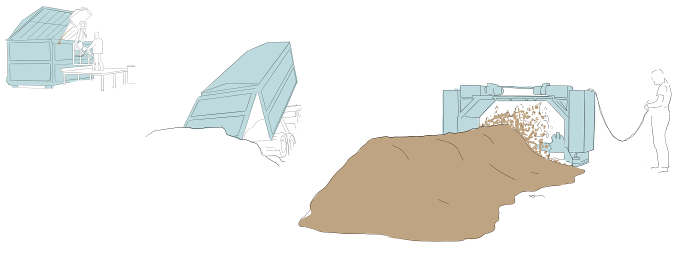
Chamber composting of collected feces in urban context

This non-profit organization works to promote dry sanitation and the management of human excreta. The organization collects jerry cans of urine and bins containing feces from urine-diverting dry toilets from 35 households (ca. 99 individuals) in Bordeaux. At a treatment facility, the feces are co-composted with green waste and food scraps in a closed chamber (~ 30 kg in the chamber) with mechanical aeration and mixing, and temperature control. After 8 weeks of composting and 6 - 8 weeks of maturation, the compost is reused for landscaping.

F — COLLECTION — TRANSPORT — T.22 COMPOSTING CHAMBER

KREISWERK BARNIM (ZIRKULIERBAR)

Eberswalde, Germany | 2019



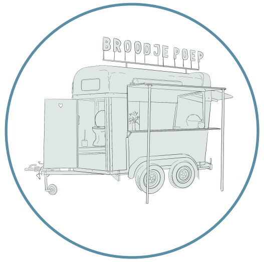
Windrow composting of human excreta from dry toilets

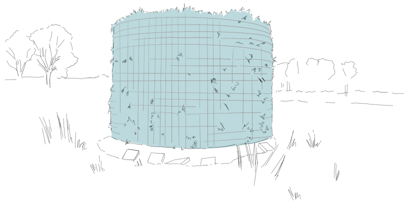
This is Germany's first recycling facility for the production of fertilizers from separately-collected feces and urine from dry toilets. After transport to the facility, the feces (and toilet paper) are first sanitized at 70 °C for 7 days in dedicated aerated "hygienization containers" to inactivate pathogens. The heat is generated by the microbial activity in the aerated container. Next, the sanitized organic matter is composted in windrows, together with other selected aggregates, and turned daily. Finally, the compost is sieved. The treatment facility can process about 200 m^3 of solids at one time, and the composting process takes 6 - 8 weeks.

Ex — COLLECTION — TRANSPORT — SANITIZATION — T.22 WINDROW COMPOSTING

BROODJE POEP

Groningen, Netherlands | 2015





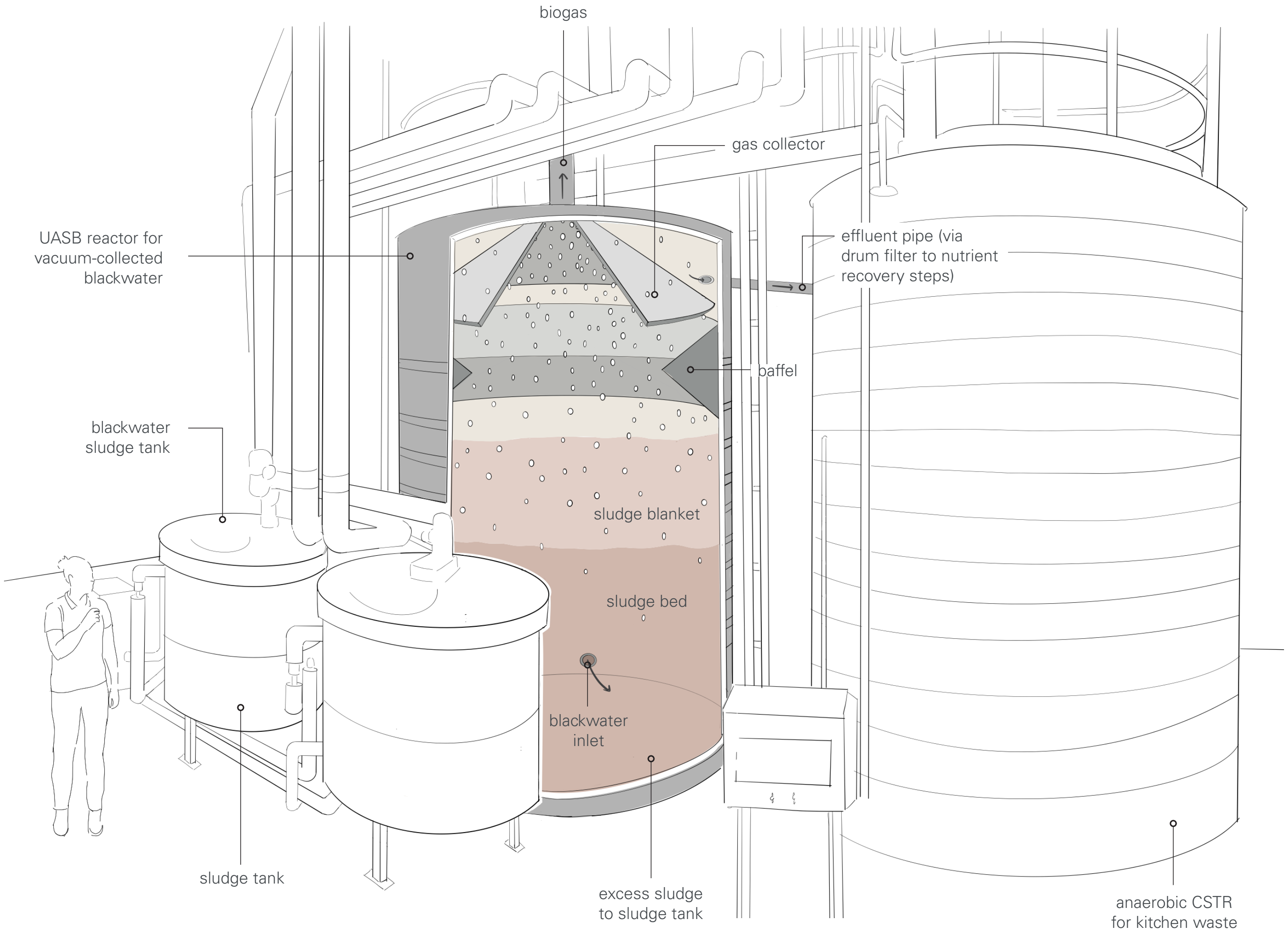
"Biomeiler" composting for nutrient and heat recovery

The Broodje Poep food truck is a social design initiative that not only prepares sandwiches, but also has a dry toilet on the side. The collected excreta are transported to a treatment facility for composting in a biomeiler system. A biomeiler (~ 35 m^3) includes an outer bufferzone of hay bales, filled with organic materials for aerobic composting, including: excreta, wood chips, sawdust, hay bales that have absorbed urine (collected from festivals), and urine. Water circulating through pipes embedded within the compost pile recover heat (~1 kW) generated in the pile. After two years, the compost is reused in agriculture to grow ingredients for the sandwiches.

Ex — COLLECTION — TRANSPORT — T.22 COMPOSTING

T.23 ANAEROBIC DIGESTION

TECHNOLOGY



Anaerobic digestion is the degradation of organic matter by microorganisms in the absence of oxygen. The technology is well-suited for wastewater and wastes with high levels of organic matter, yielding biogas, a mix of 50-75 % methane (CH_4) and 25-50 % carbon dioxide (CO_2), a reduced and stabilised sludge volume and an effluent. Anaerobic digestion spans a four-stage process in which different bacteria work to break down the carbohydrates, proteins and fats into sugars, acids, and finally, biogas. Temperature, sludge retention time (SRT) and pH are determining parameters for process performance. Typical anaerobic reactor configurations for concentrated separated household streams include Upflow Anaerobic Sludge Bed (UASB) reactors, Anaerobic Baffled Reactors (ABRs) and Continuous Stirred-Tank Reactors (CSTRs). These anaerobic reactors vary in design, operation, retention time, and biogas production.

Biogas can be used as a renewable energy source (heat and electricity). Methane is a greenhouse gas 28 times more potent than carbon dioxide. Recovering it can avoid its emission to the atmosphere.

INPUT STREAMS

- BW Blackwater
- MW Dewatered mixed wastewater

TARGET OUTPUT(S)

- Biogas
- Solid fraction, sludge
- Liquid fraction, effluent

OCEANHAMNEN, RECOLAB

Helsingborg, Sweden | 2021

Two anaerobic digesters to treat blackwater and kitchen waste

This waterfront development that has a "three-pipes out" collection of greywater, vacuum-collected blackwater and kitchen waste scaled for 2100 p.e., treated at the Recolab building. The blackwater is anaerobically treated in a UASB. The sludge is sent to the wastewater treatment plant next door for further treatment. The effluent undergoes struvite precipitation and ammonia stripping for nutrient recovery; in the future, the effluent will join the greywater treatment.


BW

COLLECTION TANK

T.23 UASB

biogas

sludge

T.42 DRUM FILTER

T.4 STRUVITE PRECIPITATION

struvite

T.5 AMMONIA STRIPPING

ammonia salts

SPECIFICATIONS

INFRASTRUCTURE

Anaerobic digester types span simple to more complex configurations and require expert design and construction. Digesters can be built in prefabricated tanks, or in steel, concrete or brick tanks. They can be placed below or above ground. Low-rate reactors (e.g., ABRs, CSTRs) often have larger footprints compared to high-rate reactors (e.g., UASB). Depending on the type of reactor and amount of inoculum, reactors may require a start up time of several months to establish the microorganisms for treatment. For most configurations, inflow and outflow design is specifically crucial, to regulate influent distribution, optimize hydraulic retention times (HRTs), safely collect produced biogas, and remove sludge. For configurations that require mechanical mixing, running pumps or heatoing, access to energy is necessary. The biogas produced can often be used to heat and power the digester, as well as the building.

OPERATION & MAINTENANCE

Anaerobic systems rely on skilled operators to monitor the reactor and/or repair parts. Operational activities include: temperature, pH and gas production monitoring to ensure stable microbial activity, biogas system cleaning and inspections to prevent leaks and corrosion, and periodical digestate/sludge removal and safe handling. Digester maintenance include periodic servicing per manufacturer schedules, calibration of sensors and safety systems, and replacement or repair of parts (often minimal if well-designed).

TARGET OUTPUTS

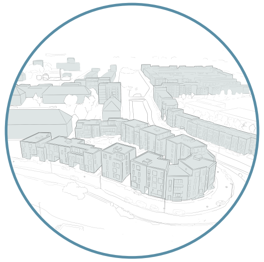
Anaerobic digestion yields biogas, sludge and effluent. The produced biogas can be converted into heat in a burner or used in combined heat and power (CHP) systems for electricity and heat. The digestate or sludge, rich in organics and nutrients, can be used as a soil amendment, however further treatment is recommended (e.g., composting, drying, pasteurization) before soil application to inactivate pathogens. The effluent can be treated for nutrient removal or nutrient recovery, and water reuse. Struvite precipitation, for phosphorus recovery, or ammonia stripping, for nitrogen recovery, allows for targeted nutrient extraction from the effluent; aerobic treatment, filtration and disinfection to achieve a water quality suitable for reuse.

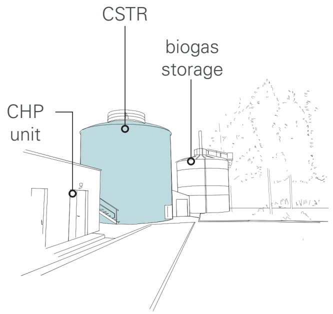
Soil application of sludge/digestate are beneficial for soil fertility, structure, water retention and microbial activity. Pathogen and heavy metal risks remain. These are often lower compared to sewage sludge or animal manure application and can be mitigated through additonal treatment and appropirate application measures. Persistent micropollutants also need to be considered before application.

SELECTED CASE STUDIES

JENFELDER AU

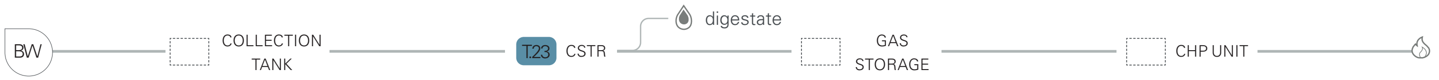
Hamburg, Germany | 2013





CSTR for digestion of blackwater and grease trap sludge

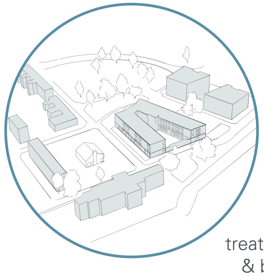
Vacuum-collected blackwater from this neighborhood (~2000 residents) is transported through a 3.7km underground vacuum sewer network to a treatment facility. It is fed fed into a 900m^3 CSTR, together with grease trap sludge from commercial kitchens. The biogas is converted by an onsite combined heat and power (CHP) unit into ~450,000 kWh of electricity and 690,000kWh of heat per year. This is enough to meet the electricity demand of ~225 Hamburg households and heat demand of 70 households. The digestate is sent to sewer as reuse in agriculture is currently not permitted.

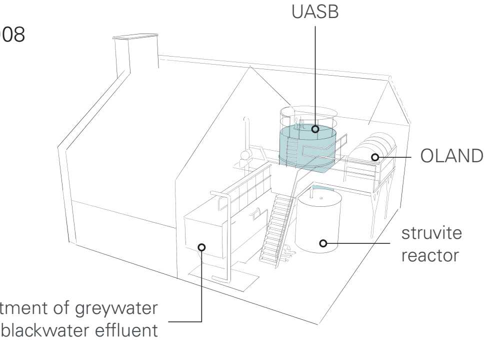


BW
COLLECTION TANK
T.23 CSTR
digestate
GAS STORAGE
CHP UNIT

NOORDERHOEK

Sneek, the Netherlands | 2008





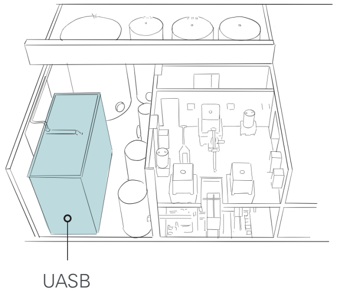
Flagship anaerobic treatment of blackwater and kitchen waste

In a neighborhood of 232 households (~400 residents), blackwater from vacuum toilets and kitchen waste, collected via kitchen grinders, are transported together via a vacuum sewer to a centralized treatment facility. The concentrated stream is digested in a UASB. The effluent from the digester flows through an OLAND (Oxygen Limited Autotrophic Nitrification Denitrification) reactor for nitrogen removal and then struvite precipitation for phosphorus recovery. The effluent is treated together with the greywater in an activated sludge system.

BW
COLLECTION TANK
T.23 UASB
biogas
sludge
OLAND REACTOR
T.4 STRUVITE PRECIPITATION
struvite

DE NIEUWE DOKKEN

Ghent, Belgium | 2020



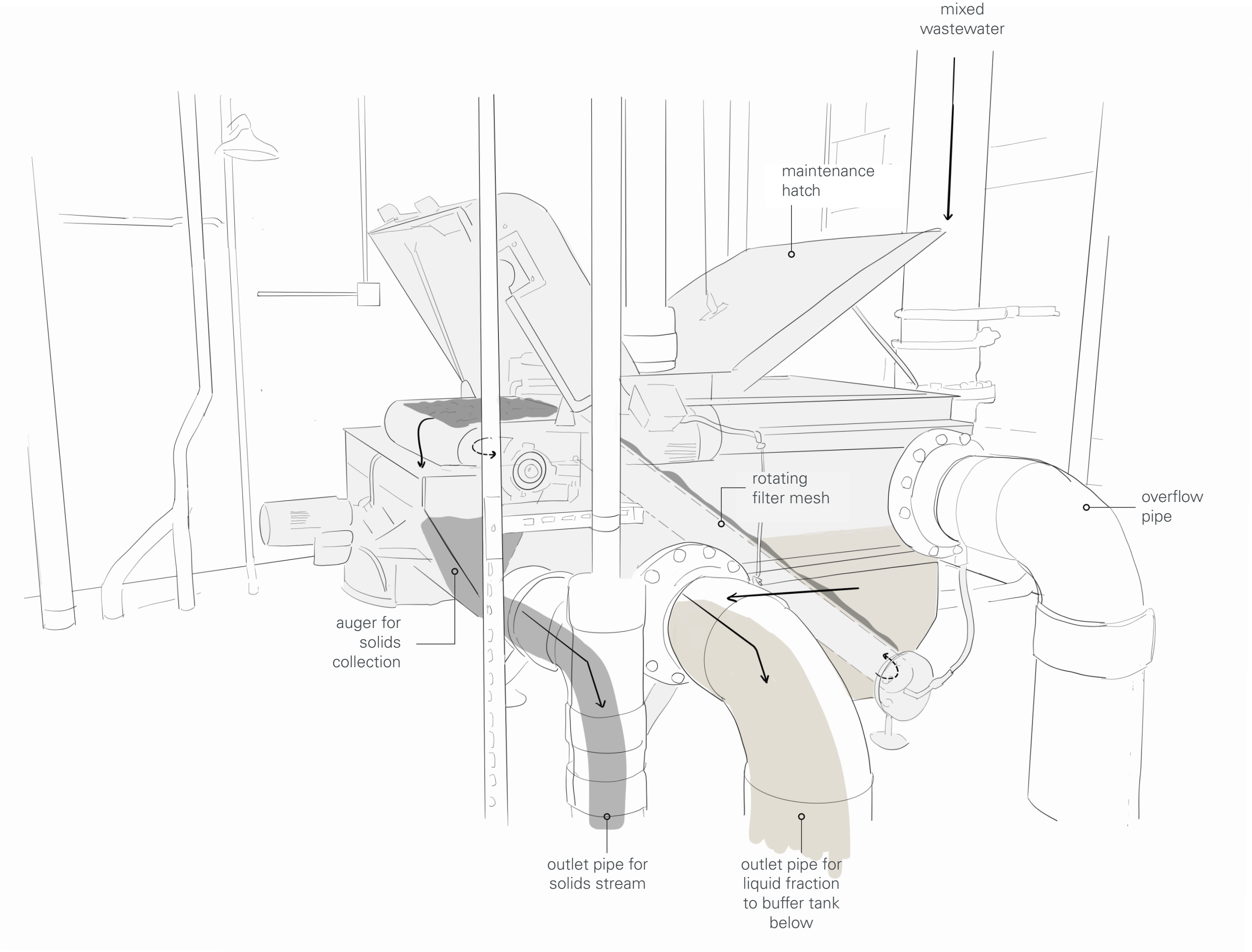
UASB with struvite precipitation

The residential and commercial district (ca. 1200 p.e.) is situated in a former industrial area. The vacuum-collected blackwater is treated in an underground mechanical room in several UASB reactors, together with kitchen waste collected via communcal depots for grinding and conveyance. The aerobic sludge from the greywater treatment also goes into the anaerobic reactor. The produced biogas is converted to energy (~600 MWh/year) via a CHP and fed into the district heating network. The effluent from the digester undergoes struvite precipitation (~ 1.2 tons/y), for phosphorus recovery.

BW
T.23 UASB
biogas
sludge
T.4 STRUVITE PRECIPITATION
struvite

T.42 SETTLING TANKS | SCREENS

TECHNOLOGY



Settling tanks and screens are used for the separation of large solids and suspended matter from wastewater streams. These technologies are generally implemented as a primary treatment step to protect and/or to simplify subsequent biological or advanced treatment steps in water treatment and reuse. Additionally, the separation of solids, allows for their valorization as a source of organics and nutrients. Settling tanks retain water at a low flow, allowing heavier suspended particles (i.e., grit, sand, organic particles) to settle by gravity. The settled sludge must be periodically pumped out of the tank (desludging). Settling tanks are sometimes called sedimentation tanks, clarifiers or septic/Imhoff tanks. Screens are physical (static or mechnical) separation devices that retain suspended solids on one side of the barrier, while allowing water to flow through to the other side. Screens are typically at the beginning of the treatment train, but can also be used between biological treatment and filtration or disinfection steps. Different screen configurations exsist made out of wires, plates, discs, or mesh. Coarse screens (e.g., bar screens) remove large debris, while fine screens (e.g., drum and disc filters) target small suspended particles.

INPUT STREAMS

- MW Mixed wastewater
- BW Blackwater
- GW Greywater

TARGET OUTPUT(S)

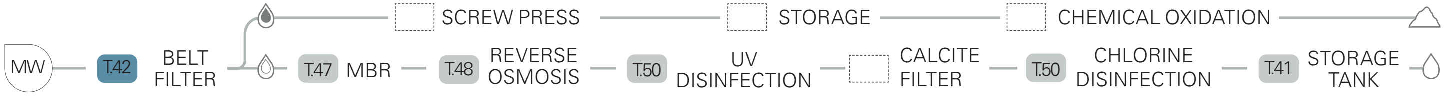
- Liquid fraction
- Solid fraction

SALESFORCE TOWER + NEMA pilot

San Francisco, CA, USA | 2019

Solids recovery and valorization from mixed wastewater

Mixed wastewater is screened by a rotating belt filter with a 350 micron mesh. The solids stream (thickened to 3-8% dry matter) is currently sent to sewer, but a pilot in a similar building in San Francisco (NEMA) showed that the solids (including food waste from kitchen grinders) could be further dewatered to 20-30% dry matter onsite with a screw press, then stored and transported to a treatment hub to be treated by chemical oxidation and used as a soil amendment.



MW — T42 BELT FILTER

SCREW PRESS — STORAGE — CHEMICAL OXIDATION

T47 MBR — T48 REVERSE OSMOSIS — T50 UV DISINFECTION — CALCITE FILTER — T50 CHLORINE DISINFECTION — T41 STORAGE TANK

SPECIFICATIONS

INFRASTRUCTURE

Settling tanks are relatively large and typically placed in the basement or undergroud. Settling tanks are often built in reinforced concrete, steel, fiberglass or durable plastic. Periodic desludging can be manual or automated, using pumps or scrapers. Sludge is often pumped to the sewer (when available), or transported away by trucks. Alternatively the solids can be treated and valorized on-site. Screens have much smaller footprints, and are usually placed in a mechanical room of a building, or outdoors. For efficient separation, wastewater should enter a settling tank or screen with a controlled flow without excessive turbulence.

OPERATION & MAINTENANCE

Settling tanks require little maintenance. For optimal performance, maintenance of settling tanks includes regular inspection of leaks, monitoring effluent clarity, monitoring of sludge accumulation, and periodic desludging. The frequency of desludging depends on the tank design, incoming solids, and retention time. Screen operation can be fully automated, however, since there are many moving parts, they require regular maintenance and inspection by skilled personel for wear or damage. Accumulated debris in a screen need to be cleaned periodically either manually or automatically.

Due to their low maintenance and desludging requirements, septic or Imhoff tanks are widespread in rural/off-grid settings. Sludge is regularly transported by vacuum truck to a treatment facility.

TARGET OUTPUTS

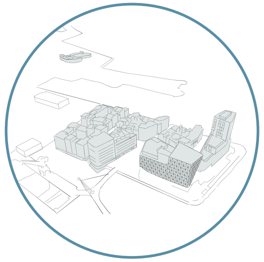
Settling tanks and screens separate wastewater into a liquid fraction and a solid fraction. The removal of solids, organics and nutrients, from the liquid fraction increases the treatment performance of subsequent treatment steps to produce water for reuse. Meanwhile, the separation of a solid fraction from the liquid fraction facilitates the recovery of organics and nutrients. However, the solids recovered from screens or settling tanks are still relatively diluted (less than 8% dry matter), and need thickening and dewatering before further treatment (i.e., sanitization and stabilization).

Settling tanks and screens enable the recovery of the organically-bound nutrients and undissolved organics (feces, toilet paper) present in a diluted mixed wastewater or blackwater stream. Once separated, these can be valorized.

SELECTED CASE STUDIES

OCEANHAMNEN

Helsingborg, Sweden | 2021



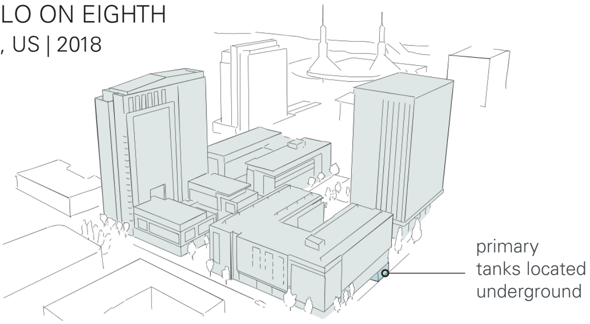
Drum filter before nutrient recovery technologies

Oceanhamnen is a waterfront development that has a "three-pipes out" collection of greywater, vacuum-collected blackwater and kitchen waste scaled for 2100 p.e., treated at the Recolab building. After anaerobic treatment of the blackater in a UASB, the effluent goes through a drum filter to remove suspended solids, organics and metals that can negatively impact the subsequent nutrient recovery steps (struvite precipitation and ammonia stripping). The drum filter, with a 40 um cloth mesh, achieves ~ approximately 74% removal of total suspended solids.

BW — COLLECTION TANK — T.23 UASB — biogas — T.42 DRUM FILTER — T.4 STRUVITE PRECIPITATION — struvite — T.5 AMMONIA STRIPPING — ammonia salt

HASSALO ON EIGHTH

Portland, US | 2018



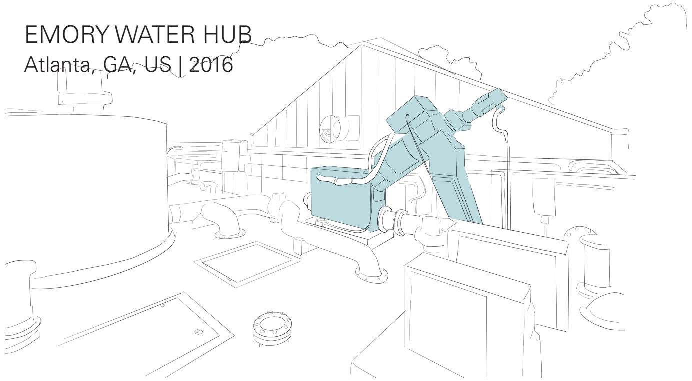
Sludge from settling tanks treated at municipal WWTP

The wastewater treatment system of this LEED Platinum neighbourhood treats an estimated 230 m³ of wastewater per day from three large residential buildings. The treated water is reused for toilet flushing, cooling systems, and landscape irrigation. The system includes four primary settling tanks, each with an emergency overflow to the sewer. The sludge is removed and transported to the centralized Durham Wastewater Treatment Facility four times per year, where it is treated anaerobically (producing biogas). The dewatered sludge is used in agriculture as a soil amendment.

MW — T.42 SETTLING TANKS — ANOXIC TANK — T.45 TRICKLING FILTERS — T.44 CONSTRUCTED WETLANDS — T.42 DISC FILTER — T.50 UV DISINFECTION — T.41 STORAGE TANK

EMORY WATER HUB

Atlanta, GA, US | 2016



Solids screened out, compacted and transported away

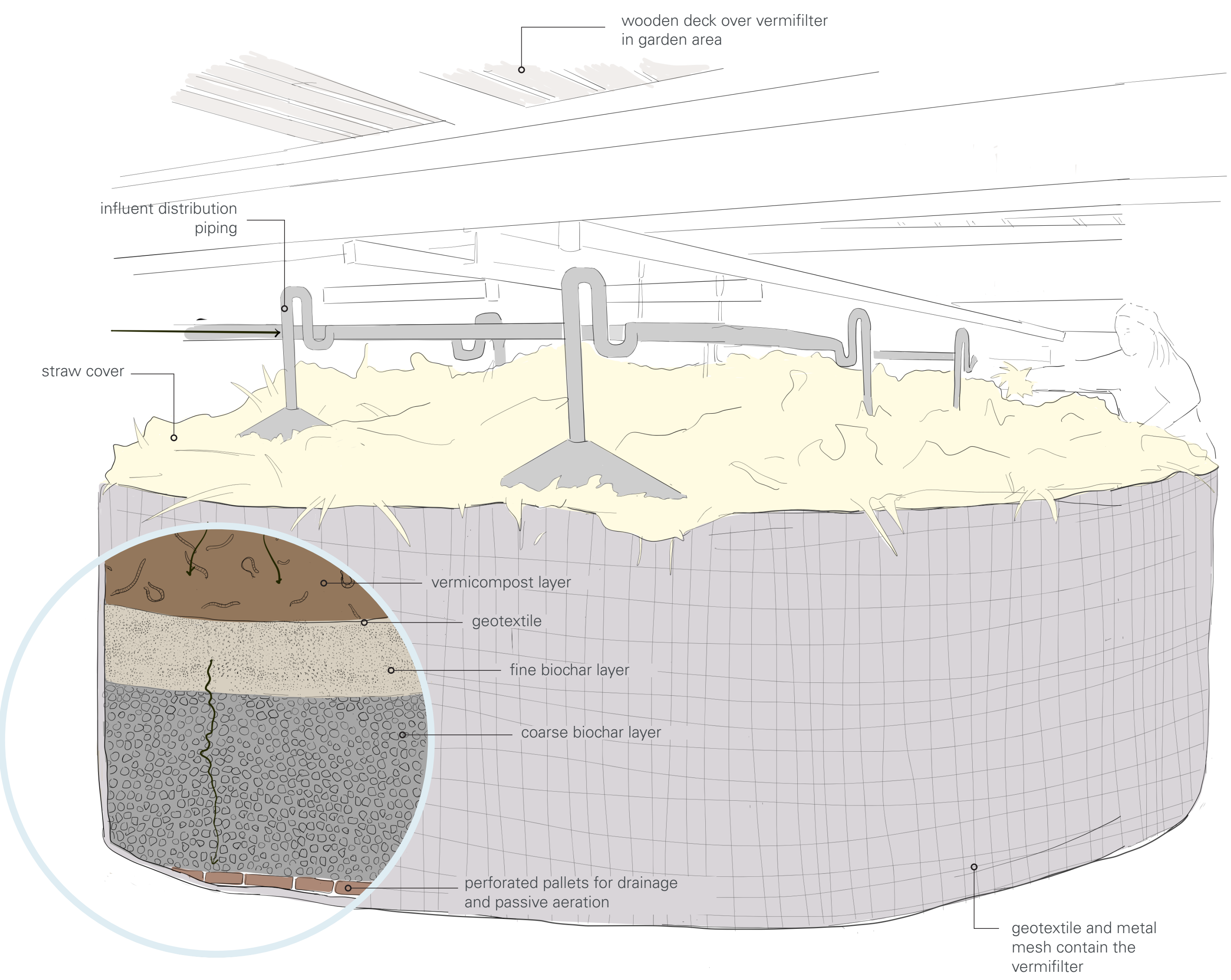
A rotary drum fine screen (with 6mm spacing) is used for primary screening of mixed wastewater before biological treatment. The screen is placed outside in the mechanical area on top of the concrete MBBR tanks and contains a screw that transports and compacts the screenings. Solids are not recovered; they are sent down a chute to a bin and transported to a facility for further treatment.

MW — T.42 ROTARY DRUM FINE SCREEN — T.46 MBBR & FBBR — T.42 DISC FILTER — T.50 UV DISINFECTION

T.43

VERMIFILTERS

TECHNOLOGY



Vermifilters treat blackwater or mixed wastewater in a multi-layered system that includes solid-liquid separation, vermicomposting of the solid fraction, and aerobic biological treatment of the liquid fraction. The wastewater is distributed on top of the vermifilter and seeps vertically down through the filter. The solids (feces and toilet paper) are retained at the top, where earthworms and microbiota degrade and process it into compost. The liquid percolates through a porous layer (of e.g., gravel, biochar, wood chips), which provides a large surface area for adsorption and further biological treatment by microorganisms growing in biofilms. While the composting layer is aerated through the borrowing activity of the worms, the drainage layer is designed to allow a passive flow of air through the filter media. Vermifilters are not an optimal technology to treat source-separated greywater, but can be fed grease and solids from a greywater grease trap.

Vermifilters are a robust, low maintenance and energy option for on-site treatment that can be maintained by the users themselves. The technology is well suited for settings without source-separation of streams, and where wastewater loads may be variable in time (e.g., alpine settings, holiday homes).

INPUT STREAMS	TARGET OUTPUT(S)
BW Blackwater	Treated Water
MW Mixed Wastewater	Soil Amendment, compost

SOUBEYRAN

Geneva, Switzerland | 2017

First example of a vermifilter in an urban setting, serving ~100 p.e.

A large vermifilter (8 m in diameter) is located below ground, under a wooden deck in the garden area (total area: 80 m2, depth: 3 m). Blackwater from toilets is alternately distributed over half of the vermifilter. The liquid effluent is treated further and reused onsite together with treated greywater and rainwater for toilet flushing and irrigation. Excess treated water is piped to the local storm drain. Vermicompost (~1m3/year) is used in the garden after maturation.

SPECIFICATIONS

INFRASTRUCTURE

Vermifilters perform more efficiently when treating blackwater, but can also treat mixed wastewater. It can therefore be retrofitted without modifying the plumbing system as an "end-of-pipe" solution. Vermifilters are best placed in a basement or underground for several reasons:

1) Temperatures are relatively constant, and freezing is avoided.
2) Filters are directly fed by gravity, without the need for a buffer tank. When gravity feeding is not an option, macerating pumps in a small collection tank are possible.
3) Space requirements may be less of a constraint since vermifilters require up to 0.5 m² per p.e.. In either configuration, it is important to leave enough head and elbow space to be able to reach the entirety of the filter surface for maintenance.

OPERATION & MAINTENANCE

Very little to no energy consumption is necessary for vermifilter operation. Energy is only required for the feed pumps, if necessary. No control system is required and the system has few to no moving parts. Therefore, vermifilters require little regular maintenance: only the addition of straw, cardboard or dry plant matter to decrease humidity and increase the carbon to nitrogen (C:N) ratio for optimal composting. Grease and solids from a greywater grease trap can also be manually fed to a blackwater vermifilter. Once or twice a year, compost can be manually taken out of the filter for further maturation before use.

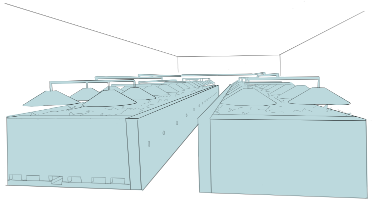
TARGET OUTPUTS

Vermifilters are robust and efficient for the removal of organic matter from blackwater or mixed wastewater but have variable performance for nitrogen removal and limited removal of pathogens and micropollutants. Therefore, the liquid effluent from the vermifilter should be treated with additional biological treatment, filtration, and/or disinfection steps to achieve the water quality necessary for the desired water reuse application. Because worms efficiently reduce the volume of the solids by 60 to 90%, relatively small volumes of vermicompost are produced. Once removed from the vermifilter, the compost will require maturation (e.g., storage during 6-12 months) before safe application as a soil amendment.

SELECTED CASE STUDIES

LA BISTOQUETTE

Geneva, Switzerland | 2025



Vermifilter in the basement of an urban building complex

Three apartment buildings (330 p.e.) belonging to La Bistoquette cooperative include source separation of greywater, urine and blackwater from urine-diverting flush toilets. The blackwater will be treated in a large vermifilter in the basement of one of the buildings. The effluent from the vermifilter will be pumped onto 20 small biochar trickling filters for post treatment. The treated water will be stored in a tank together with treated greywater and collected rainwater and used for toilet flushing and irrigation of the terraces, balconies and ground floor.

BW — T.43 VERMIFILTER (vermicompost) — T.45 TRICKLING FILTERS — T.41 STORAGE TANK

BLONAY

Vaud, Switzerland | 2024

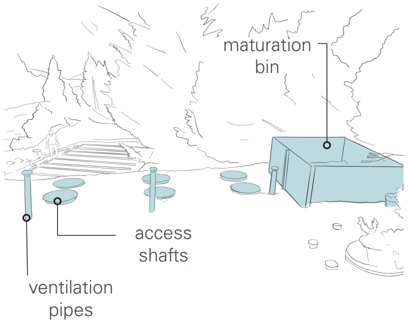
Small vermifilter in rural family home

A small vermifilter treats the mixed wastewater (excluding urine) from a family home (5 p.e.). Both the vermifilter and the dedicated urine treatment are housed in a concrete basement structure below the house. The liquid effluent from the vermifilter is infiltrated onsite.

MW — DEGREASER — T43 VERMIFILTER (vermicompost) — INFILTRATION

CHAMANNA CLUOZZA

Zernez, Switzerland | 2022



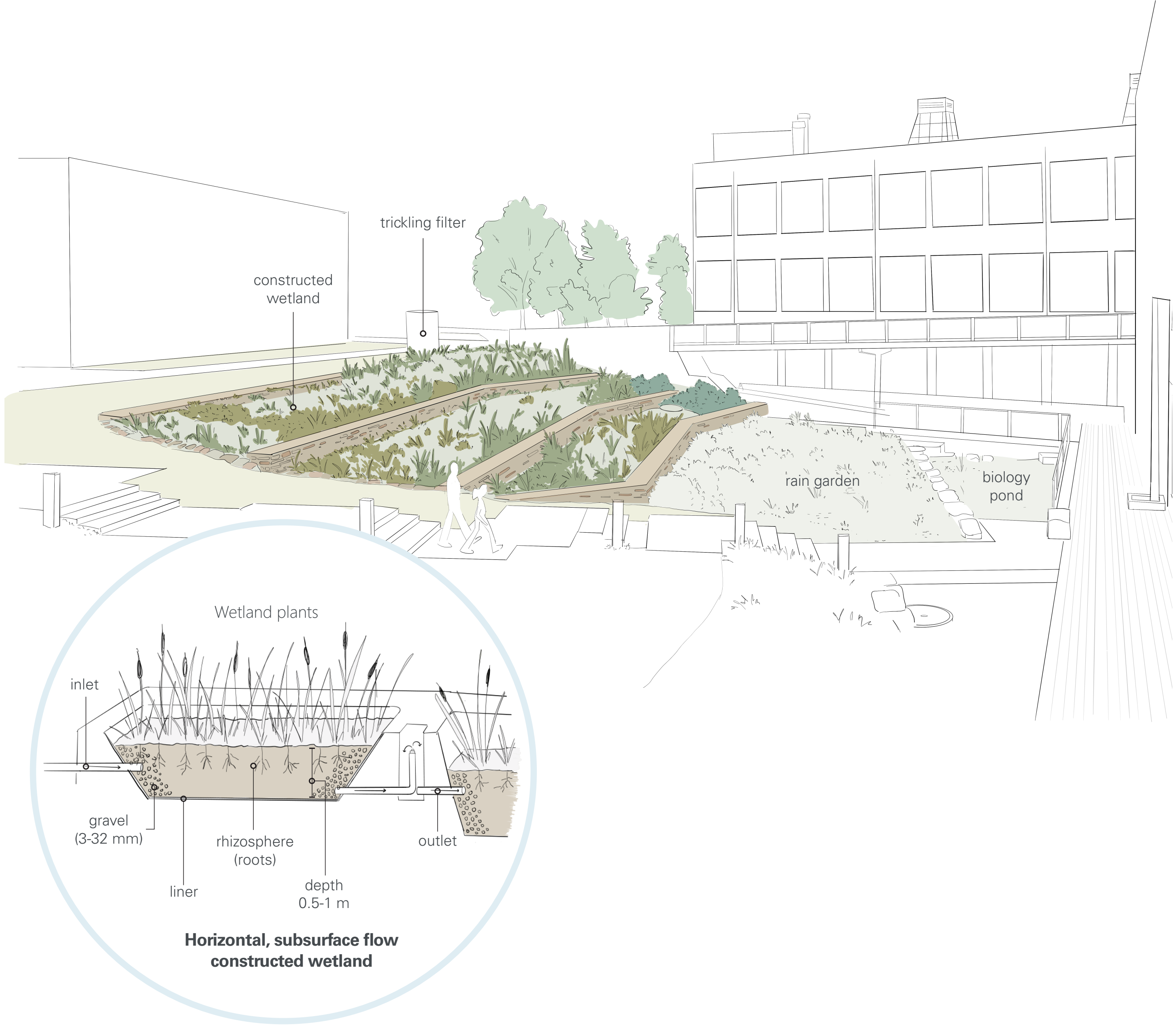
Underground vermifilters in an alpine setting

Located at 1882 m in the heart of the Swiss National Park, Chamanna Cluozza offers accommodation to (~30) hikers and staff. The mixed wastewater stream from the alpine hut is treated in three alternately-fed, underground vermifilters using woodchips as a filter media. The filters occupy an area of roughly 12 m² some distance away from the hut and feed into a 40 m² constructed wetland. The effluent is infiltrated. The vermicompost is periodically shoveled into a maturation bin, for further treatment, before use.

MW — T43 VERMIFILTER (vermicompost) — T44 CONSTRUCTED WETLAND — INFILTRATION

T.44 CONSTRUCTED WETLANDS

TECHNOLOGY



Horizontal, subsurface flow constructed wetland

Constructed wetlands (also referred to as artificial marshes, reed filters, or heliiophyte filters) are engineered marshes that mimic natural wetland mechanisms to improve water quality. Constructed wetlands consist of sealed basins filled with permeable filter substrate (soil, rock, gravel, sand, etc.) and planted with reeds and plants adapted to water-saturated conditions, called macrophytes. The water either flows over the surface of the wetland or through the porous substrate, horizontally or vertically. The material, colonized by microorganisms, allows for sorption and biological degradation of nutrients and contaminants; the plants serve to maintain the permeability of the filter, keep it aerated, assimilate nutrients, and provide a habitat for microorganisms. The treatment train for a constructed wetland often includes pre- and post-treatment steps.

Wetlands are low-tech, nature-based solutions that in addition to treating water, offer ecosystem services, and have recreational and aesthetic value. Wetlands can be integrated into the urban environment to support biodiversity, store water, and provide local cooling.

INPUT STREAMS	TARGET OUTPUT(S)
GW Pre-treated Greywater	💧 Treated Water
MW Pre-treated Mixed Wastewater	
RW Rainwater	

SIDWELL FRIENDS MIDDLE SCHOOL

Washington DC, USA | 2007

Wetland treatment for mixed wastewater at urban school

This LEED Platinum-certified school treats mixed wastewater from toilets and sinks through a series of physical and biological technologies. The gravity-fed wetland (3600 m²) treats 11 m³ per day, circulating through the entire treatment train for 3-5 days before reuse (toilet flushing and irrigation). Pre- and post-treatment steps take place in the basement. The school has reduced their water consumption by 90%. The wetland, rain garden and biology pond are used in the school curriculum.

MW — T.42 SETTLING TANK — T.44 CONSTRUCTED WETLAND — T.45 TRICKLING FILTER — T.49 SAND FILTER — T.50 UV DISINFECTION — 💧

SPECIFICATIONS

INFRASTRUCTURE

Wetlands can be designed for neighborhoods, buildings or for single households. Often placed outdoors, land requirements for constructed wetlands are high and thus lend themselves for low-density areas. In high-density areas, wetlands can be integrated into city infrastructures (e.g., in courtyards, parks, and on roofs). The technology is best suited for warm climates though can withstand low-temperature conditions (with cold-resistant plants). Key design aspects of wetland types include:

Hydraulic retention time (HRT): Wetland size depends on the time it takes the water to flow through the wetland. The longer the HRT, the greater the nutrient removal.
Flow: Water can flow horizontally or vertically, and over (surface) or below (subsurface) the wetland substrate. In tidal wetlands water is filled intermittently, with flooding and draining stages.
Plants: Plants can be floating, submerged, or emergent, and should be climate-appropriate (e.g., low-temperature resistant).

OPERATION & MAINTENANCE

Constructed wetlands are considered a cost-effective and efficient nature-based solution for water treatment. These solutions typically have low construction, operation and maintenance costs, and low to no energy demands. Maintenance includes the periodic harvesting of plant biomass, and ensuring that the filter material near the inlet zone is free from solids and biofilm build-up (clogging). Removal of solids at inlet may be necessary every 10 years. Effective primary treatment (i.e., the separation of solids) also helps reduce particles entering the wetland. Nearby tree roots can damage wetland liners. Operation includes optimization of hydraulic conditions and monitoring of treatment performance.

Wetland plants remove nutrients from wastewater via assimilation into their biomass. However, they also take up and accumulate heavy metals. Potential risks should be considered when reusing plant biomass.

TARGET OUTPUT

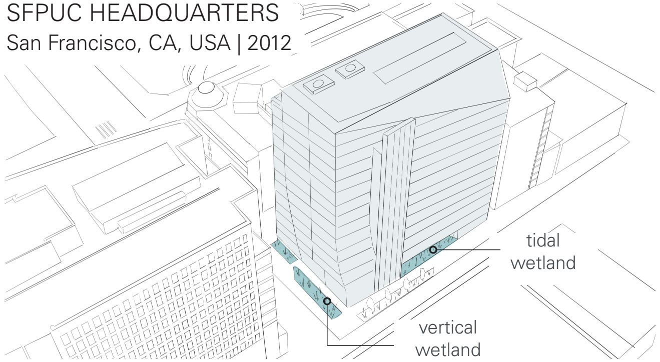
Treated water from constructed wetlands can be used outdoors or infiltrated into the soil. For use indoors, further filtration and disinfection are necessary to achieve higher water qualities (see ●).

Wetland performance for contaminant removal is variable depending on weather conditions, influent composition and operation. Water losses through evapotranspiration occur; in wet climates rainwater enters the system.

SELECTED CASE STUDIES

SFPUC HEADQUARTERS

San Francisco, CA, USA | 2012



Wetlands integrated in urban office building and sidewalk

The San Francisco Public Utilities Commission Headquarters' "living machine" treats mixed wastewater with a series of treatment steps including tidal, subsurface flow constructed wetlands and vertical flow wetlands with a capacity of ~19,000 liters per day. The treated water is used for toilet flushing in the building, reducing consumption by 50%. The wetlands are creatively integrated into the bordering sidewalk and in the ground floor atrium of the building. The building meets all available LEED water credits and is LEED Platinum certified. The living machine and rainwater harvesting system together cost 1 million USD.

MW — T.42 SETTLING TANK — T.44 CONSTRUCTED WETLAND — T.49 MEDIA FILTER — T.50 UV DISINFECTION — T.50 CHLORINE DISINFECTION — 💧

BWWB BOSCHVELD

's-Hertogenbosch, the Netherlands | 2018

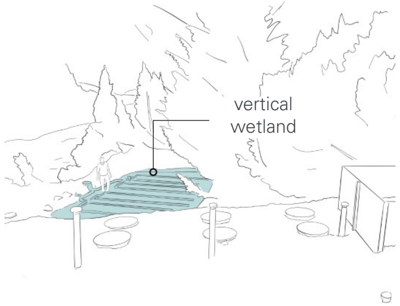
Residential greywater treatment with vertical flow wetland

BWWB (Bewonersvereniging Bewust Wonen en Werken Boschveld) is a 24 household residential "eco-neighborhood" that has opted to treat their mixed wastewater (~7,000 liters per day) with a vertical constructed wetland (250m²), located in the shared garden. Pretreatment includes two settling tanks with a five-day retention time, and a buffer tank from which the water is pumped to the wetland several times per day. The treated water is reused for toilet flushing, reducing water consumption by 40%. Excess treated water is infiltrated underground. The municipality monitors the treated water and groundwater quality regularly.

GW — T.42 SEPTIC TANK — BUFFER TANK — T.44 CONSTRUCTED WETLAND — T.41 STORAGE TANK — 💧

Chamanna Cluozza

Zernez, Switzerland | 2022



Mixed wastewater treatment at mountain lodge with wetland

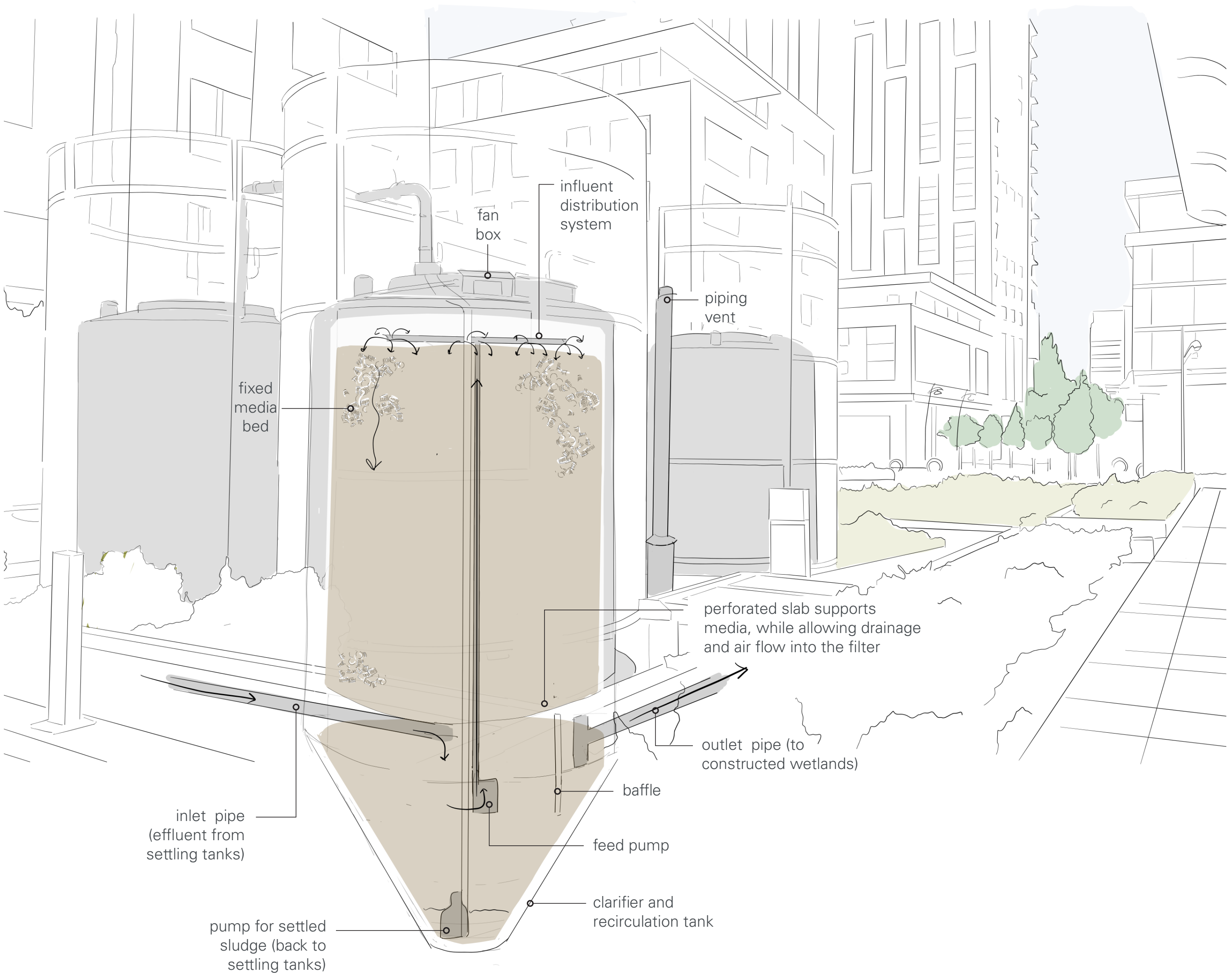
Located at 1882 m in the heart of the Swiss National Park, Chamanna Cluozza offers accommodation to (~30) hikers and staff. Water used onsite is sourced from nearby springs, the wastewater is treated decentrally. Blackwater from the flush toilets and greywater flow together through a vermifilter with charcoal filter (12 m²). The effluent is then treated with a constructed wetland (40 m²), after which it is led to an infiltration area. The water is not reused. The worm compost from the vermifilter is emptied periodically and used onsite as a soil amendment.

MW — T.43 VERMIFILTER — vermicompost — T.44 CONSTRUCTED WETLAND — INFILTRATION — 💧

T.45

TRICKLING FILTERS

TECHNOLOGY



Trickling filters (sometimes also referred to as packed bed filters, biological filters or recirculating media filters) are aerobic biological reactors that degrade organics. The wastewater trickles over a fixed bed of media with a high specific surface area (engineered textiles, wood chips, biochar, lava rock, prefabricated plastic media, coarse sand, gravel, peat moss). Microorganisms growing as a biofilm on the media surface degrade organic pollutants as the water trickles past. Trickling filters can be fed by gravity, requiring no energy input, or can be more sophisticated, requiring energy to recirculate the wastewater over the bed. To ensure efficient treatment, adequate air flow is important. Design must ensure adequate drainage to achieve unsaturated, aerobic conditions either via passive ventilation systems or intermittent feeding. The hydraulic loading rate depends on the wastewater characteristics, the type of filter media, and the ambient temperature. Rotating biological contactors (RBC) are similar to trickling filters; both are passive aeration fixed film processes. In RBCs, a biofilm growing on discs is rotated through the wastewater, intermittently exposed to air.

INPUT STREAMS

- GW Pre-treated Greywater
- BW Pre-treated Blackwater
- MW Pre-treated Mixed Wastewater

TARGET OUTPUT(S)

- Treated Water

HASSALO ON 8th

Portland, OR, USA | 2018

Four trickling filters integrated into the urban landscape

The wastewater treatment system of this LEED Platinum neighbourhood treats an estimated 230 m³ of wastewater per day from three large residential buildings. A series of trickling filters and constructed wetlands are integrated into the urban landscape. After UV disinfection, the treated water is reused for toilet flushing, cooling systems, and landscape irrigation. Excess treated water is injected into dry wells for groundwater recharge.

MW — T.42 SETTLING TANKS — ANOXIC TANK — T.45 TRICKLING FILTERS — T.44 CONSTRUCTED WETLANDS — T.42 DISC FILTER — T.50 UV DISINFECTION — T.41 STORAGE TANK —

SPECIFICATIONS

INFRASTRUCTURE

Trickling filters can be placed in a technical room within the building, but are more often placed (partly) underground and outdoors. Different prefabricated configurations are commercially available, while custom-made solutions in concrete or with liners are also possible. To prevent the filter from clogging, a preceding degreaser, screen, and/or solids removal step (usually a settling tank) is needed. A clarifying step after the filter collects the sludge, or "sloughed biomass", that has shed from the media bed. A clarifier often also serves as a recirculation tank. The sludge from the clarifier can be sent to a preceding settling tank, or to sewer, if available. Alternatively, it needs to be dewatered and properly disposed of.

OPERATION & MAINTENANCE

Trickling filters are low tech systems. Simple configurations have few to no moving parts (i.e., rely on gravity) and therefore require very little maintenance. More complex designs require control systems, a continuous power supply for pumping (i.e., recirculating the effluent over the filter) and regular maintenance. However, both energy and maintenance needs are relatively small compared to actively aerated bioreactors T.47 . Operation and maintenance is performed by a skilled operator, and includes monitoring of effluent quality, inspection of clogging or blockages, media cleaning if necessary, and sludge management. Trickling filter media may need periodic washing, to remove excess biofilm and optimize air flow through the media. Sometimes the media may need replacement.

Recirculation improves organic removal and nitrification due to longer contact times with the biofilm. Diluting the influent, lowers organic concentrations and increases the hydraulic loading rate. Recirculation also maintains moisture in the media, particularly useful when handling variable flows.

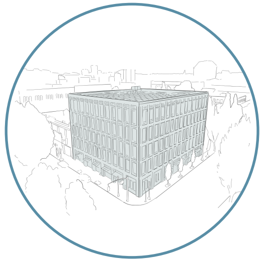
TARGET OUTPUTS

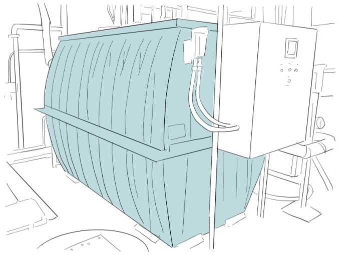
Trickling filters are used for removal of organic matter (measured in BOD_5 and COD removal) and for nitrification of ammonium to nitrate. Nutrient removal is usually not significant. As with other biological treatment steps, removal of pathogens and micropollutants is limited, therefore the effluent should be treated with additional treatment steps (e.g., filtration disinfection steps to achieve the water quality necessary for the desired water reuse application and to comply with local regulations, and public health requirements.

SELECTED CASE STUDIES

PAE BUILDING

Portland, OR, USA | 2021





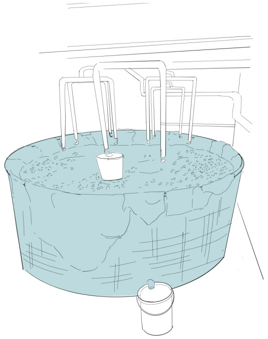
Recirculating textile filter treating office building greywater

Greywater from the PAE office building (from sinks, showers and dishwashers) is treated in the mechanical room on the first floor in a compact prefabricated unit (overdimensioned to handle unexpected peak flows) containing a lightweight, engineered textile to support biofilm growth. The wastewater is recirculated from the bottom of the tank and sprayed over the suspended textile via a pump and pressurized distribution system. The effluent flows through 30-micron bag filters and UV disinfection before non-potable reuse for flushing of the vacuum toilets, urinals and for onsite irrigation. The building is Living Building certified.

GW — T.42 SETTLING TANK — T.45 RECIRCULATING TEXTILE FILTER — BAG FILTERS — T.50 UV DISINFECTION — T.41 PRESSURIZED STORAGE TANK

SOUBEYRAN

Geneva, Switzerland | 2017



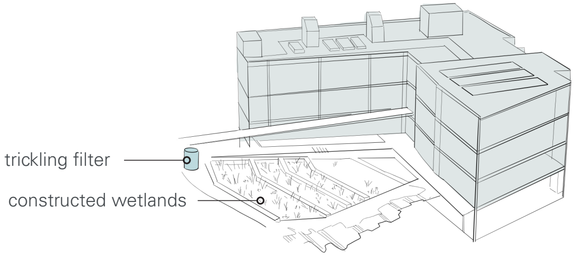
Biochar filter to treat greywater from a residential building

Soubeyran in a 6-story building comprised of 38 homes (~100 p.e.). After a degreaser, the greywater (~5.2 m^3/d) trickles down through a biochar filter placed below a wooden deck in the shared garden (adjacent to the vermifilter for blackwater treatment). Effluent from the biochar filter is treated further in a sand filter (50 m^3, vertical flow, located below) and a gravel filter (55m^3, horizontal flow, located adjacent under the grass), together with rainwater and the effluent from the vermifilter. The treated water is stored in a 26m^3 tank, and reused for toilet flushing and irrigation.

GW — DEGREASER — T.45 BIOCHAR FILTER — (RW, BW) — T.49 SAND & GRAVEL FILTERS — T.41 STORAGE TANK

SIDWELL FRIENDS MIDDLE SCHOOL

Washington DC, USA | 2007



Landscape-integrated trickling filter and constructed wetlands

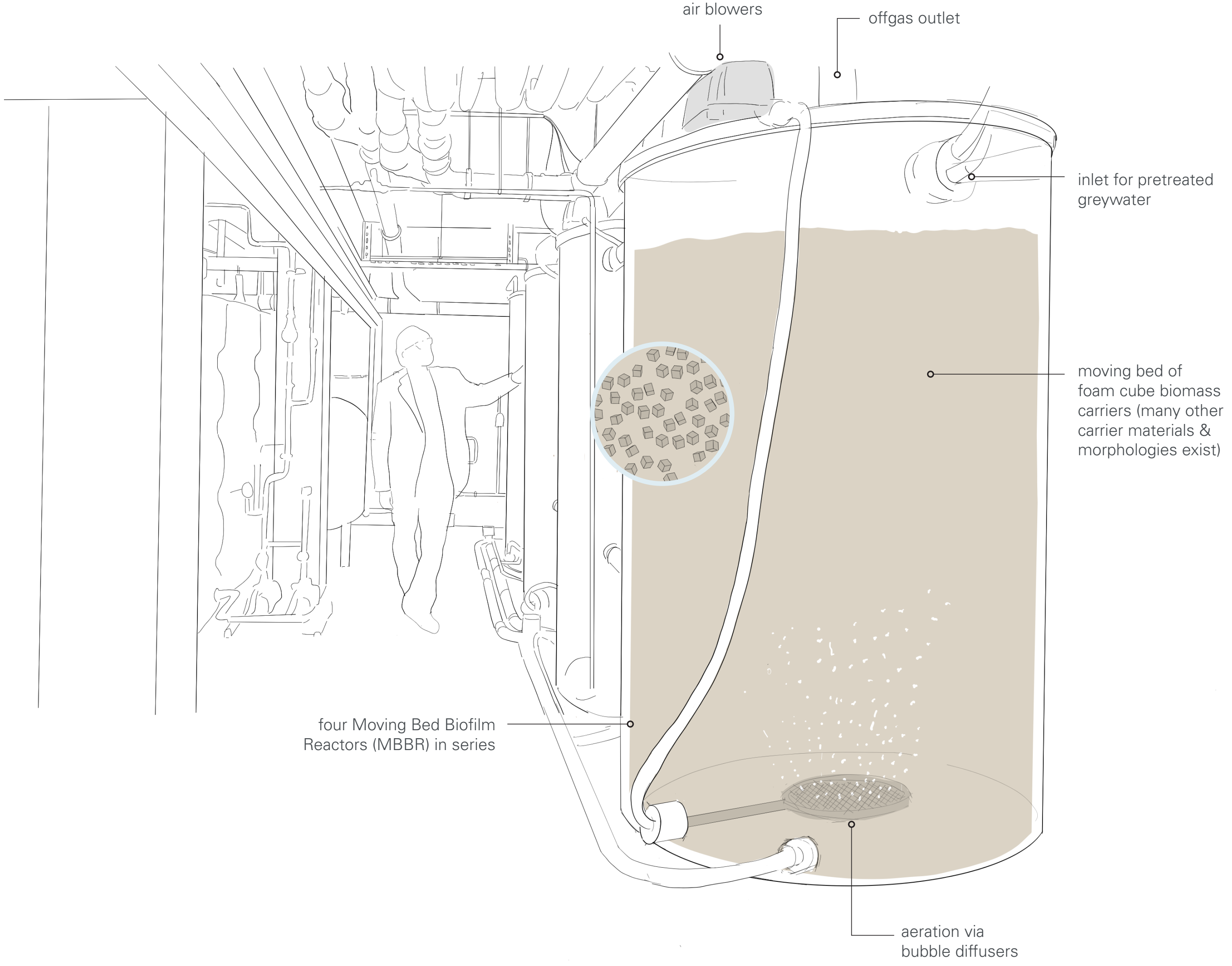
This LEED Platinum-certified school treats mixed wastewater from toilets and sinks through a series of physical and biological technologies. Mixed wastewater travels through the entire treatment train for 3-5 days before reuse for toilet flushing and irrigation on the campus. The constructed wetland and trickling filter are integrated in the landscape, adjacent to the rain garden and biology pond. The side of the trickling filter is used for educational signage and includes a diagram of the on-site wastewater and stormwater management. The school has reduced their water consumption by 90%.

MW — T.42 SETTLING TANK — T.44 CONSTRUCTED WETLAND — T.45 TRICKLING FILTER — T.49 SAND FILTER — T.50 UV DISINFECTION

T.46

AERATED BIOREACTORS

TECHNOLOGY



Aerated bioreactors make use of microorganisms growing in flocs (i.e., activated sludge), and/or biofilms on fixed beds or moving carriers, to degrade organics and remove nutrients from wastewater. Active bubble aeration maintains aerobic conditions and keeps the activated sludge and/or carriers suspended. The biological treatment can occur in one tank or be distributed over several tanks (multistage). To enhance nitrogen removal when treating mixed wastewater, the set up can include a non-aerated chamber (i.e., pre-anoxic tank) or non-aerated intervals. Aerated bioreactors are sometimes combined with plants growing hydroponically, the roots serving as an extra support for biofilm growth while taking up nutrients. Depending on the bioreactor configuration, these systems are called sequence batch reactors (SBR), moving bed biofilm reactors (MBBR), submerged fixed bed biofilm reactors (SFBBR), or integrated fixed film activated sludge (IFAS). The specific configuration of aerated bioreactors combined with integrated micro- or ultrafiltration membranes, referred to as membrane bioreactors (MBR), and is described separately in T.47.

INPUT STREAMS	TARGET OUTPUT(S)
GW Pre-treated Greywater	Treated Water
MW Pre-treated Mixed Wastewater	

BERLIN-PANKOW STUDENT HOUSE

Berlin, Germany | 2022

MBBR system for greywater treatment and reuse

Roughly 16 m³/d of greywater from showers and bathroom sinks are treated in the basement of this 450 bed student housing apartment complex with a multistage MBBR system coupled to filtration and disinfection. The treated water is reused for toilet flushing. The heat from the greywater (up to 10kWh per m³) is recovered via heat exchangers for the hot water supply to the building.

GW — T.42 SCREEN — T.61 HEAT EXCHANGER — T.46 MBBR — T.49 SAND FILTER — T.50 UV DISINFECTION — T.61 HEAT EXCHANGER — heat — T.41 STORAGE TANKS

SPECIFICATIONS

INFRASTRUCTURE

Bioreactor tanks can be prefabricated or built in concrete, and are typically placed in a mechanical room in the basement of a building, underground, or in a separate building dedicated to treatment. The design must be based on wastewater composition and volume as to not compromise treatment efficiency with an over- or under-dimensioned reactor. Different pre-fabricated reactor models are available.

Bioreactor variations with plants, integrated in a greenhouse or in the urban landscape, can provide aesthetically pleasing spaces.

OPERATION & MAINTENANCE

Energy use for aerated reactors can vary greatly depending on the configuration, though bubble aeration is generally energy intensive. Mechanical equipment such as mixers, aerators and pumps requires electricity and maintenance. Chemical consumption can also vary depending on the system configuration and wastewater characteristics. Ferric chloride ($FeCl_3$) can be used for phosphorus removal and other chemicals may be necessary to enhance settling of the sludge. Excess sludge must be regularly removed from the system and disposed of (e.g., pumped to the sewer network, if available), or valorized if there is an exisiting treatment for solid streams.

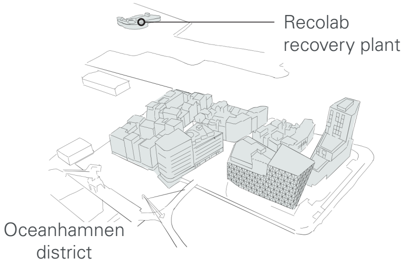
TARGET OUTPUTS

Aerated reactors are useful for the removal of organic matter (measured in COD and BOD_5 removal) and nitrogen. Effluent quality depends on the type of treatment configuration and operation. As with other biological treatment technologies, removal of pathogens and micropollutants is variable, therefore the effluent should be treated with additional biological treatment, filtration and/or disinfection steps to achieve the water quality necessary for the desired water reuse application, that also complies with local regulations, and public health requirements.

SELECTED CASE STUDIES

OCEANHAMNEN, RECOLAB

Helsinborg, Sweden | 2021



District scale treatment of greywater with activated sludge

Oceanhamnen district (2100 p.e.) uses an activated sludge system to treat greywater. The buffer tank (80m^3), biological tank (65 m^3) and a clarifier are concrete structures built below ground in the Recolab recovery plant, and can be accessed via hatches on the floor. A drum filter enhances solids separation before nanofiltration. In the future, it is expected that the liquid effluent from the blackwater and organic waste treatment will also be treated in this system. The recovered water will be used as bathing water in a neighboring swimming pool (under construction).

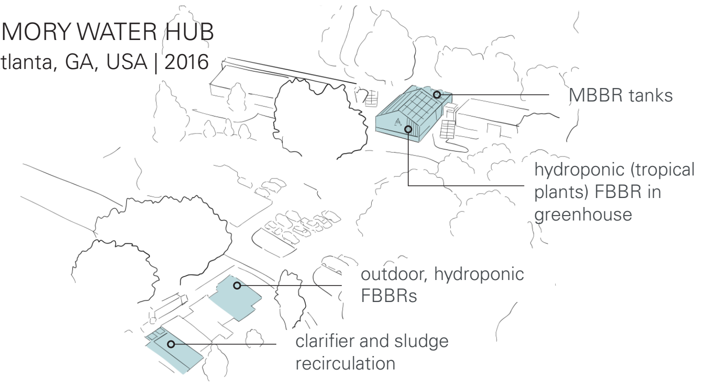
GW — COLLECTION TANK — T.46 ACTIVATED SLUDGE — T.42 DRUM FILTER — T.48 NANOFILTER — T.61 HEAT PUMP — T.41 STORAGE TANK

T.51 OZONATION

heat

EMORY WATER HUB

Atlanta, GA, USA | 2016



"Sewer mining" and "hydroponics" for water reuse on campus

The treatment plant at Emory University is designed to treat 1500 m^3/d of wastewater in a space of 195 m^2. The screened wastewater is treated in a series of moving bed biofilm reactors (MBBR) (above-ground, concrete tanks) and fixed bed biofilm reactors (FBBR) with plants, or "hydroponic reactors", (integrated in a greenhouse and outdoors). The effluent from the biological reactors is treated further with a disc filter and UV disinfection located in the technical room before storage in a ... tank. It is then redistributed around campus for non-potable reuse in steam and chiller plants, and for toilet flushing, accounting for ~40% of total water use.

MW — T.42 SCREEN — T.46 MBBR — T.46 FBBR — T.42 DISC FILTER — T.50 UV DISINFECTION — T.41 STORAGE TANK

BLITSAERD

Leeuwarden, the Netherlands | 2024

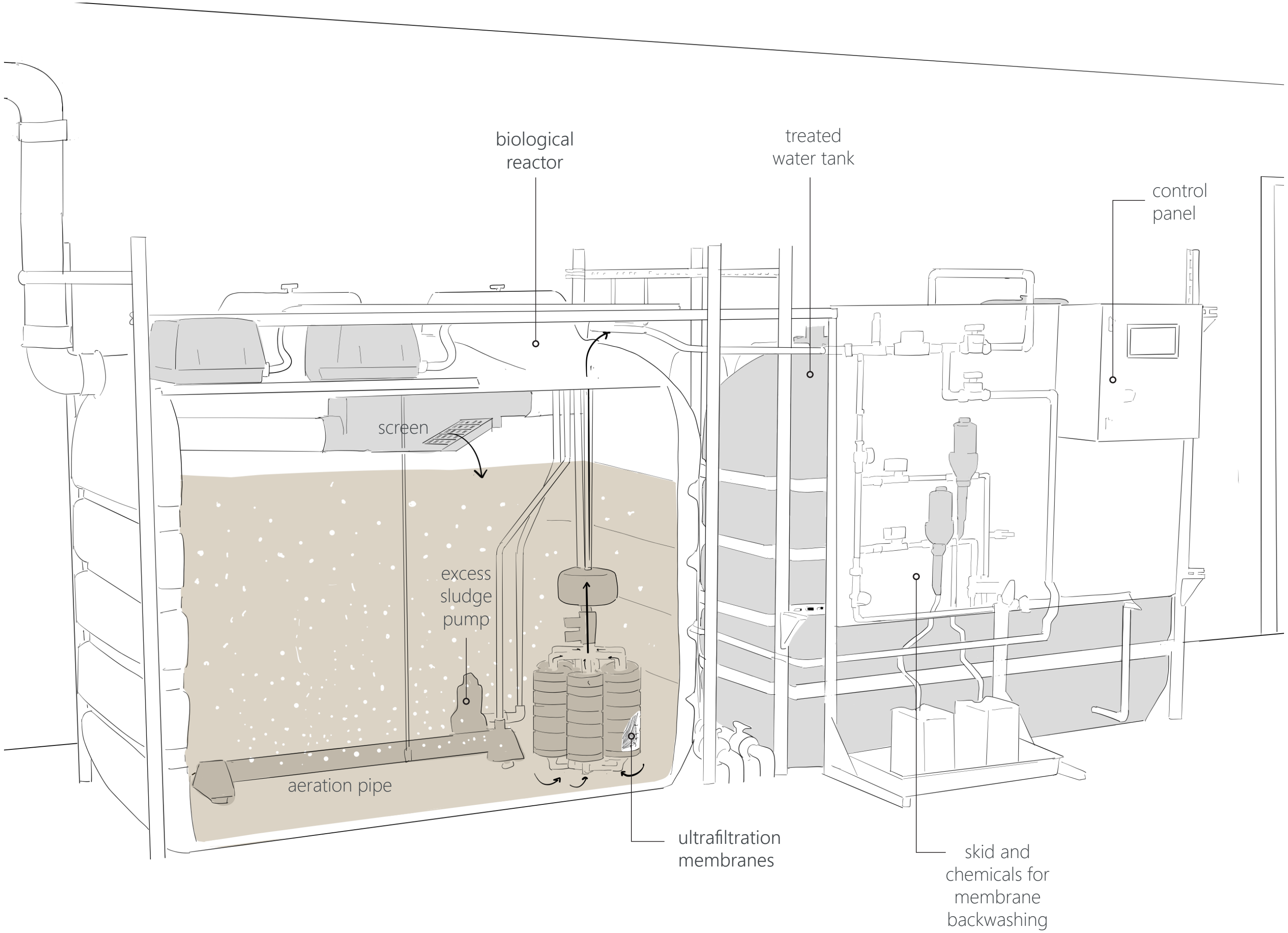
Household greywater treatment units for direct water reuse

14 homes in the new district development were built with separate greywater piping and each home is equipped with a commercially-available water treatment unit. Each treatment unit occupies 0.8 m^2. Greywater from the showers is treated and reused for toilet flushing and for laundry resulting in significant water savings. The treatment units run automatically and are monitored online by the provider. Another 27 homes in the district were also built with separate piping. Future residents can choose to install greywater or rainwater systems.

GW — PRETREATMENT — T.46 MBBR — T.50 UV DISINFECTION

T.47 MEMBRANE BIOREACTORS

TECHNOLOGY



A membrane bioreactor (MBR) combines biological treatment with membrane filtration. In the aerated bioreactor, microorganisms degrade organics and remove nutrients (see T.46 for more information on aerated bioreactors). The subsequent microfiltration or ultrafiltration membranes (pore sizes ~0.01–0.1 microns) physically separate suspended solids and microorganisms (see T.48 for more information on membrane filtration), and eliminate the need for a clarification step. Membranes (flat sheet or hollow fiber) can be directly submerged in the biological tank, or placed in a dedicated membrane tank. MBRs are compact systems, compared to other bioreactor configurations, that ensure a high quality effluent that is often already suitable for some types of non-potable reuse. The treated water can be further disinfected or treated for micropollutant removal or desalination.

> MBRs provide effective biological treatment and filtration in one system, producing high quality treated water in a relatively small footprint. They are therefore often the preferred solution for water reuse projects in urban settings where space is limited.

INPUT STREAMS	TARGET OUTPUT(S)
GW Pre-treated Greywater	Treated Water
MW Pre-treated Mixed Wastewater	
SW Stormwater	

GW — T.42 SCREEN — T.47 MBR — T.50 UV DISINFECTION —

GUESTHOUSE

Schleswig-Holstein, Germany | 2021

Greywater treatment and reuse

Source-separated greywater from a guesthouse serving 62 users is treated with a membrane bioreactor followed by UV disinfection. The treatment system is located in the basement of the building. The treated water is used to cover the water demand (~1.5 m³/d) for toilet flushing (35 toilets) and running two large washing machines.

SPECIFICATIONS

INFRASTRUCTURE

MBRs are typically installed in a technical room, often in the basement of the building. Often a concrete foundation or slab is needed to support the weight of the tankage and equipment. Biological tanks, and membrane tanks (if separate), can be prefabricated or reinforced concrete tanks. These tanks require space and access to a reliable power supply to operate the blowers and pumps. Additional space is needed to store chemicals required for cleaning the membranes, and for buffer and treated water storage tanks. If a connection to the sewer is available, waste streams from membrane cleaning and excess sludge can be discharged to the sewer. For off-grid configurations, waste streams have to be collected and disposed of at regular intervals.

OPERATION & MAINTENANCE

Smaller plug and play systems can be managed by users; custom systems serving larger buildings are usually operated and maintained by skilled personnel to ensure long-term performance and cost-effectiveness. Main tasks for operation include aeration adjustment to optimize biological treatment efficiency, membrane fouling management, and sludge management. Membranes require regular chemical cleaning, which can be highly automated with sensors and feedback loops. For submerged membranes, air scouring reduces sludge buildup on the membrane. For chemical cleaning, chemicals such as NaOCl or citric acid are required. Membrane modules have a high cost and typically need replacement every 5-10 years depending on type and usage.

A membrane bioreactor is an efficient water treatment technology with a relatively small footprint. The combination of biological treatment with a physical barrier eliminates the need for additional clarifiers for secondary treatment.

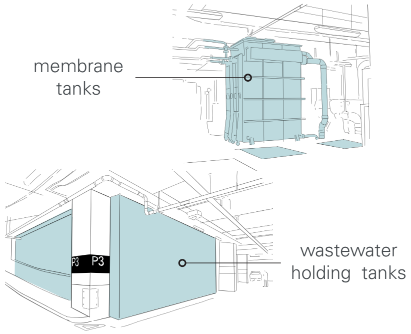
TARGET OUTPUTS

Membrane bioreactors yield high-quality treated water thanks to biological treatment combined with a physical barrier (the membrane). For single-family systems treating greywater, a MBR produces water that is suitable for toilet flushing. A further disinfection step increases reuse safety by removing smaller viruses and helps prevent microbial regrowth during storage and transport of the water before reuse. Suitability of the treated water for reuse depends on the type of water treated, intended use, local regulations, and public health requirements.

SELECTED CASE STUDIES

SALESFORCE TOWER

San Francisco, CA, USA | 2019



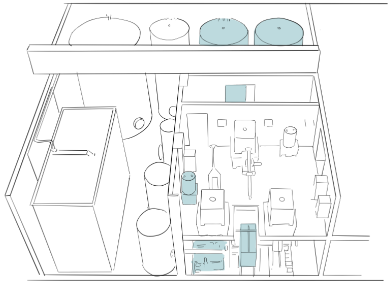
MBR in concrete tank for mixed wastewater treatment

Salesforce tower harbors the largest in-building water recycling system in the USA, treating 150 m^3 of mixed wastewater per day to non-potable water reuse standards. The biological concrete tanks of the MBR are integrated in the building structure (in the parking garage), while the mechanical room, including a separate membrane tank, a membrane operating skid and other treatment units, is situated one floor above. The treated water is redistributed through the building via a dedicated pipe network used for toilet flushing, drip irrigation and cooling towers. Water savings (76%) are equivalent to the annual average water consumption of 16,000 residents in San Francisco.

MW — T.42 SCREEN — T.41 BUFFER TANK — T.47 MBR — T.48 REVERSE OSMOSIS — T.50 UV DISINFECTION — CALCITE FILTER — T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK

DE NIEUWE DOKKEN

Ghent, Belgium | 2020



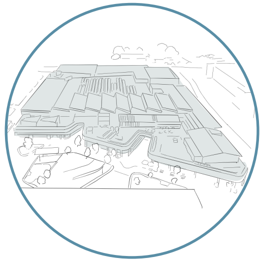
District scale treatment with MBR

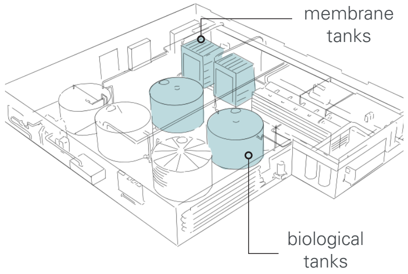
An MBR system treats greywater and effluent from the vacuum-collected blackwater treatment and sends the treated water to a neighboring soap factory to be used as process water. The biological reactors are large (PE) tanks spanning the height of two floors. They require the addition of a carbon source for denitrification and Ferric Chloride (FeCl$_3$) for phosphorus removal. The ultrafiltration membranes are located in a separate membrane tank. The offgases from the biological tanks are treated with biofilters; the excess sludge is sent to the blackwater treatment train.

GW — T.42 SCREEN — BW — T.41 BUFFER TANK — T.47 MBR — T.49 ACTIVATED CARBON FILTER — T.61 HEAT EXCHANGER & HEAT PUMP — heat — T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK

BURWOOD BRICKWORKS

Melbourne, Australia | 2019





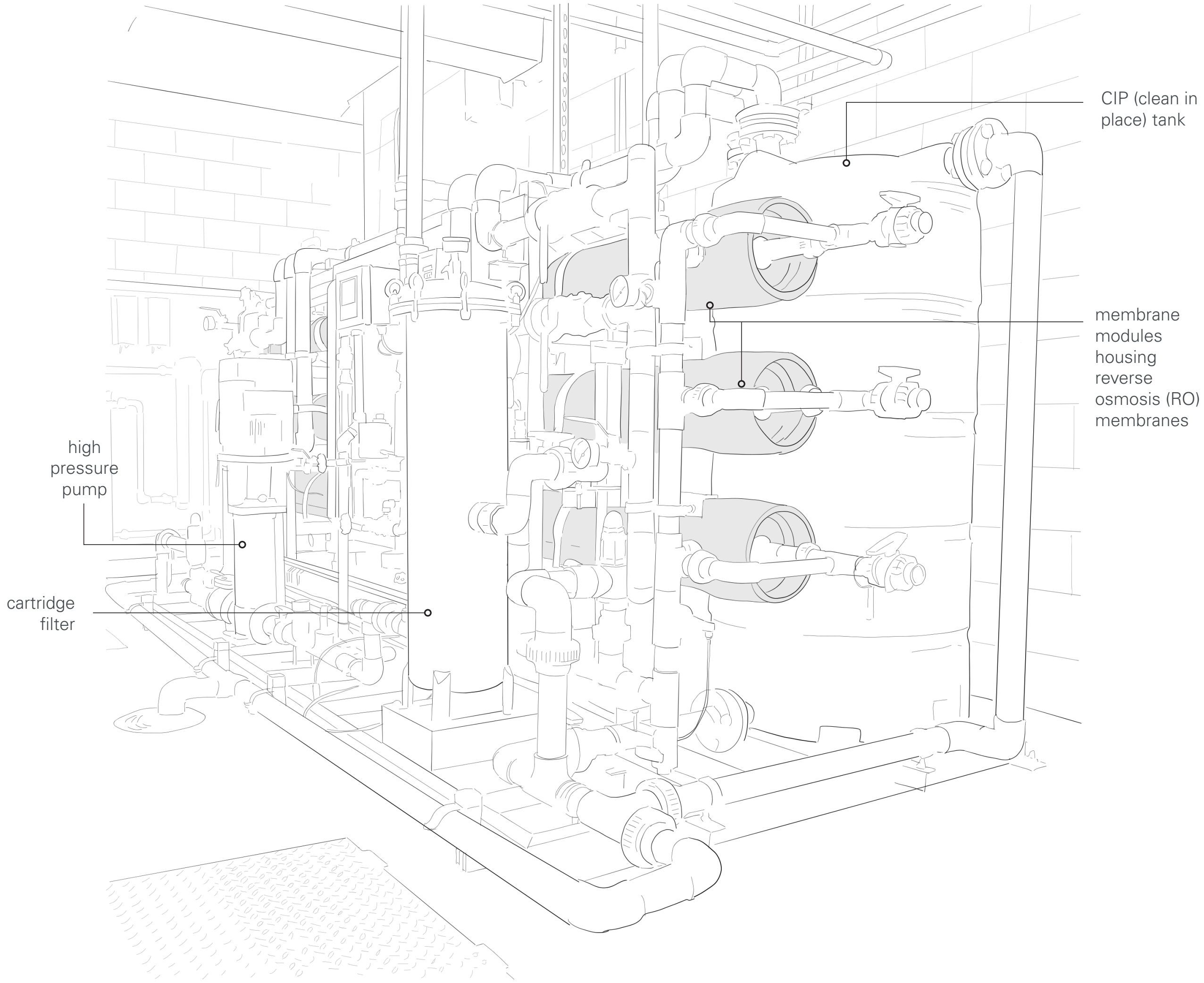
Large MBR treating mixed wastewater and stormwater

Burwood Brickworks is a large retail center certified by the Living Building Challenge for its contributions towards achieving "net zero water". An MBR is the core technology of the water reuse treatment train, designed to treat 60 m^3 of mixed wastewater and 30 m^3 of stormwater per day. The treated water is reused via the dedicated water pipe network for toilet flushing, for irrigation and in cooling towers.

MW — SW — T.42 SCREEN — T.41 BUFFER TANK — T.47 MBR — RW — T.51 OZONATION — T.50 UV DISINFECTION — T.49 ACTIVATED CARBON FILTER — T.41 STORAGE TANK

T.48 MEMBRANE FILTERS

TECHNOLOGY



Membrane filtration is a pressure-driven separation process where water is pumped through a semi-permeable membrane to filter out contaminants. Membrane pores allow water to filter through, but hold back contaminants that do not fit through the pores. Membranes can be hollow fiber or spiral wound, and have different pore sizes: microfiltration (~0.1), ultrafiltration (~0.01), nanofiltration (~0.001), and reverse osmosis (dense membranes). Depending on the type of membrane chosen, membrane filters can be used to remove suspended solids and colloids, pathogens (bacteria and viruses), organic micropollutants (e.g., PFAS, microplastics), compounds causing odor or color, and salts or ions from a water stream. Membrane bioreactors (MBR) have microfiltration or ultrafiltration membranes integrated directly into the biological treatment (see T.47).

Membrane units are often used as a filtration step after biological treatment of greywater or mixed wastewater, or for the treatment of rainwater. Micro- and ultrafiltration membranes are often placed before nanofiltration and reverse osmosis membranes to protect them from fouling.

INPUT STREAMS	TARGET OUTPUT(S)
GW Pre-treated Greywater	Treated Water
MW Pre-treated Mixed Wastewater	
RW Rainwater	

SALESFORCE TOWER

San Francisco, CA, USA | 2019

Reverse osmosis treats MBR effluent for on-site water reuse

The Salesforce Tower treats 150 m^3 of mixed wastewater per day to non-potable water reuse standards. A reverse osmosis system, set up as a skid in the mechanical room, treats the effluent from an MBR. The filtered water is disinfected and remineralized with a calcite filter before distribution in the building via a dedicated water network for toilet flushing, drip irrigation and cooling towers. Brine, produced as a byproduct of the reverse osmosis unit, is discharged to the sewer.

MW — T.42 SCREEN — T.47 MBR — T.48 REVERSE OSMOSIS — T.50 UV DISINFECTION — CALCITE FILTER — T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK —

SPECIFICATIONS

INFRASTRUCTURE

Membranes filters (hollow fiber or spiral wound) are housed inside membrane modules (cylindrical pressure vessels). These are generally mounted on a metallic structure (skid) together with high-pressure pumps, interconnecting piping, inline valves, control systems, and backwash and cleaning systems. These skids facilitate transport and practical operation of the system, and ensure a compact footprint. They are usually placed in a (basement) mechanical room together with pre- and post- treatment steps. Infrastructure to handle brine (reject stream) from nanofiltration and reverse osmosis should be carefully considered. Significant volumes of brine are produced (e.g., 15-25% of the treated stream for reverse osmosis) and due to its high content in salts, it is sometimes not possible to send the brine to the sewer.

OPERATION & MAINTENANCE

Membrane filters can have relatively high energy requirements when they require high-pressure pumps. Reverse osmosis is the most energy-intensive of the membrane filters with operational pressures of more than 6 bar. Micro- and ultrafiltration require much less energy. Though much of the membrane filtration process can be automated, specialized personnel is usually responsible for its operation and maintenance. Conventional micro- and ultrafiltration systems must be regularly backwashed (i.e., the flow is temporarily reversed) to remove foulants accumulating on the membrane surface. Membranes also require periodic chemical cleaning to remove the long-term accumulation (scaling) of salts, organic materials or biolfilm on the membranes with citric acid, caustic, detergents or chlorine (e.g., every 30-60 days for micro- and ultrafiltration, or every 3-12 months for nanofiltration and reverse osmosis). Membranes must be replaced depending on fouling rates and operational conditions every 10-15 years.

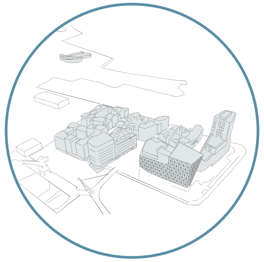
TARGET OUTPUTS

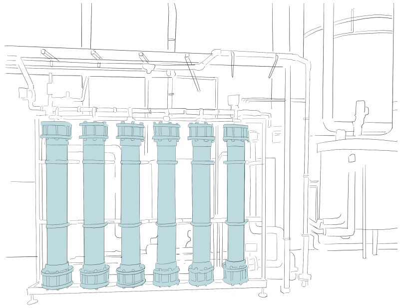
The quality of the filtered water (in terms of pathogen, dissolved organics and salt content) will depend on the type of membrane system used. Micro- and ultrafiltration membranes are generally sufficient for non-potable water reuse applications when followed by a disinfection step (to further remove pathogens) and/or advanced oxidation step (to remove micropollutants). Nanofiltration and reverse osmosis retain bacteria and viruses, and deionize and/or desalinize the stream to, e.g., avoid long term damage to plumbing fixtures, and heating and cooling systems. A multibarrier approach with redundancy in pathogen and micropullutant removal steps, helps ensure safe water reuse.

SELECTED CASE STUDIES

OCEANHAMNEN

Helsinborg, Sweden | 2021





Nanofiltration coupled to ozonation for micropollutant removal

Greywater from the neighborhood (scaled for 2100 p.e.) is treated in an activated sludge system followed by a drum filter (10 μm) and nanofiltration. The nanofiltration unit comprises a skid with 12 membrane modules, a permeate tank and a cleaning skid. The reject stream from the nanofiltration is treated by ozonation, to break down persistent micropollutants, before being recycled back into the activated sludge system. The backwash is also recycled back to the activated sludge, while the water from the chemical cleaning of the membranes is discharged to the sewer.

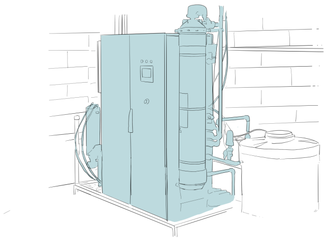
T.51 OZONATION

heat

GW — COLLECTION TANK — T.46 ACTIVATED SLUDGE — T.42 DRUM FILTER — T.48 NANOFILTER — T.61 HEAT PUMP — T.41 STORAGE TANK

HOLLAND PARK

London, UK | 2021



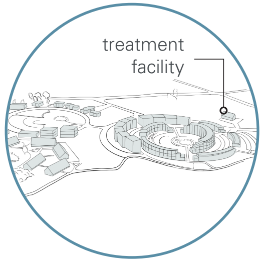
Greywater treatment "on demand" with ultrafiltration

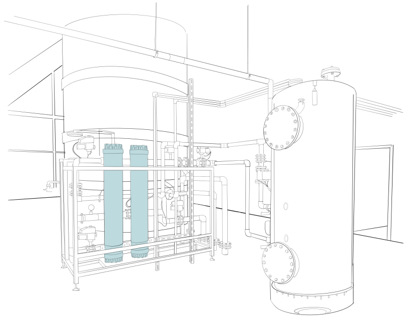
Ultrafiltration membranes are the core technology of this greywater treatment unit. At this 25-home residential complex, greywater is collected from sinks, baths, and showers and is sent via a dedicated piped network to a storage tank in the basement. The water is treated without a biological step due to very strict space limitations. Key to the correct operation of this system is that greywater can be quickly treated and reused on demand and does not need to be stored for long periods of time. A high pressure disc filter ensures that the membranes will not clog. The water is reused for toilet flushing.

GW — T.41 STORAGE TANK — T.42 DISC FILTER — T.48 ULTRAFILTRATION MEMBRANES — T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK

NYE SUBURB

Aarhus, Denmark | 2018





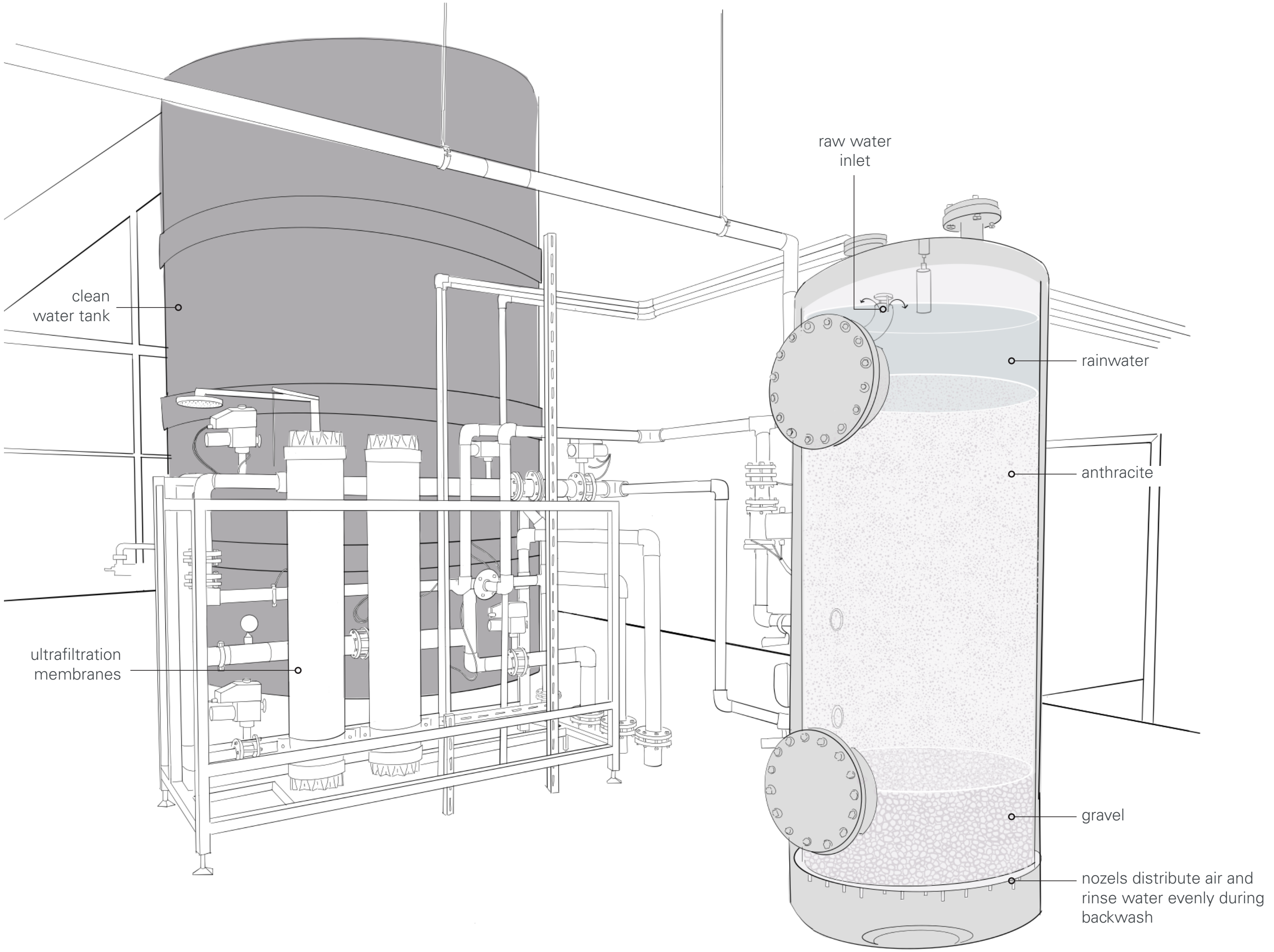
Rainwater treatment with ultrafiltration for non-potable reuse

The Aarhus suburb of Nye (~13,500 p.e.) is a modular housing project, with a rainwater reuse system operated by the local utility. Rainwater is treated in a multimedia pressure filter followed by ultrafiltration membranes (0.2 μm) before storage in a clean water tank (55 m³). Before distribution, the water undergoes UV disinfection. The treated water is reused for toilet flushing and in washing machines, providing 40% of the water demand in Nye.

RW — T.41 CISTERN — T.49 MULTIMEDIA FILTER — T.48 ULTRAFILTRATION MEMBRANES — T.41 STORAGE TANK — T.50 UV DISINFECTION

T.49 GRANULAR MEDIA FILTERS

TECHNOLOGY



Granular media filtration removes suspended and colloidal particles by passing (treated) water downward through one or several layers of granular filter material (e.g., sand, anthracite, activated carbon, zeolite, gravel, etc.). These porous filters are based on three main types of retention mechanisms: straining at the surface, attachment of particles to the media (adsorption, ion exchange) or settling. Pressure filters are water-tight, closed systems in which the water flows through the media under pressure. In open sand filters water flows though the media by gravity. During (prolonged) operation, suspended solids will clog the media pores, increasing hydraulic resistance in the filter. To restore filter capacity, the filter either needs to be cleaned (by backwashing) or discarded (typically cartridge filters). For relatively clean water streams, granular media filtration can be implemented directly. If the water contains high solids concentrations, pretreatment is recommended.

Granular media filters are effective in removing suspended solids. Some filters are effective for the removal of pathogens, organics and inorganics, and for odor, color and taste correction.

INPUT STREAMS

GW Pre-treated Greywater
MW Pre-treated Mixed Wastewater
RW Rainwater

TARGET OUTPUT(S)

Treated Water

NYE SUBURB

Aarhus, Denmark | 2018

Multimedia filter for rainwater treatment for non-potable use

This Aarhus suburb (~13,500 inhabitants) is a modular housing project, with a rainwater treatment and reuse system operated by the local utility. Rainwater, collected in outdoor lakes, is first treated with a multimedia pressure filter, followed by ultrafiltration and storage in a clean water tank (55 m^3). Before distribution, the water undergoes UV disinfection, and is used for toilet flushing and laundry, providing 40% of the water demand in Nye.

RW — T.41 CISTERN — T.49 MULTIMEDIA FILTER — T.48 ULTRAFILTRATION — T.41 STORAGE TANK — T.50 UV DISINFECTION —

SPECIFICATIONS

INFRASTRUCTURE

In urban contexts, compact media filters are often placed in a (basement) technical room together with pre- and post- treatment steps. These systems are often pressure filters (that require backwashing) or cartridge filters (that are periodically replaced).

> Open sand filters are placed outdoors and have larger footprints than encased granular media filters. However, open sand filters can be integrated into courtyard and garden landscapes for aesthetic appeal.

OPERATION & MAINTENANCE

Operation and maintenace of media filters includes the pumping of water into the system and the cleaning of the filters, either by backwashing or replacement.

Backwash-based: To clean the filter, the direction of the water flow through the filter is reversed to release captured solids and restore filtration efficiency. This needs to be performed in regular intervals (e.g., either manually, or automatically). During a short period, high energy consumption takes place to pump the water and air through the system.

Cartridge: Once cartridge filters have reached loading capacity, the cartridges are discarded and replaced periodically. Their replacement is done manually. Costs for material and personel are low, though recurring.

> Backwash water is a byproduct stream of granular media filtration that requires additional treatment. Typically, this stream is sent to sewer, meaning the technology lends itself best to contexts where a connection to sewer is possible.

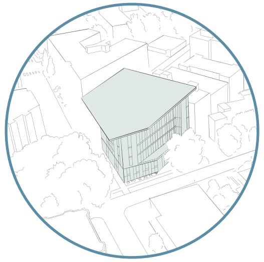
TARGET OUTPUTS

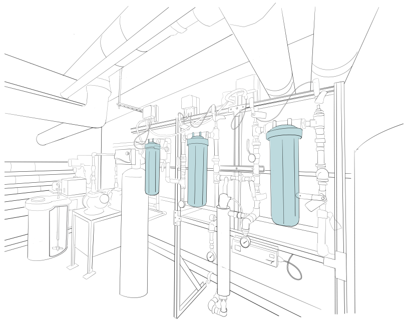
Granular media filtration renders a treated water stream. Removal of suspended particles and organic matter is the primary treatment objective of the technology. Pathogens are also partially removed. The treated water is often treated further (e.g., membrane filtration and/or disinfection) to achieve higher water quality. Suitability of the treated water for reuse depends on the type of water treated, intended use, local regulations, and public health requirements.

SELECTED CASE STUDIES

BULLITT CENTER

Seattle, WA, USA | 2015





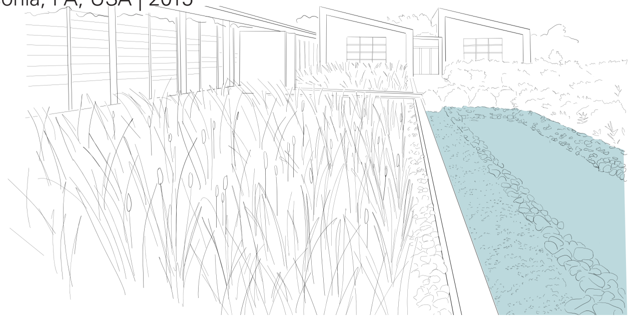
Cartridge filters for rainwater treatment in office building

The Bullitt Center is a six-story office building (175 occupants) with a rain-to-tap treatment system. From the rooftop catchment area to a 800 m^3 cistern in the basement, the rainwater is treated by a 5 micron activated carbon cartridge filter, a first 0.5 micron cartridge filter, UV disinfection, a second 0.5 micron cartridge filter, remineralization, and chlorination. Treated water is stored in two 2 m^3 tanks before reuse as tap water; vacuum toilets are flushed with separately-treated greywater. The building uses 94% less water than an average building in the city and is Living Building Challenge (LBC) certified.

RW — T.41 CISTERN — T.49 CARBON FILTERS — T.50 UV DISINFECTION — T.49 CARBON FILTER — CALCITE FILTER — T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK

EDEN HALL CAMPUS

Gibsonia, PA, USA | 2015



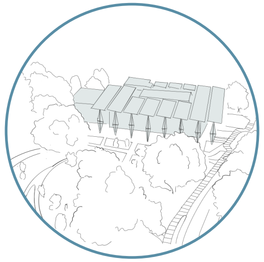
Open sand filter treats university greywater and wastewater

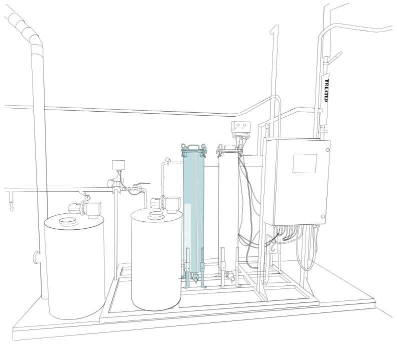
The wastewater system collects greywater and blackwater for treatment using a low-energy plant-based system with a design flow of 23 m^3 per day. The sand filter is an encased, rectangular bed of sand and gravel with subsurface horizontal flow through the filter. The treated water accounts for 16% of the onsite water consumption and covers 100% of the toilet flushing demand. Excess water is used for subsurface irrigation. Their water reuse strategy helps them meet building accreditation goals including LEED platinum and Living Building Challenge (LBC).

GW (BW) — T.42 SETTLING TANK — T.45 TRICKLING FILTER — T.44 CONSTUCTED WETLAND — T.49 SAND FILTER — EFFLUENT TANK — T.50 UV DISINFECTION

KENDEDA BUILDING

Atlanta, GA, USA | 2017





Media filtration for rainwater to tap in university building

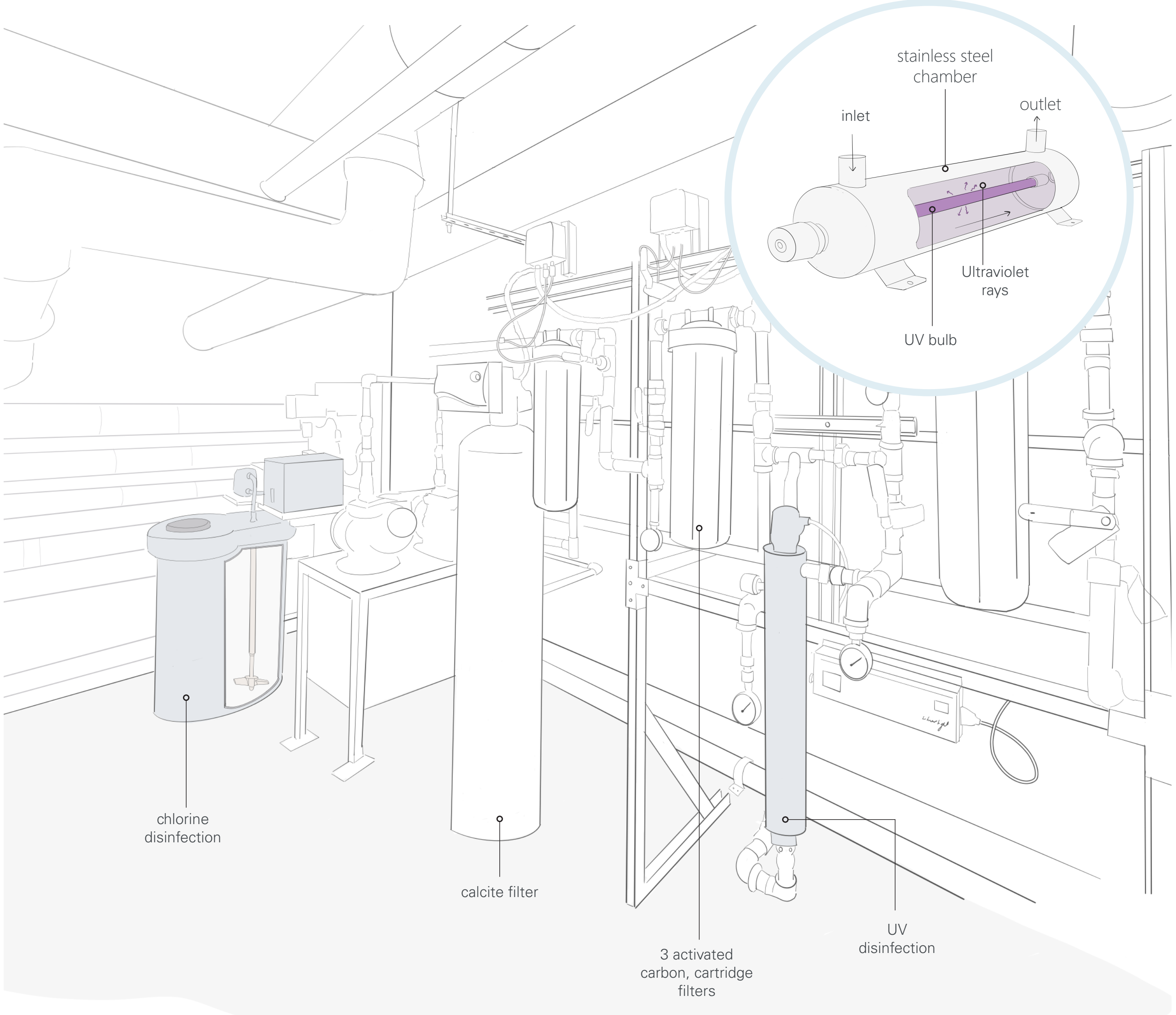
Rainwater is harvested from the green roof and PV paneled-roof deck of the classroom building at Georgia Tech University. After collection and coarse filtration, it is stored in a cistern (190 m^3) in the basement. Treatment includes media filtration (turbidity reduction filter), ultrafiltration, UV and chlorine disinfection, and point-of-use dechlorination. While 41% of the rainwater is treated and used to supply all potable water demands for the building, 59% is directly directed to onsite stormwater systems. The building is certified under the Living Building Challenge (LBC).

RW — T.41 CISTERN — T.49 MULTIMEDIA FILTER — T.48 ULTRAFILTRATION — T.50 UV DISINFECTION — T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK

T.50

UV & CHLORINE DISINFECTION

TECHNOLOGY



RW — T.41 CISTERN — T.49 CARBON FILTERS — T.50 UV DISINFECTION — T.49 CARBON FILTER — CALCITE FILTER — T.50 CHLORINE DISINFECTION — 💧

Ultraviolet (UV) disinfection and chlorination are treatments to inactivate pathogens, including bacteria, viruses and protozoa present in the water. UV disinfection is based on physical mechanisms (i.e., electromagnetic radiation). As water passes along UV bulbs, the UV light damages the pathogens' genetic material, leaving them unable to replicate. Inactivation by UV depends on the continuous exposure to and intensity of the light (typically 254 nm), the duration of exposure, and the absence of suspended particles. Chlorination is a quick, simple, and cheap method of disinfection based on chemical mechanisms: by adding chlorine to the water to attack pathogens. Chlorination is the only treatment that provides residual disinfection, preventing regrowth of pathogens in water distribution networks and storage tanks. For effective disinfection, the influent requires pre-treatment to remove organic matter, nutrients, and suspended particles.

Chlorine disinfection removes odor, taste, and color, and provides residual disinfection, however, it also produces potentially harmful disinfection byproducts (e.g., trihalomethanes). UV has no effect on color, odor, taste and regrowth prevention, and does not produce disinfection byproducts.

INPUT STREAMS

- GW Pre-treated Greywater
- MW Pre-treated Mixed Wastewater
- RW Pre-treated Rainwater

TARGET OUTPUT(S)

- 💧 Treated Water

BULLITT CENTER

Seattle, WA, USA | 2015

Rainwater-to-tap with UV and chlorine disinfection

Rainwater from the rooftop catchment area of this six-story office building (175 occupants) is led to a 800 m³ cistern in the basement. From there, the rainwater is treated by a 5 micron carbon cartridge filter, a 0.5 micron cartridge filter, UV disinfection, a second 0.5 micron cartridge filter, remineralization (calcite filter), and chlorination. Treated water is stored in two 2 m³ tanks. The building uses 94% less tap water than an average building in the city and is Living Building Challenge (LBC) certified.

SPECIFICATIONS

INFRASTRUCTURE

Both chlorine and UV disinfection are compact treatment processes that can be scaled to context. Commercial set ups are widely available for both. Automiatic chlorine dosing requires an energy source for pumps, and mixing mechanisms, while UV systems require an energy source to power the UV bulbs. It is recommended to install UV disinfection units as close as possible to point of water reuse.

> Chlorine derivatives are sometimes included on sustainable building certification 'red lists'. However, certifications can still be granted where regulations require chlorine disinfection for water treatment.

OPERATION & MAINTENANCE

UV disinfection generally has low operation and maintenance requirements, though needs a constant source of electricity and initial equipment costs are higher than chlorine disinfection. After installing UV, operation includes a constant source of electricity and monitoring of the flow rate to and retention of water in the UV disinfection unit. Bulbs need to be cleaned, when dirty, to maintain light emission intensity. While the system has a long lifespan, the bulbs should be replaced in regular intervals (e.g., 12 months).

Chlorination requires continuous or periodic dosing of liquified chlorine gas or sodium hypochlorite solution, or by using on-site chlorine production via electrolysis. Though chlorine is widely available, its sourcing, transport, and dosing needs to be coordinated and carefully executed. Dosing can either be manual or automatic, and is often based on regular monitoring of water quality. It is important to dose chlorine correctly to ensure adequate inactivation, and provide enough residual chlorine to prevent regrowth in pipes and tanks, without negatively affecting taste or even human health.

> Both UV and chlorination lend themselves for on-site and off-grid water treatment for reuse thanks to their compact form and simple use and maintenance. Access to chlorine chemicals or replacement bulbs is required.

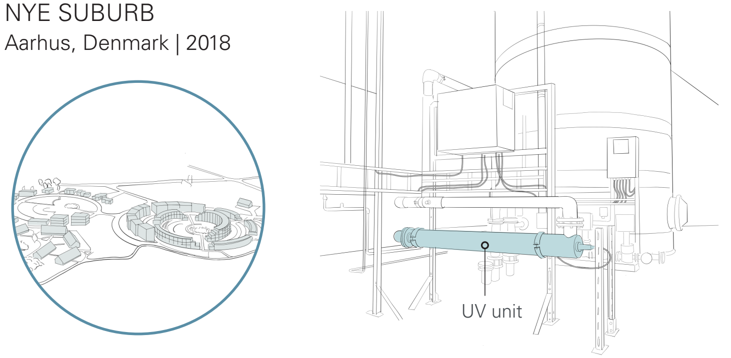
TARGET OUTPUTS

The treated water from both disinfection processes is suitable for high-quality reuse. The combination of disinfection processes with the preceding treatment technologies renders a high-quality treated water for onsite, often indoor, reuse. In some instances, the water is even safe for drinking (e.g., Bullitt Center).

SELECTED CASE STUDIES

NYE SUBURB

Aarhus, Denmark | 2018



Neighborhood rainwater treatment with UV disinfection

The Aarhus suburb of Nye (~13,500 inhabitants) is a modular housing project, with a rainwater treatment and reuse system operated by the local utility company. Rainwater, collected in outdoor collection ponds, is first treated in a multi-media pressure filter, followed by ultafiltration and storage in a clean water tank. Before distribution, the water undergoes UV disinfection. The treated rainwater is reused for toilet flushing and in washing machines, covering 40% of the water demand in Nye.

RW — T.41 CISTERN — T.49 MULTIMEDIA FILTER — T.48 ULTRAFILTRATION — T.41 STORAGE TANK — T.50 UV DISINFECTION — 💧

DE NIEUWE DOKKEN

Ghent, Belgium | 2020

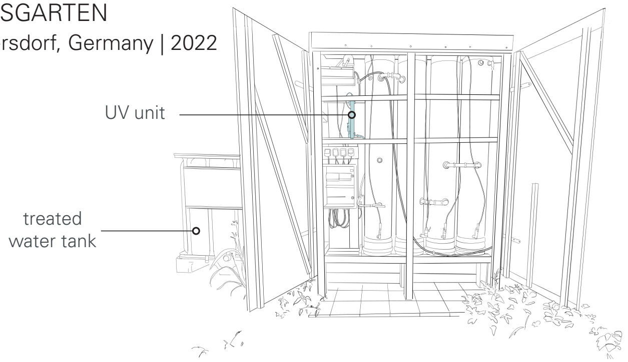
Greywater treatment with chlorination for district reuse

At De Nieuwe Dokken source-separated greywater and the effluent from vacuum blackwater treatment (including anaerobic digestion and struvite precipitation) is treated biologically, followed by an activated carbon filter to remove color, a heat exchanger for heat recovery, and chlorination for disinfection. The treated water is reused as process water by a neighboring soap factory. The treatment train is designed for 430 apartments (1200 p.e.), and the expected water available for reuse is ~30,000 m³ per year.

GW — T.42 SCREEN — (BW) T.41 BUFFER TANK — T.47 MBR — T.49 ACTIVATED CARBON FILTER — T.61 HEAT EXCHANGER & HEAT PUMP — (heat) T.50 CHLORINE DISINFECTION — T.41 STORAGE TANK — 💧

GUTSGARTEN

Hellersdorf, Germany | 2022



UV disinfection of kitchen greywater for irrigation

Located on the historic Hellersdorf estate, the Gutsgarten community vegetable garden treats kitchen greywater for onsite plant irrigation. The treatment includes a sieve and grease trap to retain solids and remove grease. After a buffer tank, the water is biologically treated in a four-columned Moving Bed Biofilm Reactor (MBBR) using foam cube carriers. The last treatment step is UV disinfection to reduce pathogenic risks during reuse. The treated water is used to irrigate 60 raised garden beds.

GW — T.42 SCREEN — T.42 DEGREASER — T.46 AERATED BIOREACTOR — T.50 UV DISINFECTION — T.41 STORAGE TANK — 💧

T.51

OZONATION | ADVANCED OXIDATION

TECHNOLOGY

Ozonation is the injection of ozone gas into a water stream for the chemical removal (i.e., via oxidation) of organic and some inorganic pollutants, as well as odor and color. Ozone (O_3) is an unstable chemical which, when injected in water, forms free radicals (HO_2, •OH) that react with organic and inorganic compounds to break them down or inactivate them. Due to this strong oxidizing capacity, ozonation is effective for disinfection of pathogens, as well as for the removal of persistent organic micropollutants, that are broken down into smaller, more readily biodegradable compounds. These smaller, often insoluble compounds can then be removed in subsequent treatment steps. Advanced Oxidation Processes (AOPs) work by generating highly reactive oxygen species, mainly hydroxyl radicals (•OH), that oxidize and degrade micropollutants. These processes can be, for example, ozone-based, hydrogen peroxide-based, photocatalytic (i.e., UV/light-driven).

Ozonation and other AOPs can be used for the targeted removal of organic micropollutants (like pesticides, pharmaceuticals and PFAS) from treated water for potable reuse applications, or when stricter discharge regulations apply.

INPUT STREAMS	TARGET OUTPUT(S)
GW Pre-treated Greywater	Treated Water
MW Pre-treated Mixed Wastewater	
RW Rainwater	

GILETTE STADIUM & PATRIOT PLACE

Foxborough, MA, USA | 2003

Ozonation and UV for mixed wastewater treatment and reuse

A large water reuse system, designed to treat approximately 950 m³/d of mixed wastewater, provides treated water for toilet flushing, cooling, and other services for the stadium and adjacent shopping center. Excess treated water is discharged to a groundwater recharge field. Ozonation is used to remove residual color from the effluent of the MBR, and is followed by UV for disinfection.

MW — T.41 BUFFER TANK — T.46 MBR — T.51 OZONATION — T.50 UV DISINFECTION — T.41 STORAGE TANK —

SPECIFICATIONS

INFRASTRUCTURE

Ozonation or AOP systems are typically placed in a technical room and usually occupy a relatively small space compared to biological or filtration treatment units.
Ozonation systems typically include (1) an oxygen/air supply system (e.g., oxygen production/storage), (2) an ozone generator, where the dry air or oxygen gas is submitted to an electrical field to generate ozone gas, (3) an ozone contact chamber, where ozone is injected into the stream, and (4) an off-gas destructor, to safely remove excess ozone. Basic monitoring sensors for ozone dosing, residual ozone and oxidation-reduction potential are also required.
AOPs rely on a combination of treatments, and therefore include more complex infrastructure. This can include infrastructure for ozonation, together with, for example, dosing systems for hydrogen-peroxide, or UV lamps and reactors for photocatalytic systems.

OPERATION & MAINTENANCE

Capital and operational costs are generally higher for ozonation and AOPs, compared to UV or chlorine disinfection T.50 alone because they are more complex technologies, and because ozone generation uses significant amounts of electrical power. Safety in operation and maintenance of ozonation systems is required as ozone is a toxic gas and explosive at high concentrations. An ambient ozone monitoring system to detect ozone leaks, and operation and maintenance by specialized personnel is advised for these systems. For ozonation, operators mainly ensure a steady oxygen/air supply, monitor ozone dosage/leaks, clean contact tanks and maintain/replace ozone generator parts. For AOPs, operators need to coordinate multiple inputs (chemicals, UV, pH), replace lamps and catalysts, manage chemical storage and perform frequent monitoring.

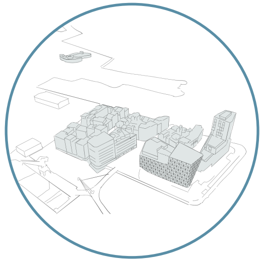
TARGET OUTPUTS

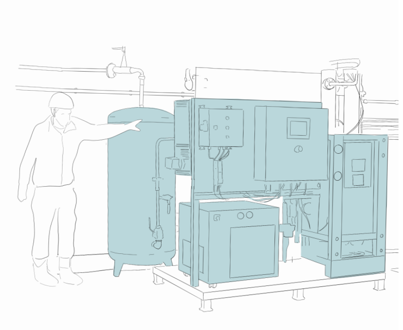
Ozonation and AOPs are used to obtain a disinfected, colorless, and odorless treated water streams for water reuse. Ozonation, like UV disinfection, is sometimes a preferred disinfection technology over chlorination because it leaves no chlorinated residuals in the stream. However, this also means that care must be taken to avoid microbial regrowth in the treated water during storage and distribution. This can be dealt with by regular booster ozonation during distribution or regularly recirculating the stored treated water through the ozonation system. Sometimes, chlorine is added to the treated water stream after ozonation as an additional precaution.

SELECTED CASE STUDIES

OCEANHAMNEN

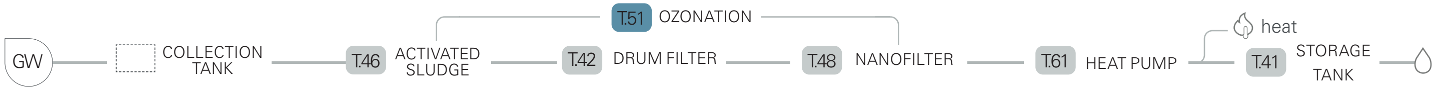
Helsinborg, Sweden | 2021





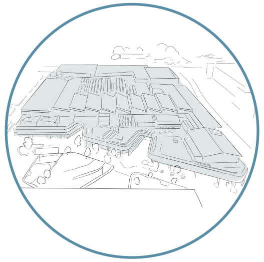
Ozonation for micropollutant removal

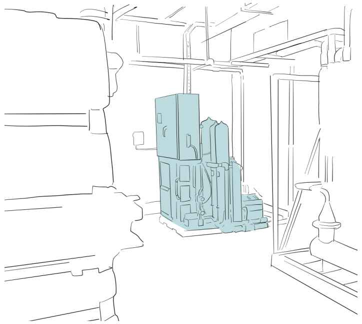
Greywater collected from the Oceanhamnen district (2100 p.e.) is treated with an activated sludge system coupled to nanofiltration. The reject stream from the nanofiltration is treated by ozonation, to break down persistent micropollutants, before being recycled back into the activated sludge system. In the future, it is expected that the liquid effluent from the blackwater and organic waste treatment will also be treated in this system. The recovered water will be used as bathing water in a neighboring swimming pool (under construction).



BURWOOD BRICKWORKS

Melbourne, Australia | 2019



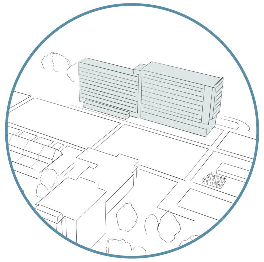


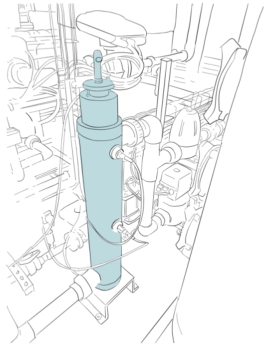
Ozonation and biological filtration for micropollutant removal

Burwood Brickworks is a large retail center certified as a Living Building that prioritizes good on-site water management. An MBR is the core of the water reuse treatment train, designed to treat 60 m³/day mixed wastewater and 30 m³/d stormwater, to be reused via the recycled water pipe network for toilet flushing, cooling towers, and irrigation. The effluent from the MBR is treated in an ozone system to break down persistent organic compounds followed by UV and BAC (biologically activated carbon). Collected rainwater, bypasses the MBR treatment and joins the input stream before ozonation.

SUPERLOCAL

Kerkrade, the Netherlands | 2021





Advanced oxidation for potable reuse from rainwater

SuperLOCAL, or Super Circular Estate project, is a suburban, residential, new build and retrofit development of 129 apartments (250 p.e.) based on circular material and waste design principles. Next to on-site vacuum sanitation and greywater treatment, rainwater collected from roof surfaces and paved areas, is treated for potable reuse. The treatment system with a capacity of 2.5 m³/h is placed in a dedicated building over a rainwater storage cistern (250 m³). After coarse filtration and nanofiltration, the water is treated by advanced oxidation (UV combined with ozone).