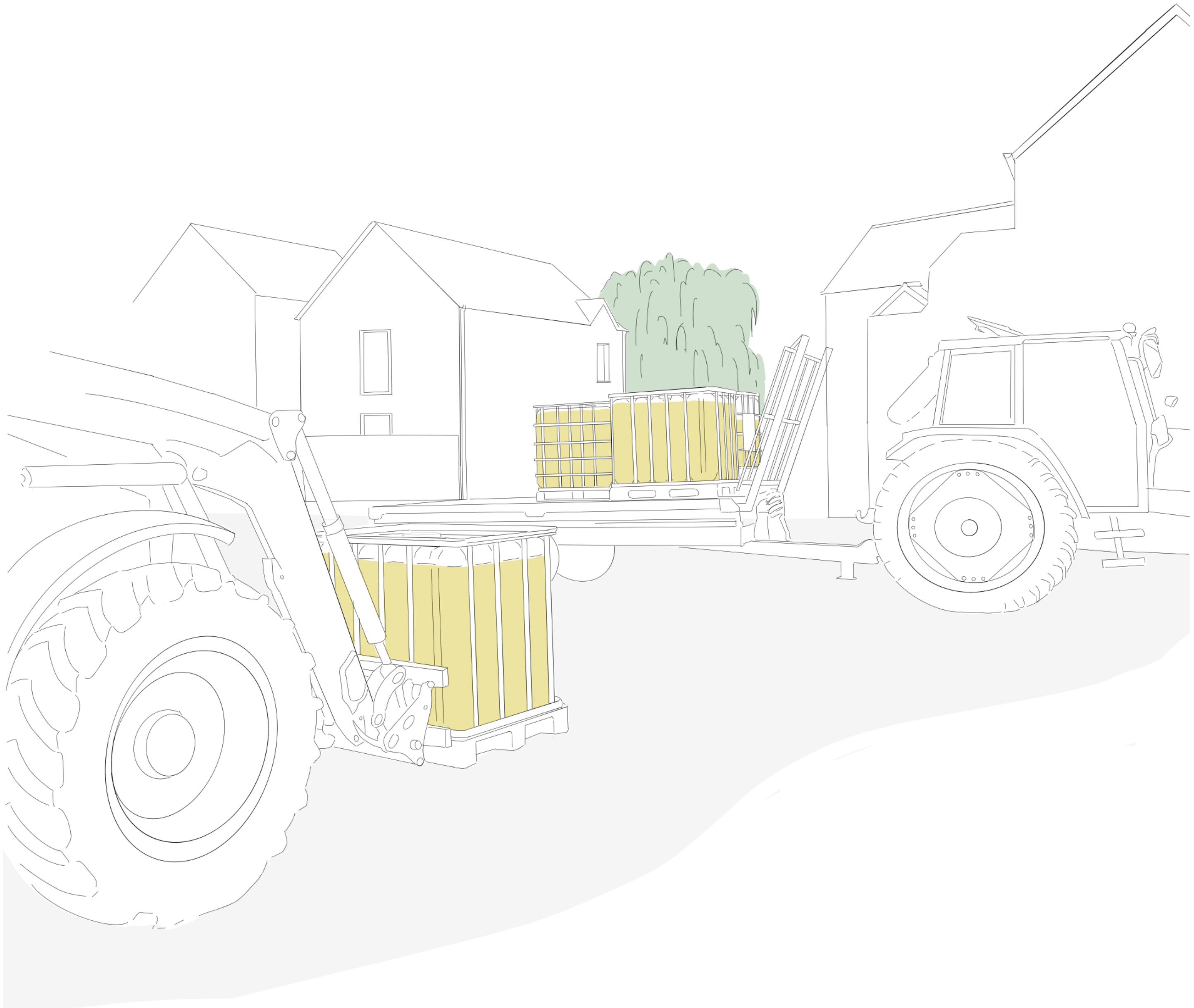
URINE STORAGE | PASTEURIZATION

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)
Urine	Liquid Fertilizer
Yellow water	

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

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 5m³ 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.

SPECIFICATIONS

INFRASTRUCTURE

After separate collection (via urine diversion toilet, urinal or jerry-can), 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 m³/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

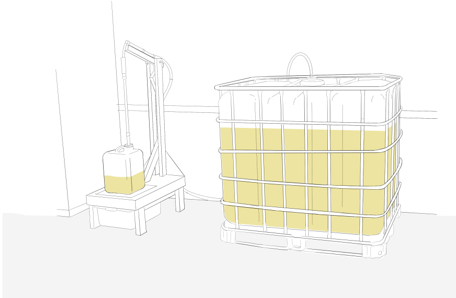
Stored urine can be used as a multi-nutrient liquid fertilizer. Precipitates that settled in the tank can be mixed into the liquid fraction before application, or separated out from the liquid fraction (this increases the N:P ratio and removes essential compounds like magnesium and calcium from the liquid 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.

Circular Sanitation TOOLBOX | 2025 | © Eawag
References and further information available at www.eawag.ch/en/wh/toolbox

SELECTED CASE STUDIES

RICH EARTH INSTITUTE

Brattelboro, VT, USA | 2012



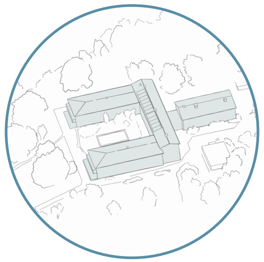
Community-scale urine collection and off-site pasteurization

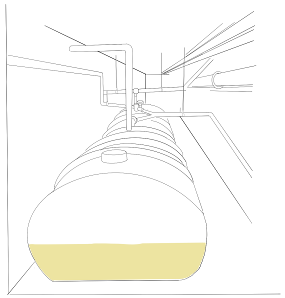
The Institute's Urine Nutrients Reclamation Program collects 45 m³ of urine each year from home and business installations and via a portable toilet service. Some households bring their urine (in portable jerrycans) to a urine depot, while others have onsite plumbed collection tanks. Urine from both 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





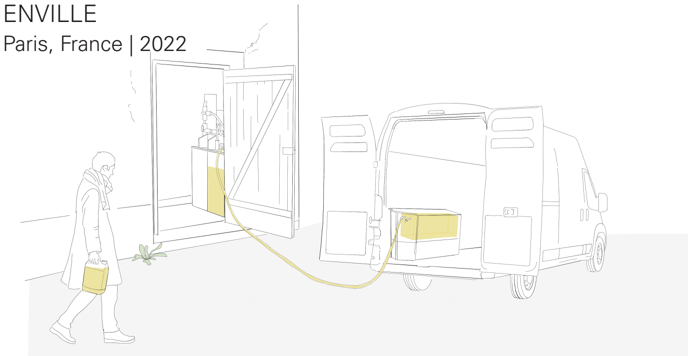
Urine collection and storage for fertilizer use on barley fields

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 m³) 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



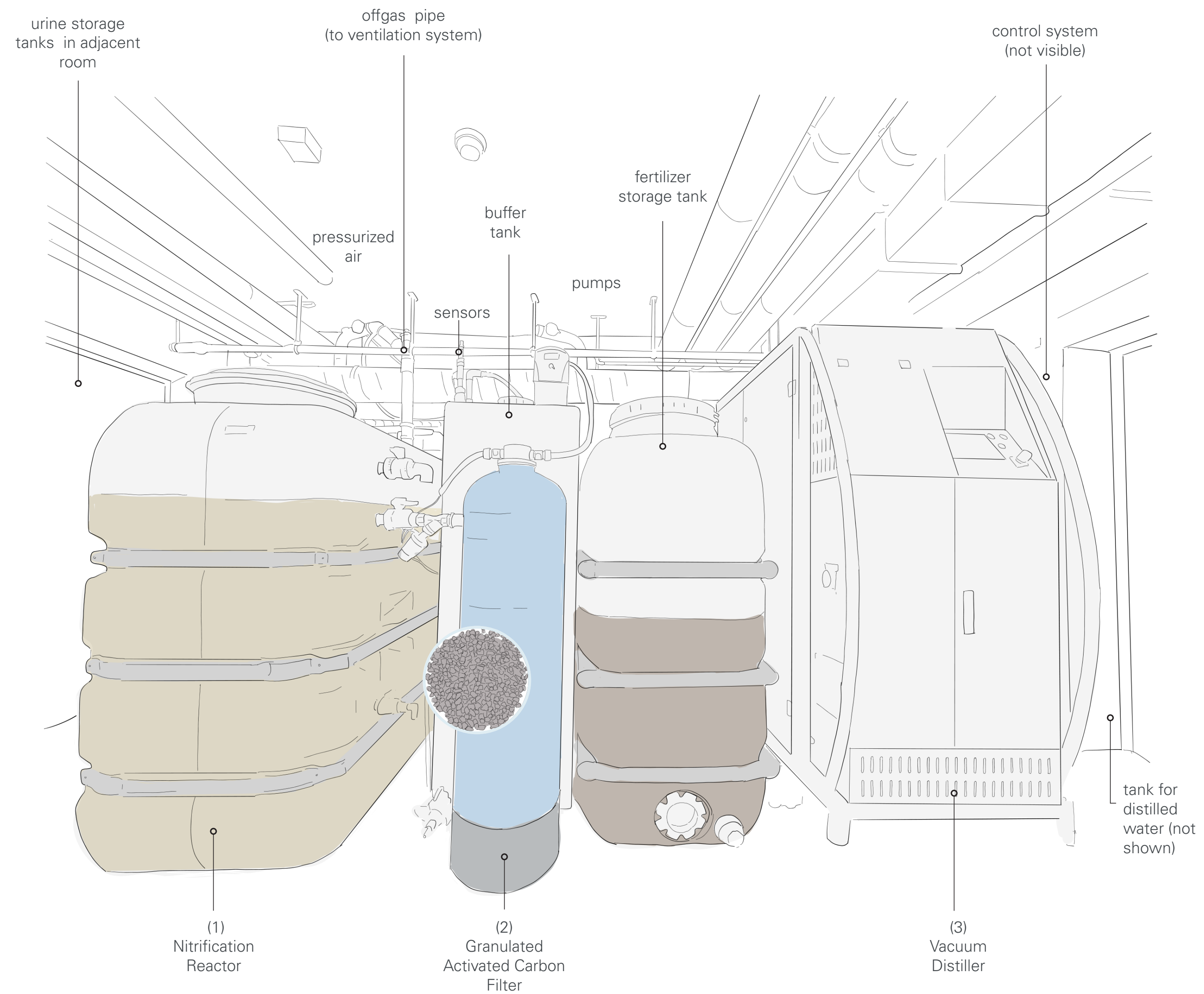
Citizen urine collection, stored and transported by partner farms

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

NITRIFICATION-DISTILLATION

TECHNOLOGY



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)
Urine	Liquid Fertilizer
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.

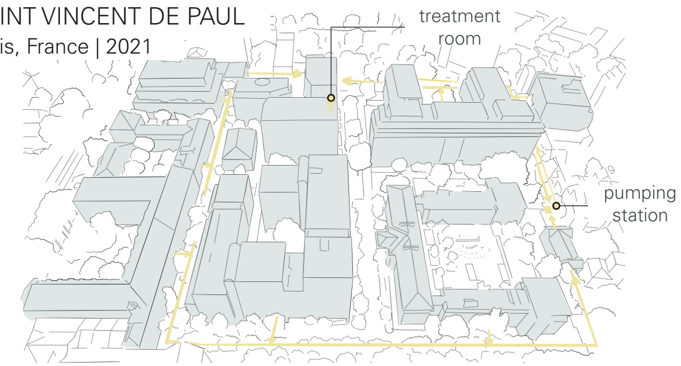
Energy: Energy is required mainly for the distillation process, and a small amount is needed for aeration and for pumps (to pump solutions between processes).
Consumables: The granular activated carbon filter for micropollutant removal is designed to be exchanged 1-2 times/year.
Byproducts: Distilled 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

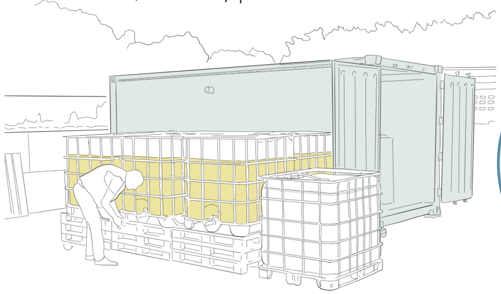


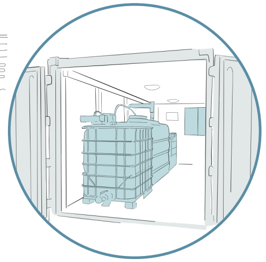
Urine diversion and treatment at neighborhood scale

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



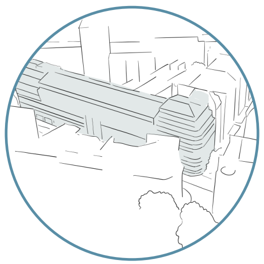


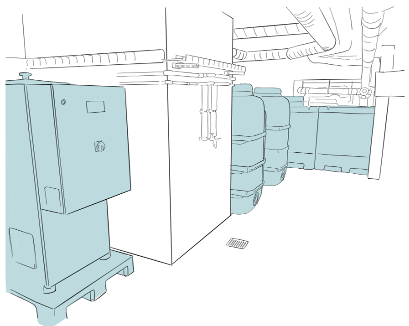
Nitrification-distillation of collected urine in centralized location

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





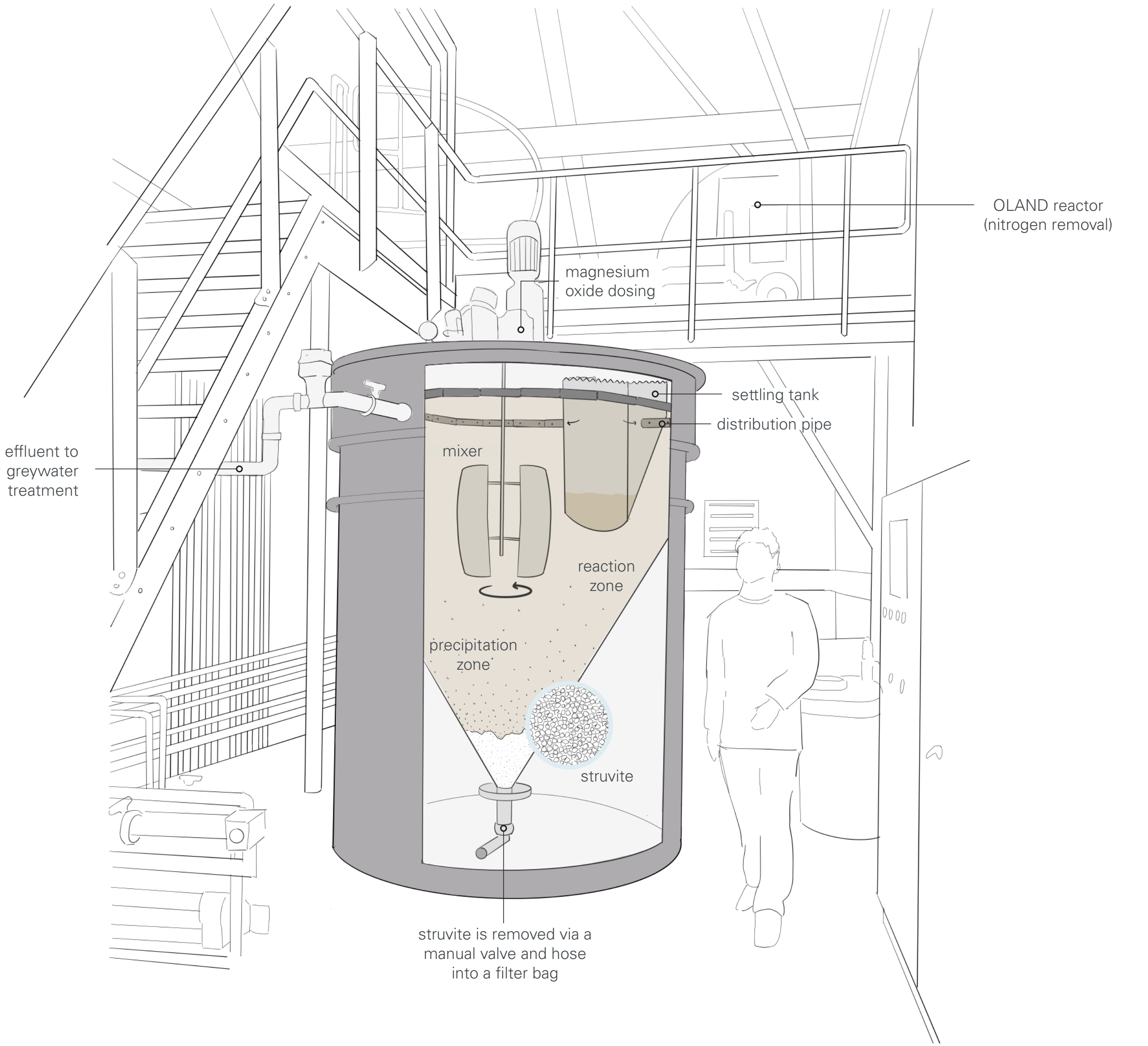
Nitrification-distillation fit into newly refurbished office building

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)

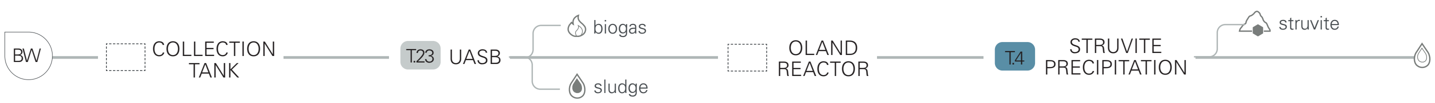
- Struvite

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 needs 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

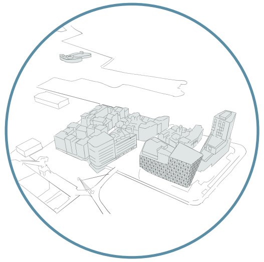
Struvite precipitation is the targeted recovery of phosphorus, which under optimal conditions can result in more than 90% recovery. Struvite can be used for crop fertilization. It provides phosphorus, magnesium, and ammonium in a slow-release form. Struvite can contain pathogens and heavy metals that 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.

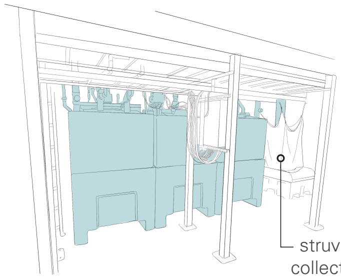
Struvite can be directly used in agriculture as a slow release fertilizer, though the low nutrient solubility and nutrient ratios may not meet full crop nutrient requirements. Struvite application rates may need to be adjusted compared to conventional phosphate fertilizers. Alternatively, struvite can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

SELECTED CASE STUDIES

OCEANHAMNEN

Helsingborg, Sweden | 2021



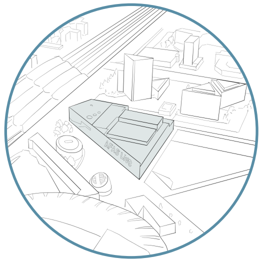


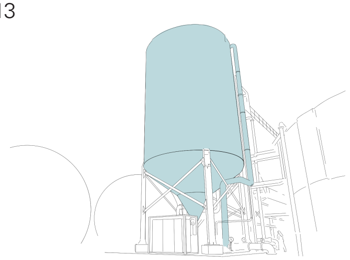
Struvite recovery from effluent from two anaerobic digesters

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



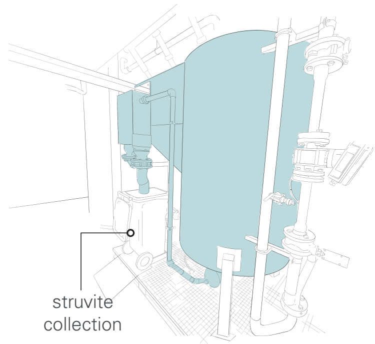


Struvite recovery from urine at centralized location

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

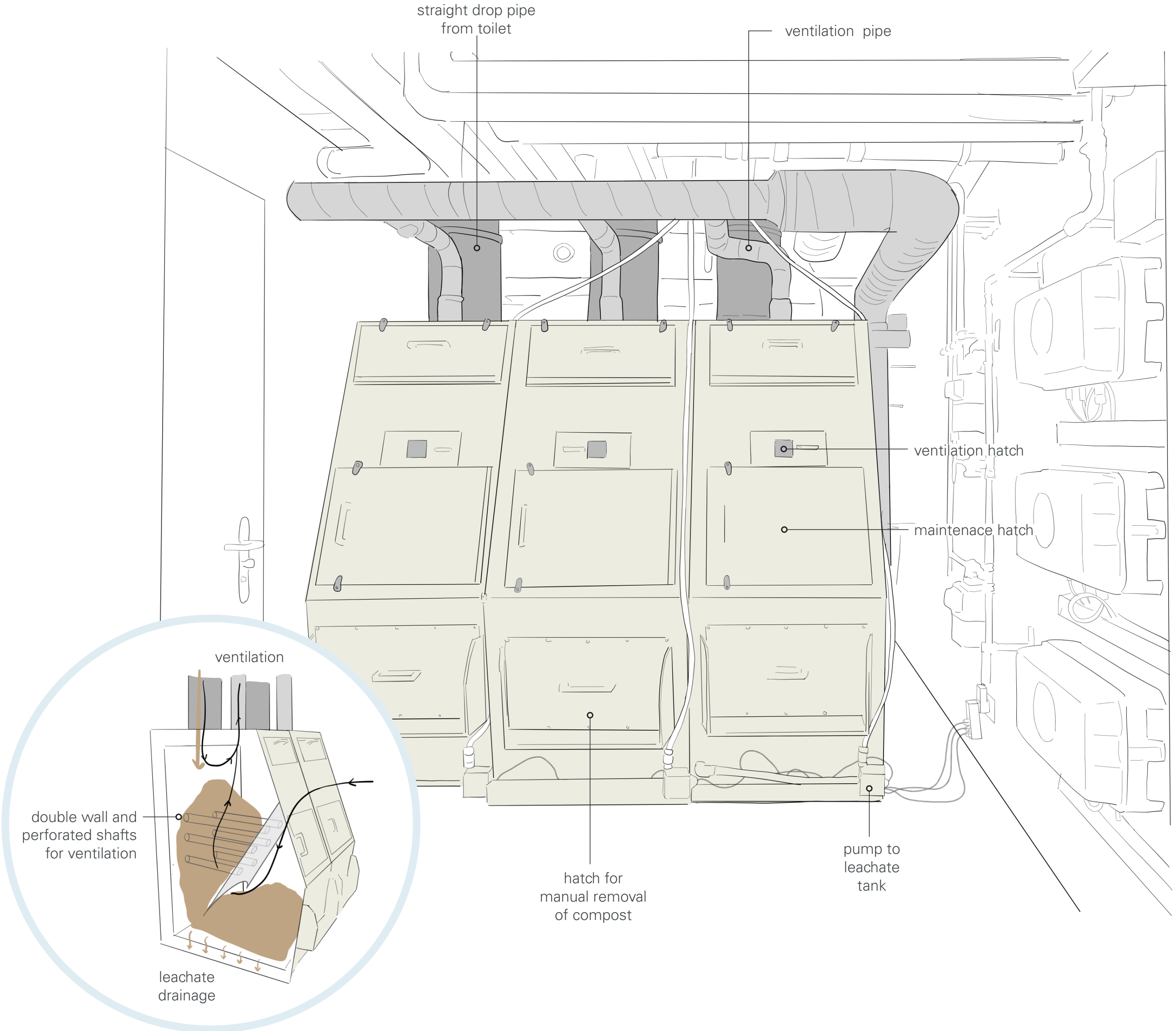


Struvite precipitation after anaerobic treatment

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



F — T21 COMPOSTING CHAMBER — COMPOST STORAGE — △

leachate

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

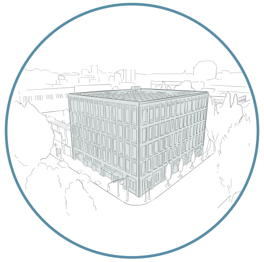
Operation and maintenance of decentralized composting or vermicomposting is relatively simple and can be carried out by the users/residents themselves. Depending on the chamber or container design and stream treated, varying operational measures may be required, for example, the addition of a bulking 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).

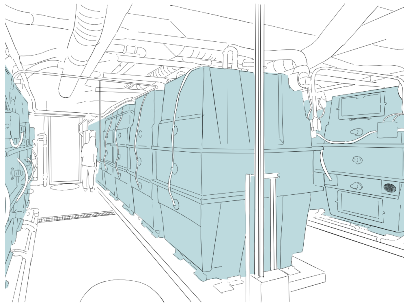
TARGET OUTPUTS

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



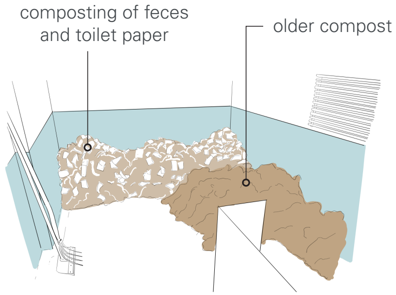


On-site composting from vacuum-collected blackwater

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

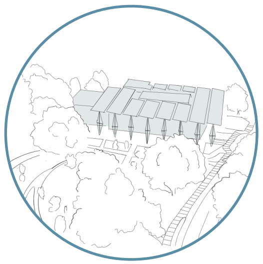


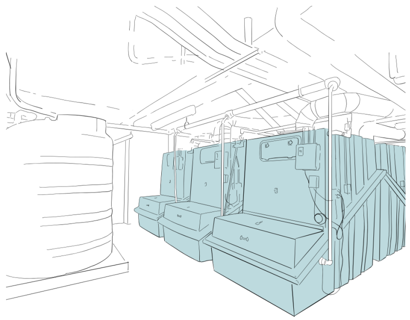
Vermicomposting of feces in alpine hut

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





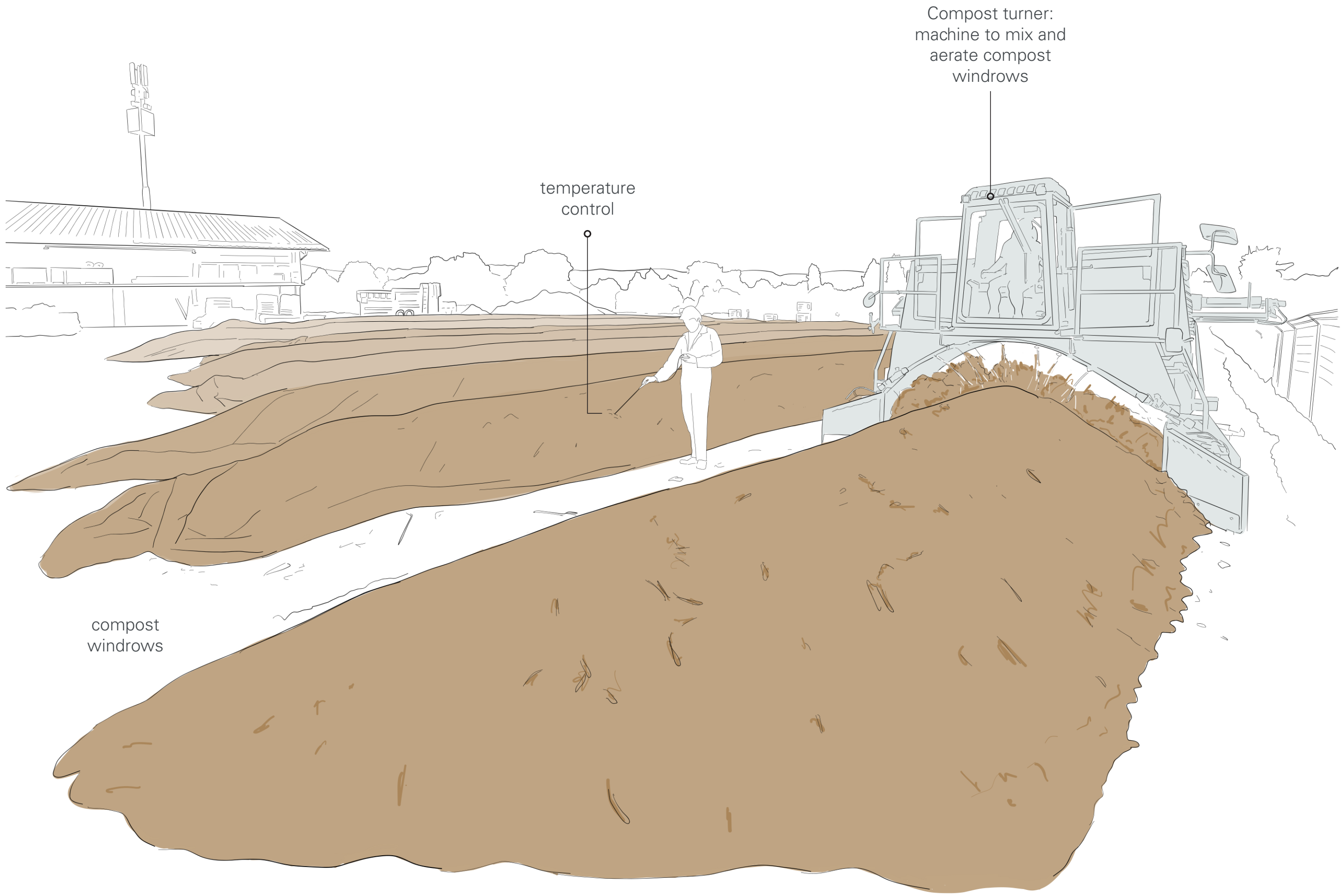
University building with foam flushing toilets

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 — T.22 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.

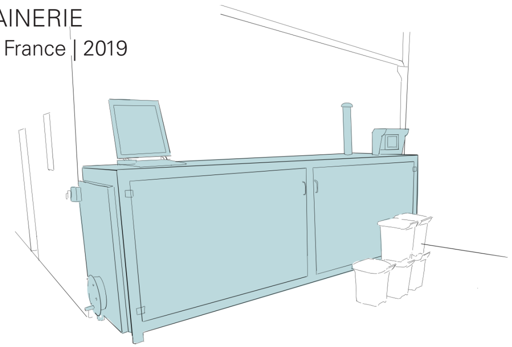
TARGET OUTPUTS

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

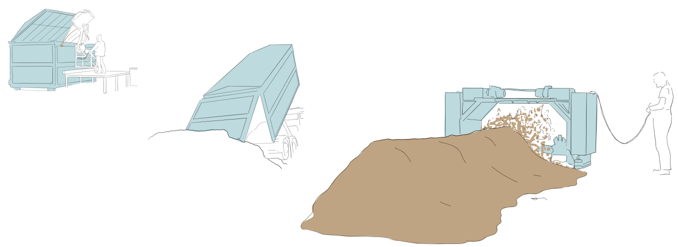


Chamber composting of collected feces in urban context

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

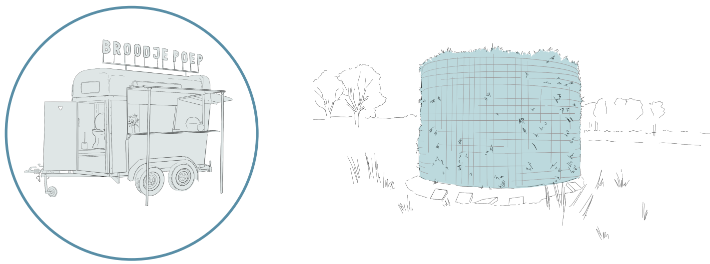


Windrow composting of human excreta from dry toilets

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

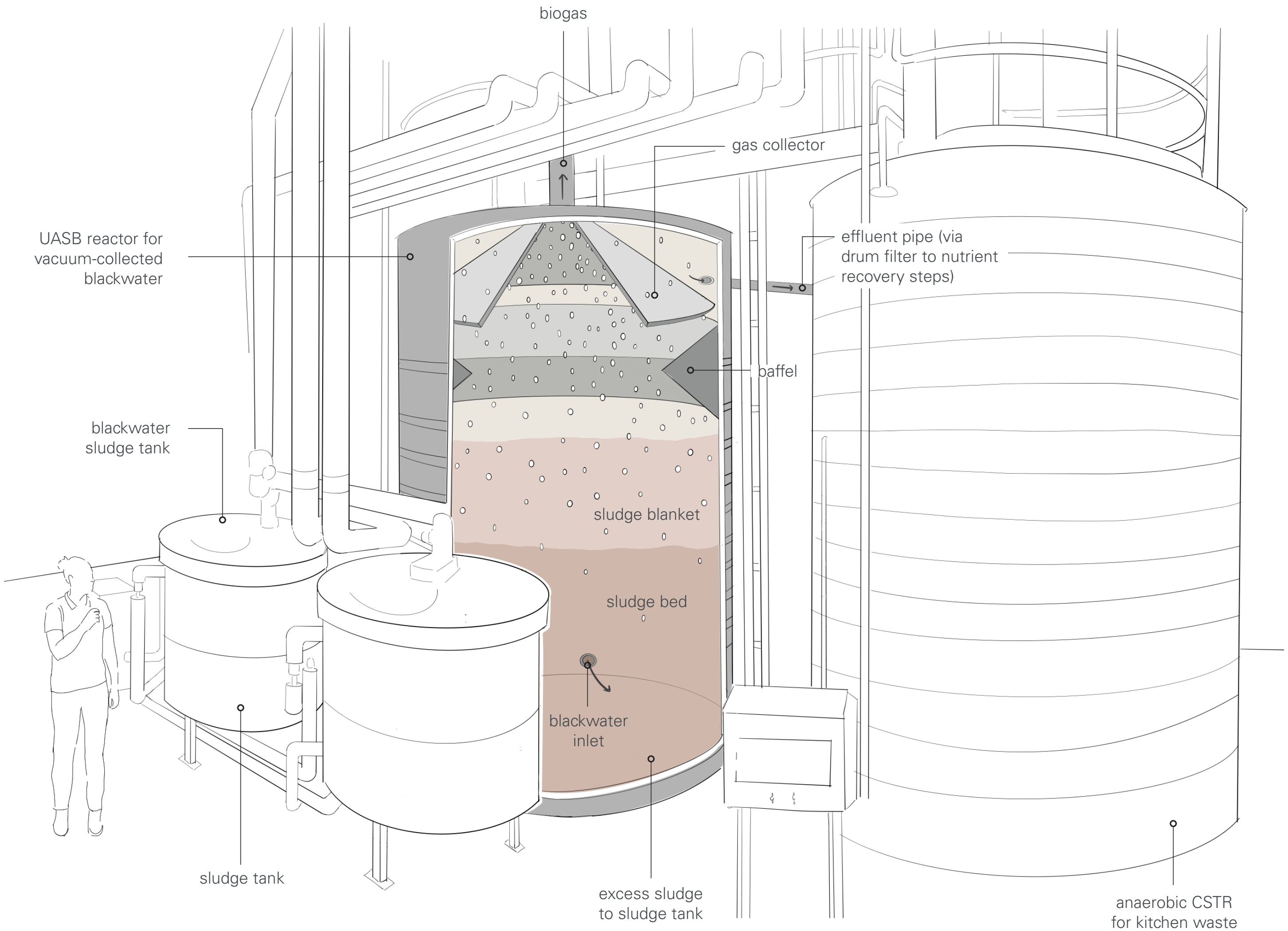
The Broodje Poep food truck is a social design initiative that not only prepares sandwiches, but also has a dry toilet on the side. The collected excreta are transported to a treatment facility for composting in a biomeiler system. A biomeiler (~ 35 m^3) includes an outer bufferzone of hay bales, filled 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

ANAEROBIC DIGESTION

TECHNOLOGY

eawag aquatic research



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.

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).

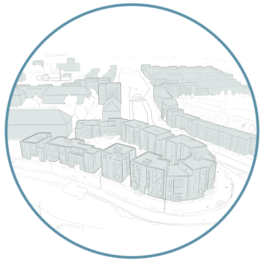
TARGET OUTPUTS

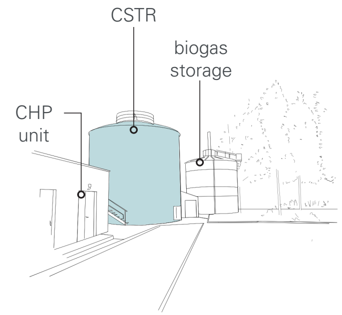
Anaerobic digestion yields biogas, sludge and effluent. The produced biogas can be converted into heat in a burner or used in combined heat and power (CHP) systems for electricity and heat. The digestate or sludge, rich in organics and nutrients, can be used as a soil amendment, however further treatment 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

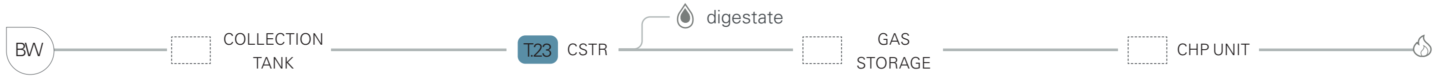
JENFELDER AU
Hamburg, Germany | 2013



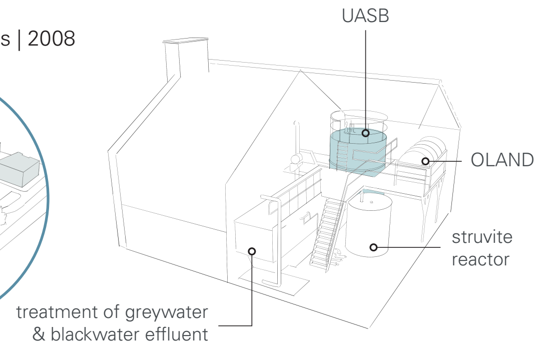


CSTR for digestion of blackwater and grease trap sludge

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.

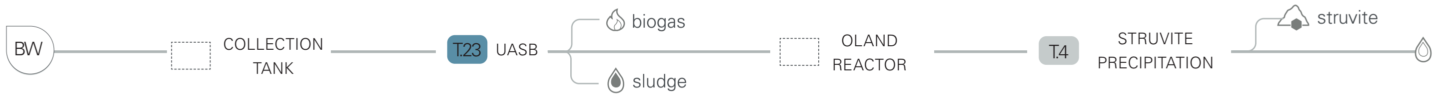


NOORDERHOEK
Sneek, the Netherlands | 2008

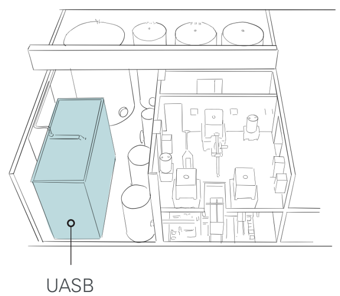


Flagship anaerobic treatment of blackwater and kitchen waste

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.



DE NIEUWE DOKKEN
Ghent, Belgium | 2020

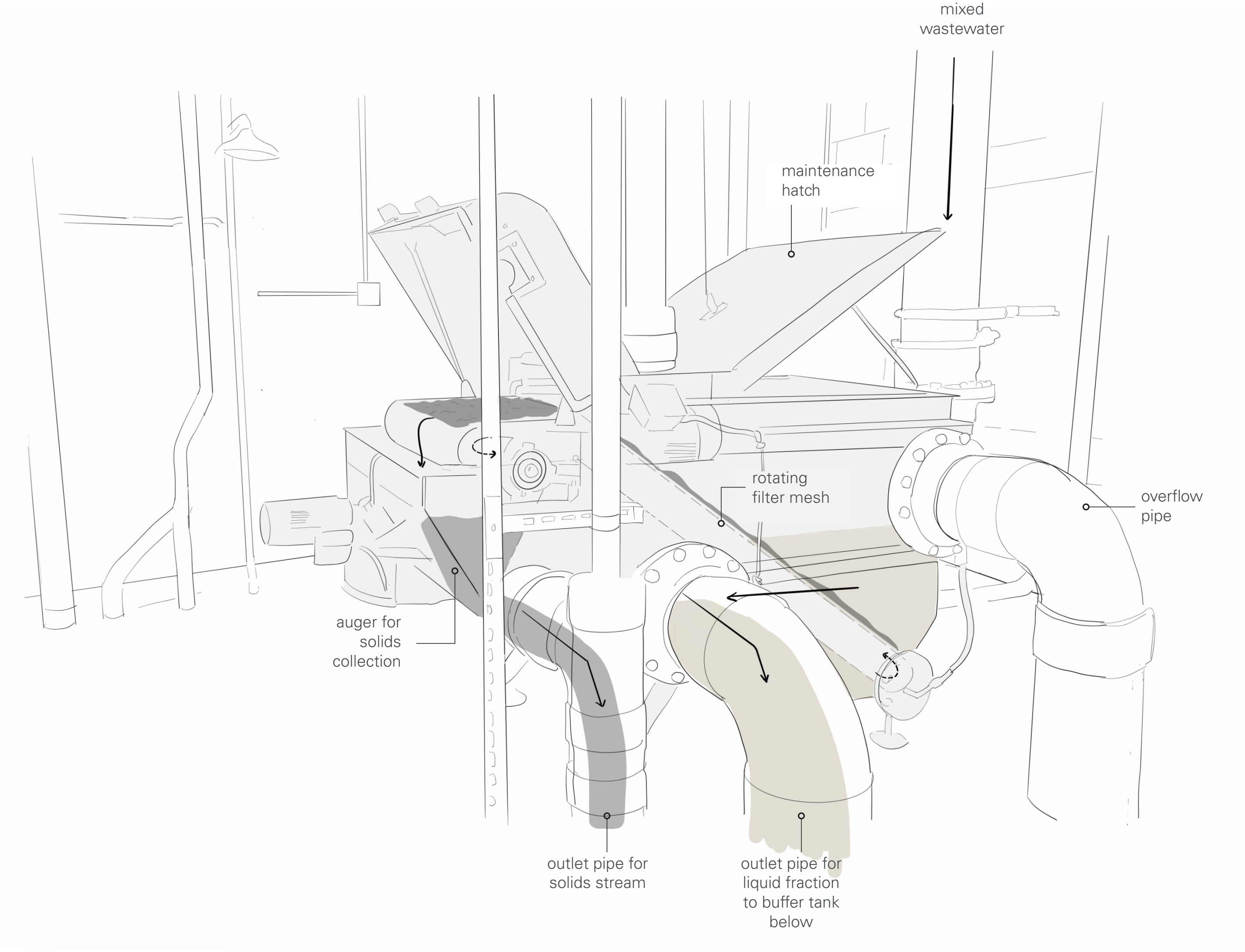


UASB with struvite precipitation

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.

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 — (solid fraction) SCREW PRESS — STORAGE — CHEMICAL OXIDATION

(liquid fraction) — 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.

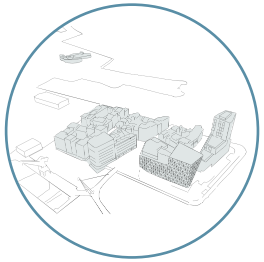
TARGET OUTPUTS

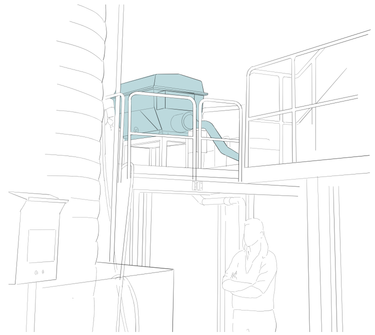
Settling tanks and screens separate wastewater into a liquid fraction and a solid fraction. The removal of solids, organics and nutrients, from the liquid fraction increases the treatment performance of subsequent treatment steps to produce water for reuse. Meanwhile, the separation of a solid fraction 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



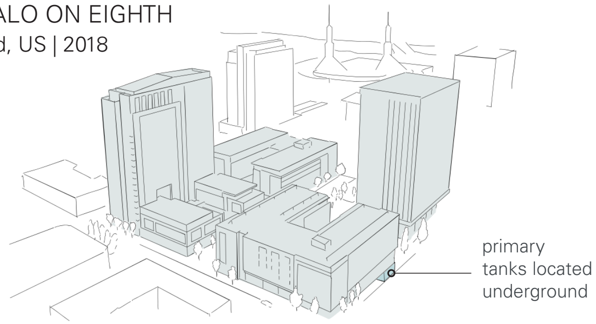


Drum filter before nutrient recovery technologies

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

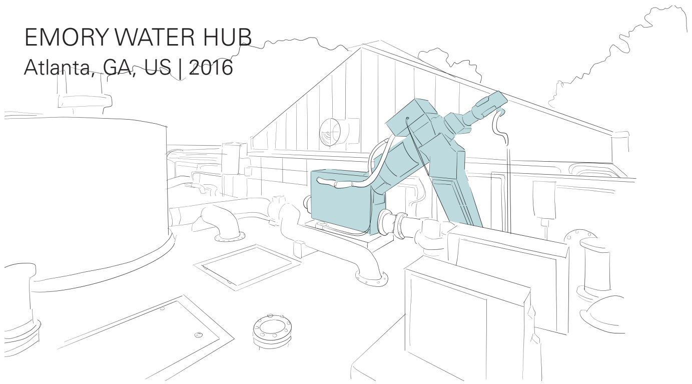


Sludge from settling tanks treated at municipal WWTP

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



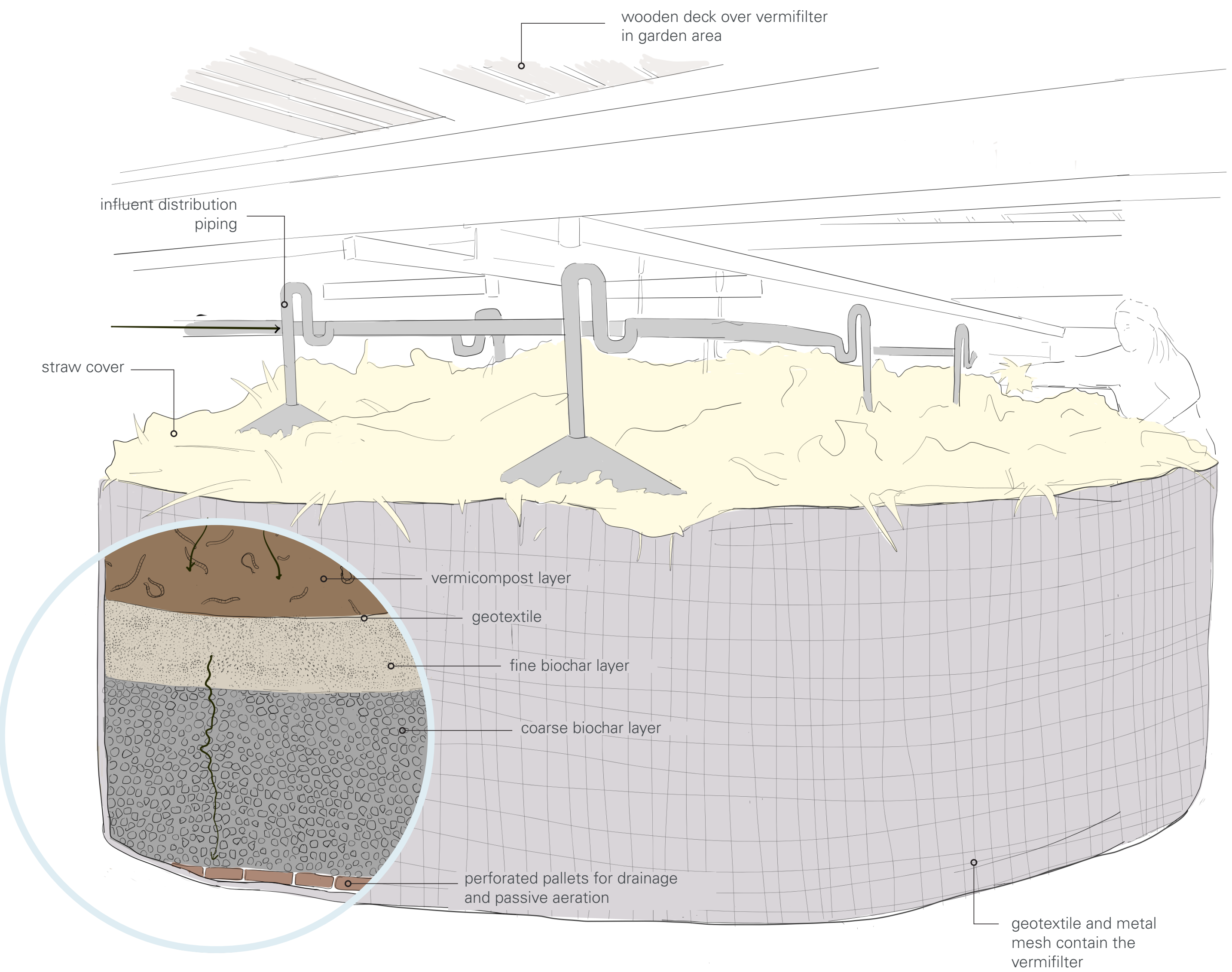
Solids screened out, compacted and transported away

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

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

- BW Blackwater
- MW Mixed Wastewater

TARGET OUTPUT(S)

- Treated Water
- 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

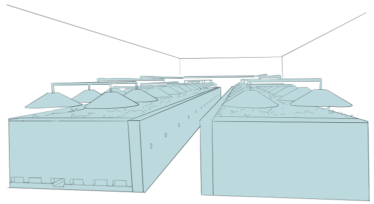
Very little to no energy consumption is necessary for vermifilter operation. Energy is only required for the feed pumps, if necessary. No control system is required and the system has few to no moving parts. Therefore, vermifilters require little regular maintenance: only the addition of straw, cardboard 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

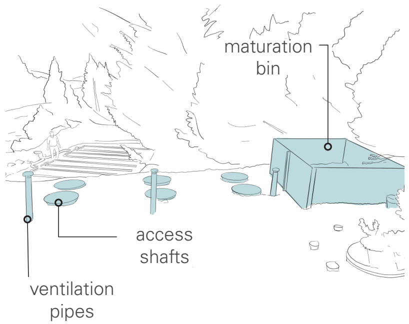
BLONAY
Vaud, Switzerland | 2024

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 — T.43 VERMIFILTER (→ vermicompost) — INFILTRATION

CHAMANNA CLUOZZA
Zernez, Switzerland | 2022



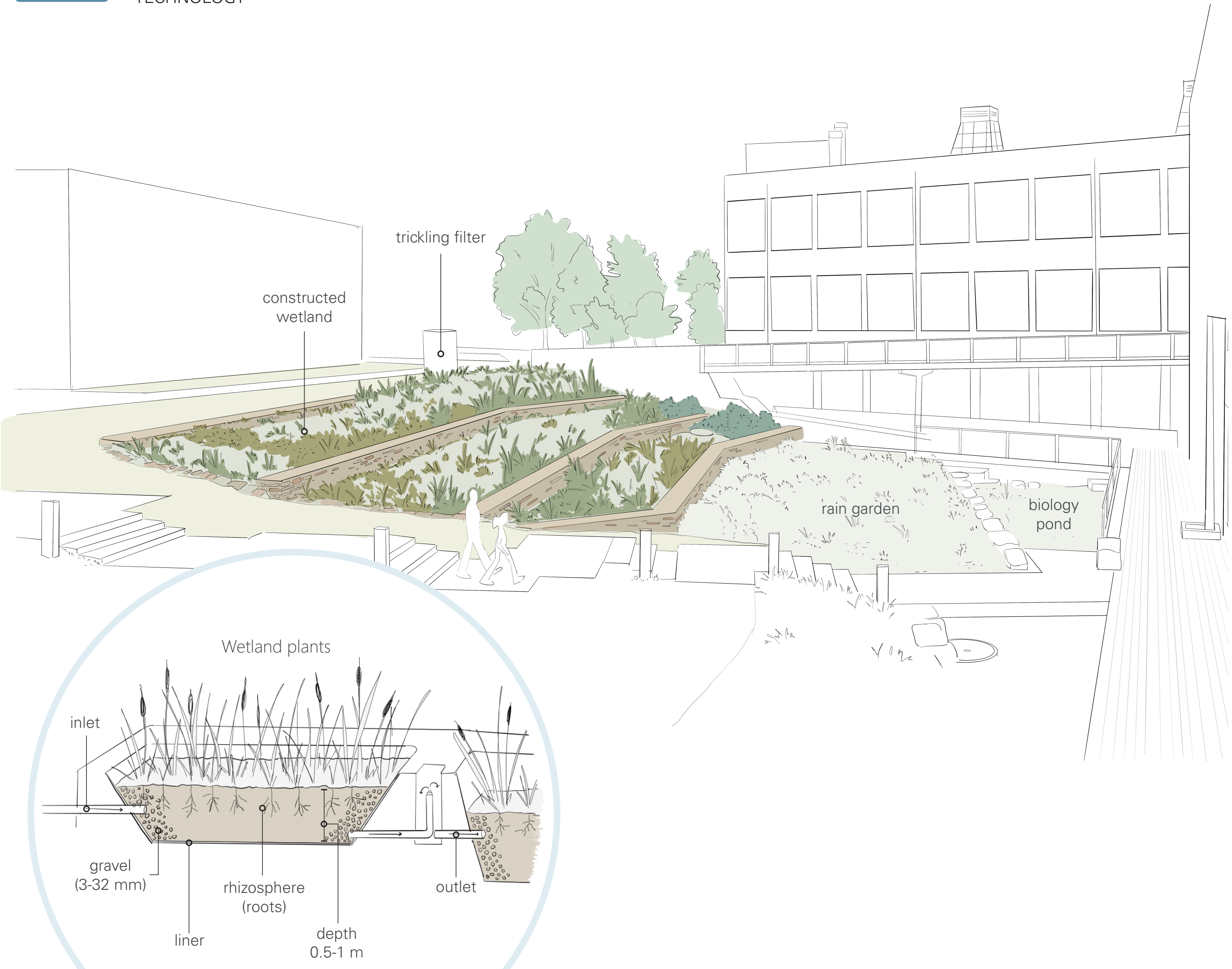
Underground vermifilters in an alpine setting

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 — T.43 VERMIFILTER (→ vermicompost) — T.44 CONSTRUCTED WETLAND — INFILTRATION

T.44 CONSTRUCTED WETLANDS

TECHNOLOGY



Horizontal, subsurface flow constructed wetland

Constructed wetlands (also referred to as artificial marshes, reed filters, or heliophyte 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

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

TARGET OUTPUT(S)

- Treated Water

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 — (treated water)

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.

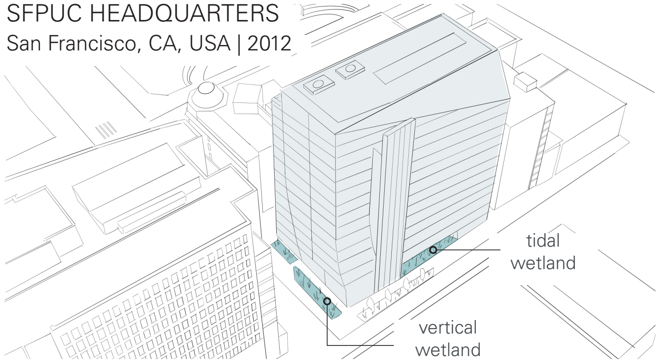
TARGET OUTPUT

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

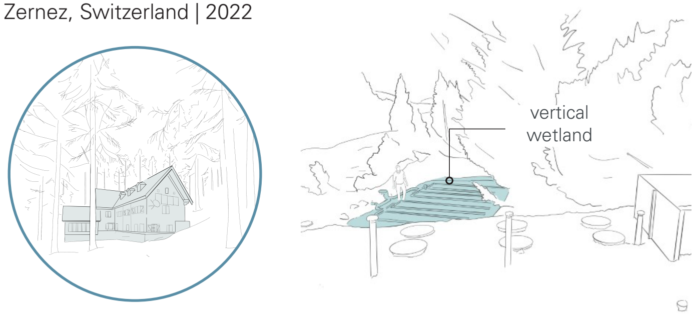
BWWB BOSCHVELD
's-Hertogenbosch, the Netherlands | 2018

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. Pre-treatment 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

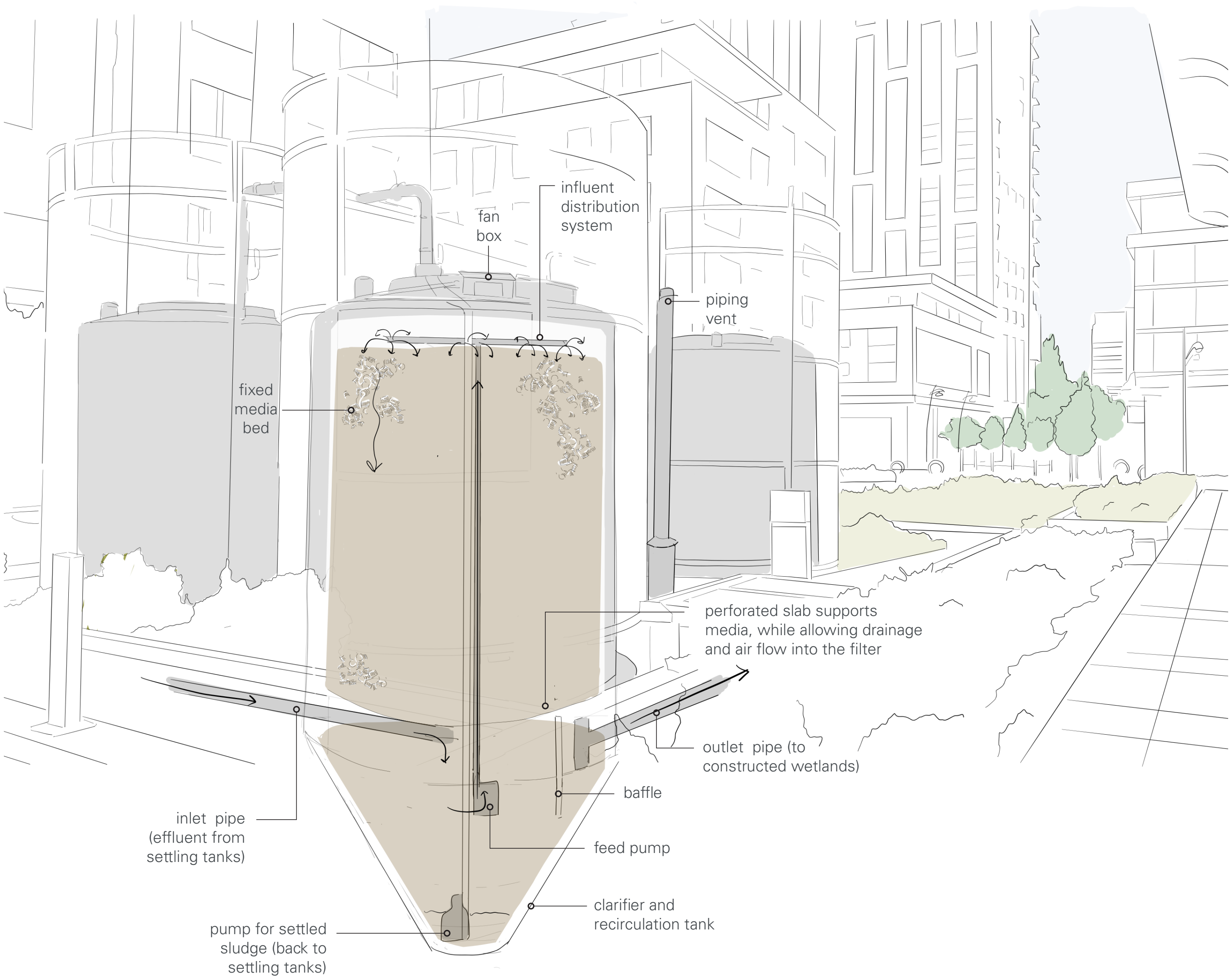
Located at 1882 m in the heart of the Swiss National Park, Chamanna Cluozza offers accommodation to (~30) hikers and staff. Water used onsite is sourced from nearby springs, the wastewater is treated decentrally. Blackwater from the flush toilets and greywater flow together through a vermifilter with 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

eawag
aquatic research



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

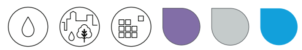
- GW Pre-treated Greywater
- BW Pre-treated Blackwater
- MW Pre-treated Mixed Wastewater

TARGET OUTPUT(S)

- Treated Water

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 — (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.

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.

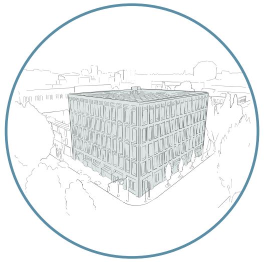
> Recirculation improves organic removal and nitrification due to longer contact times with the biofilm. Diluting the influent, lowers organic concentrations and increases the hydraulic loading rate. Recirculation also maintains moisture in the media, particularly useful when handling variable flows.

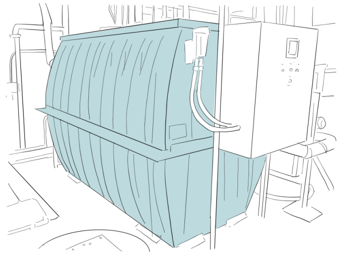
TARGET OUTPUTS

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



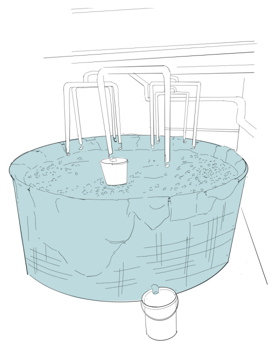


Recirculating textile filter treating office building greywater

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

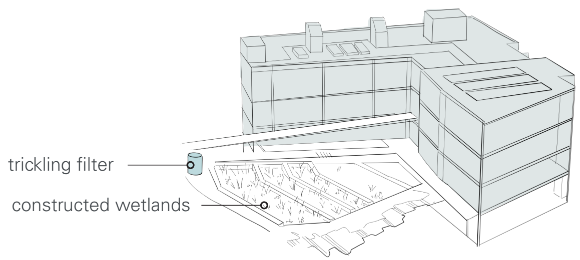


Biochar filter to treat greywater from a residential building

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



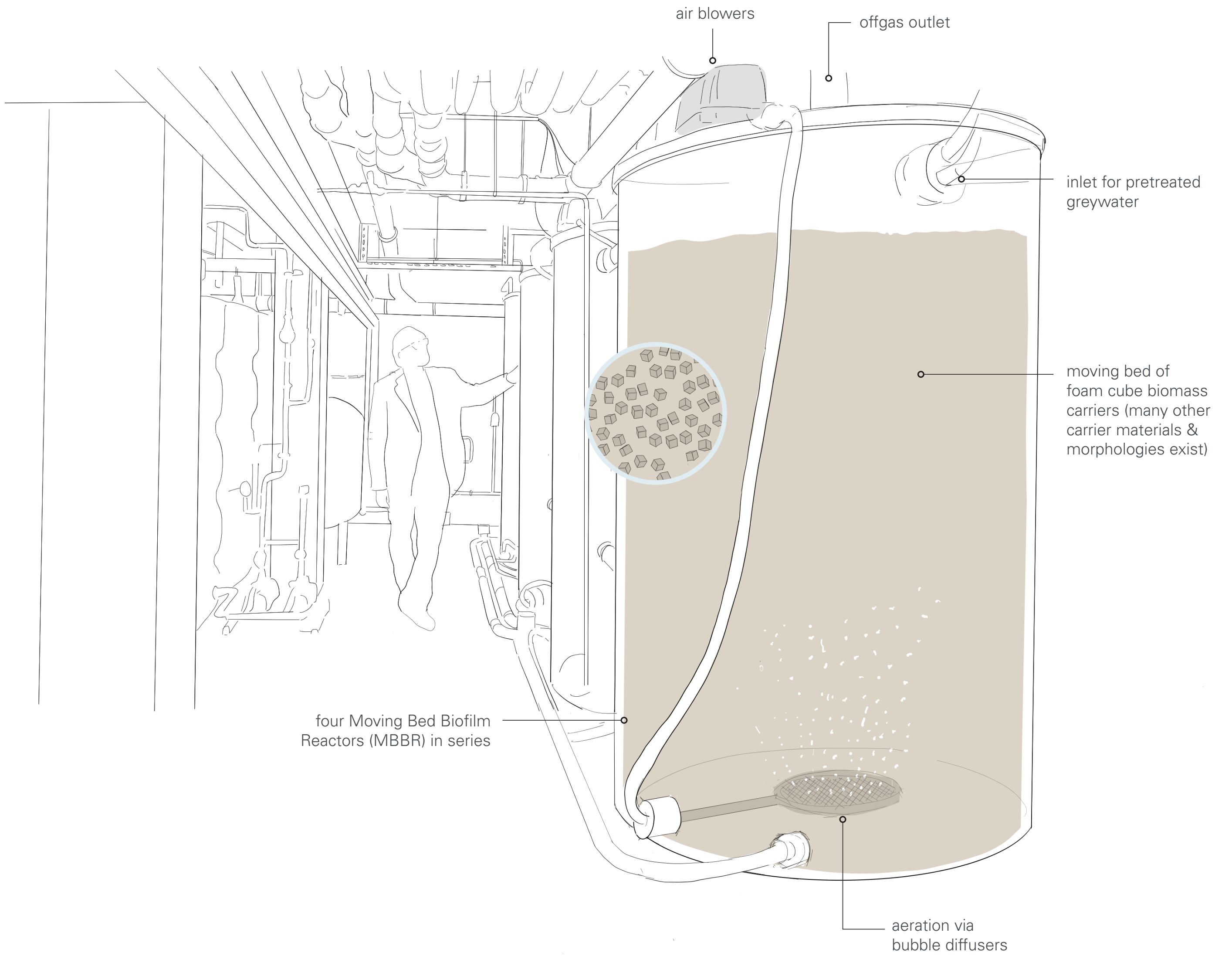
Landscape-integrated trickling filter and constructed wetlands

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

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

TARGET OUTPUT(S)

- Treated Water

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.

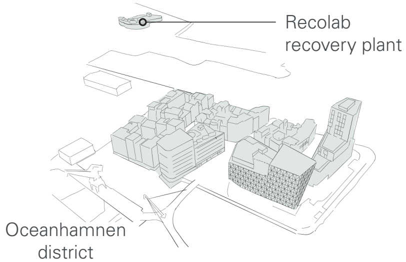
TARGET OUTPUTS

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



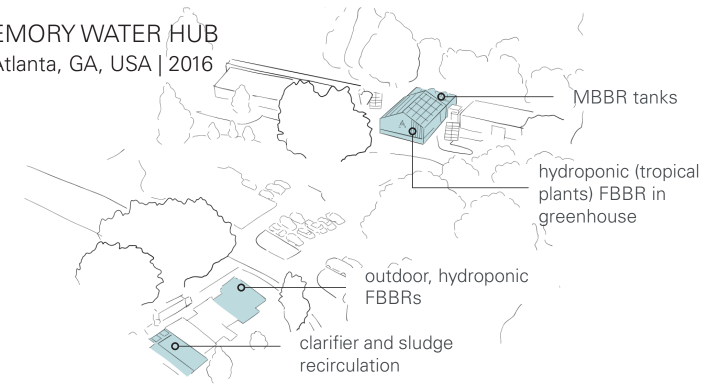
District scale treatment of greywater with activated sludge

Oceanhamnen district (2100 p.e.) uses an activated sludge system to treat greywater. The buffer tank (80m³), biological tank (65 m³) 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 — (heat) T.41 STORAGE TANK
(T.51 OZONATION: between ACTIVATED SLUDGE and NANOFILTER)

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 m³/d of wastewater in a space of 195 m². The screened wastewater is treated in a series of moving bed biofilm reactors (MBBR) (aboveground, 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

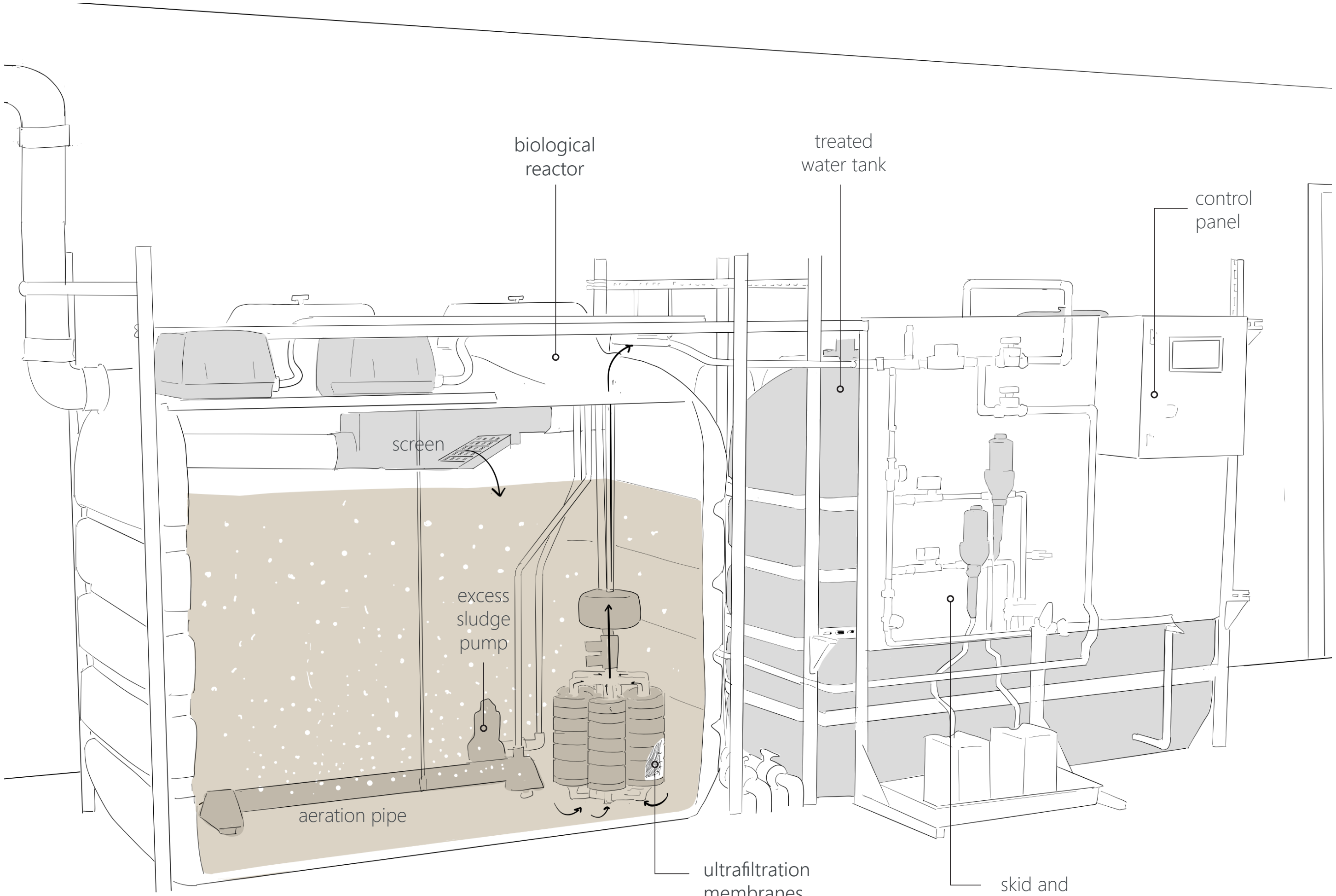
Household greywater treatment units for direct water reuse

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 m². 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

- GW Pre-treated Greywater
- MW Pre-treated Mixed Wastewater
- SW Stormwater

TARGET OUTPUT(S)

- Treated Water

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.

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

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.

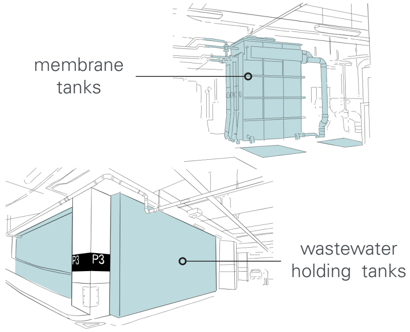
TARGET OUTPUTS

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



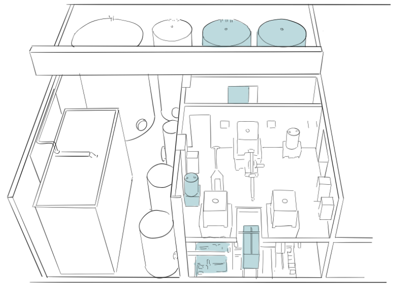
MBR in concrete tank for mixed wastewater treatment

Salesforce tower harbors the largest in-building water recycling system in the USA, treating 150 m³ 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



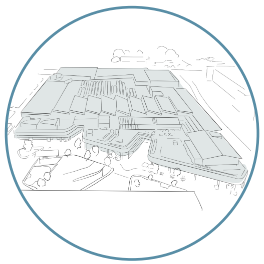
District scale treatment with MBR

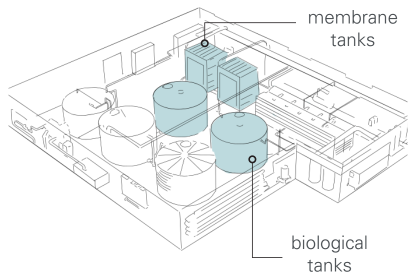
An MBR system treats greywater and effluent from the vacuum-collected blackwater treatment and sends the treated water to a neighboring soap factory to be used as process water. The biological reactors are large (PE) tanks spanning the height of two floors. They require the addition of a carbon source 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





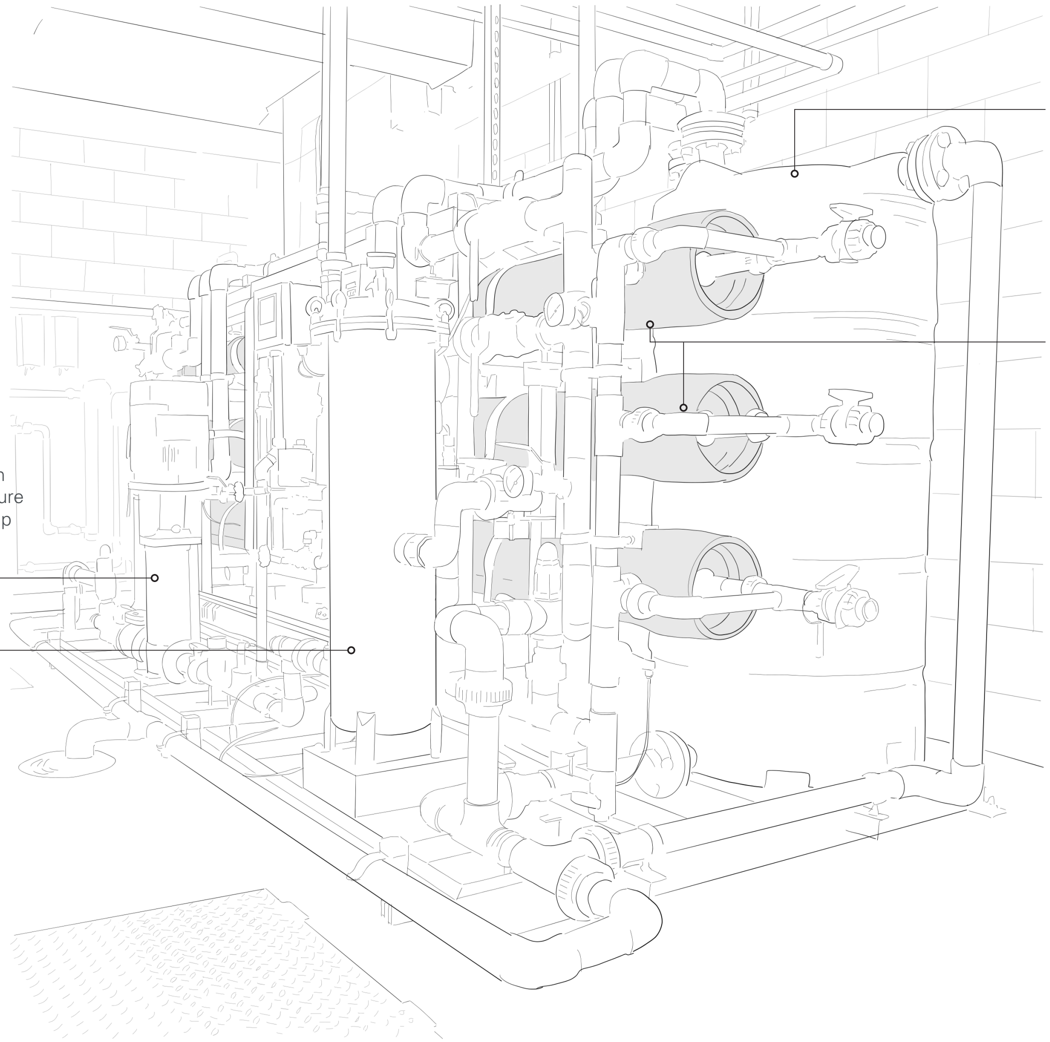
Large MBR treating mixed wastewater and stormwater

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 m³ of mixed wastewater and 30 m³ 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

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 m³ 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 — Treated Water

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

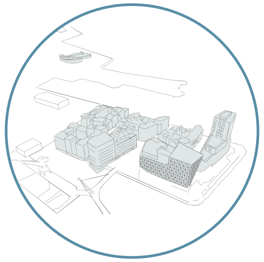
Membrane filters can have relatively high energy requirements when they require high-pressure pumps. Reverse osmosis is the most energy-intensive of the membrane filters with operational pressures of more than 6 bar. Micro- and ultrafiltration require much less energy. Though much of the membrane filtration 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.

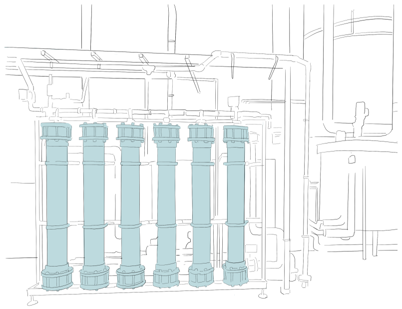
TARGET OUTPUTS

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



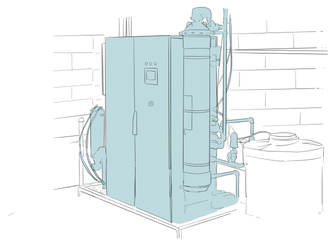


Nanofiltration coupled to ozonation for micropollutant removal

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.

GW — COLLECTION TANK — T.46 ACTIVATED SLUDGE — T.42 DRUM FILTER — T.48 NANOFILTER (— T.51 OZONATION) — T.61 HEAT PUMP (heat) — T.41 STORAGE TANK

HOLLAND PARK
London, UK | 2021

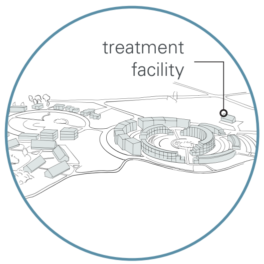


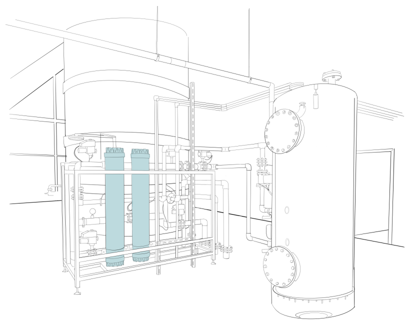
Greywater treatment "on demand" with ultrafiltration

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





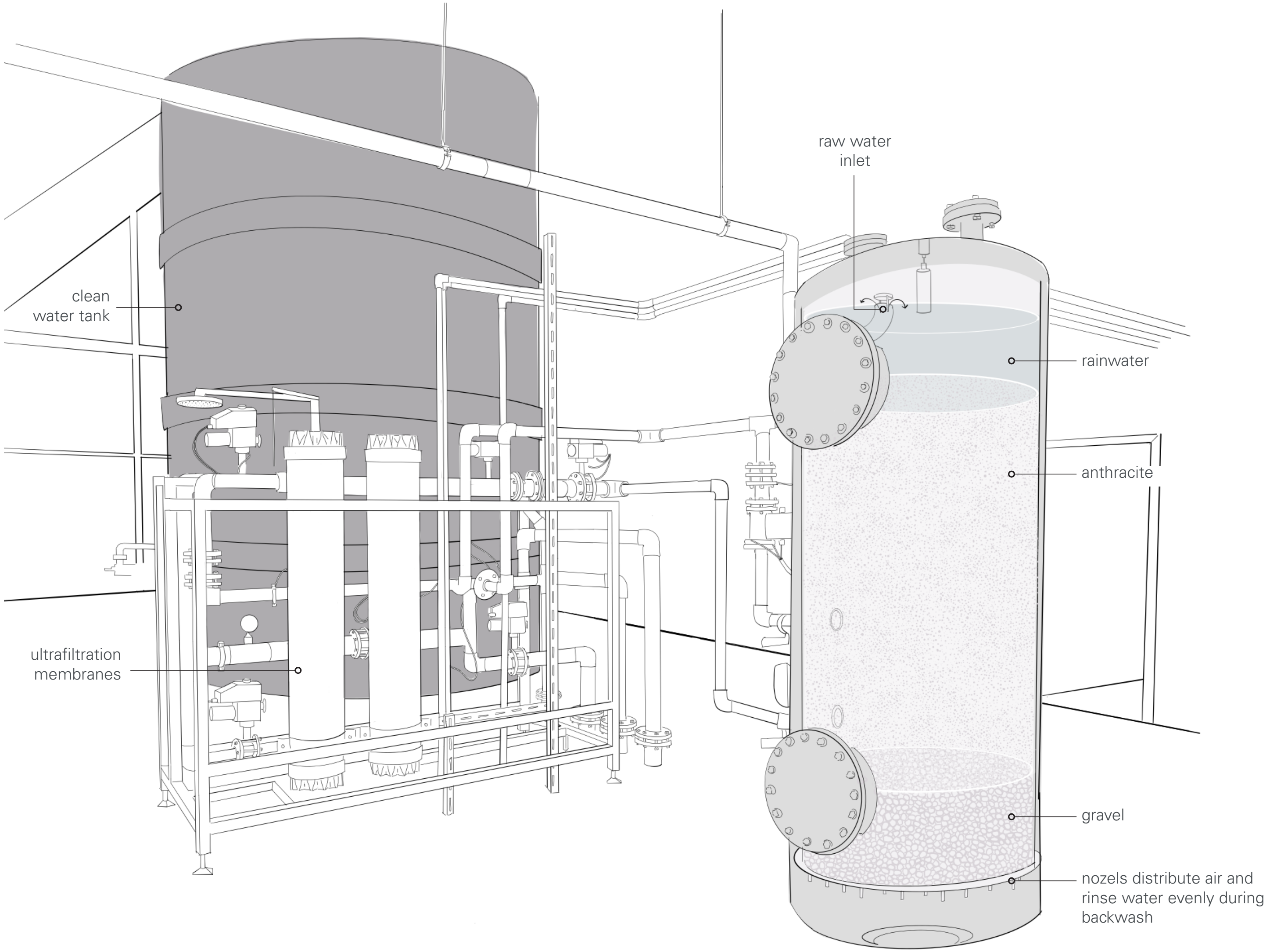
Rainwater treatment with ultrafiltration for non-potable reuse

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 — Treated Water

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 back-washing) 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.

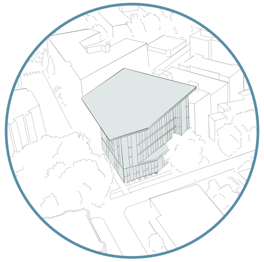
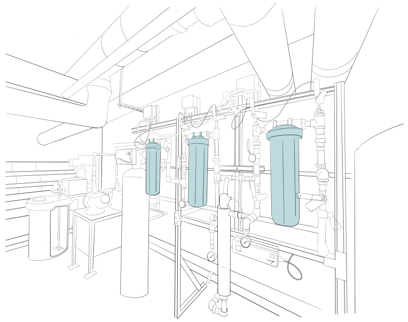
Backwash water is a byproduct stream of granular media filtration that requires additional treatment. Typically, this stream is sent to sewer, meaning the technology lends itself best to contexts where a connection to sewer is possible.

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

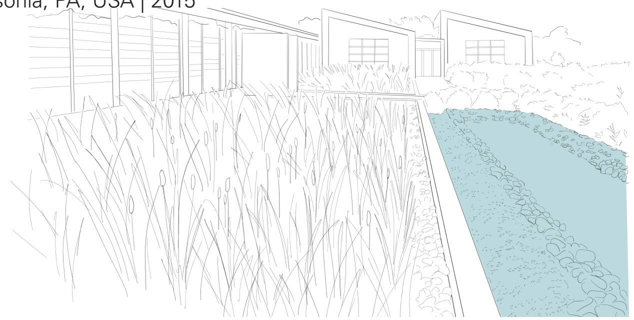



Cartridge filters for rainwater treatment in office building

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 m³ 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 m³ 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

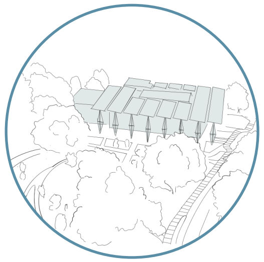
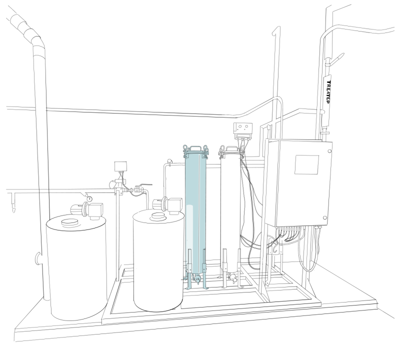


Open sand filter treats university greywater and wastewater

The wastewater system collects greywater and blackwater for treatment using a low-energy plant-based system with a design flow of 23 m³ 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 m³) 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).

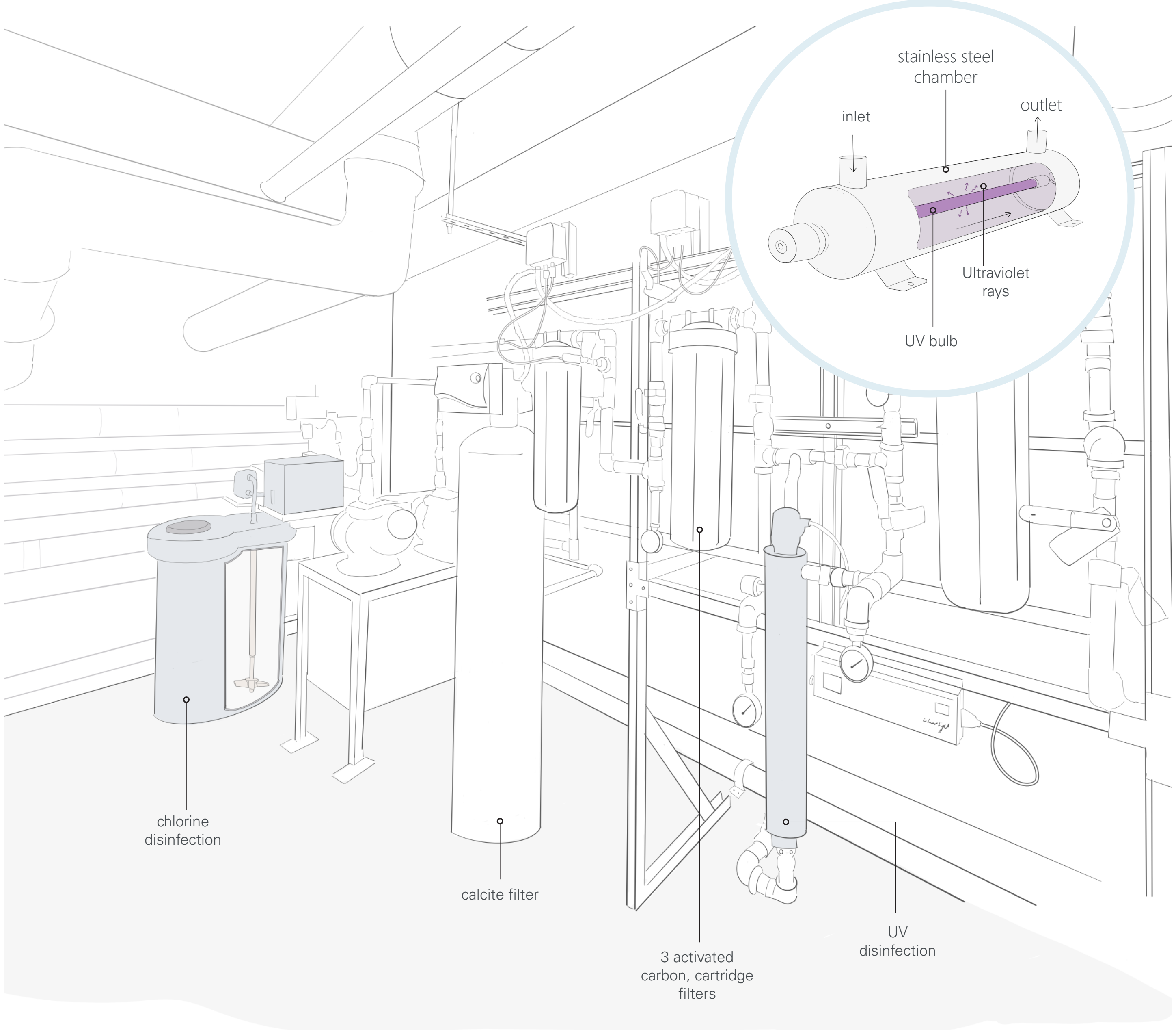
RW → T.41 CISTERN → T.49 MULTIMEDIA FILTER → T.48 ULTRAFILTRATION → T.50 UV DISINFECTION → T.50 CHLORINE DISINFECTION → T.41 STORAGE TANK

T.50

UV & CHLORINE DISINFECTION

eawag aquatic research

TECHNOLOGY



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

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

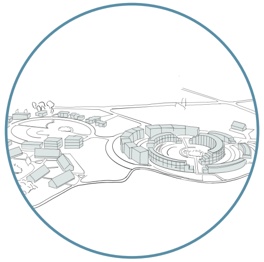
TARGET OUTPUTS

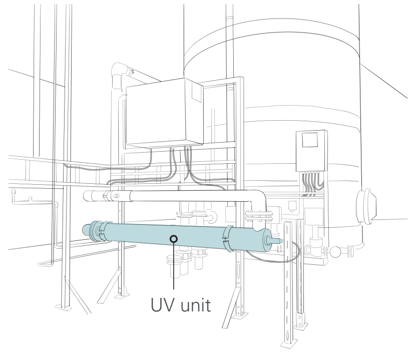
The treated water from both disinfection processes is suitable for high-quality reuse. The combination of disinfection processes with the preceding treatment technologies renders a high-quality treated water for onsite, often indoor, reuse. In some instances, the water is even safe for drinking (e.g.,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

SELECTED CASE STUDIES

NYE SUBURB

Aarhus, Denmark | 2018





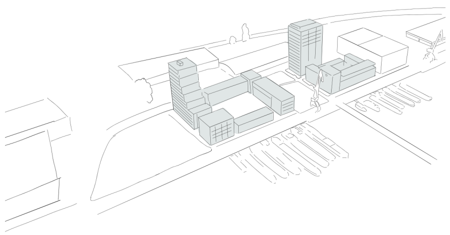
Neighborhood rainwater treatment with UV disinfection

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



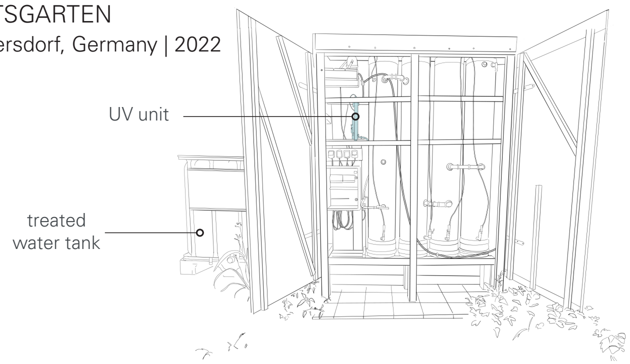
Greywater treatment with chlorination for district reuse

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

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

TARGET OUTPUT(S)

- Treated Water

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 — Treated Water

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.

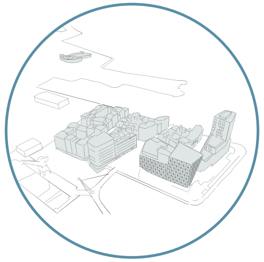
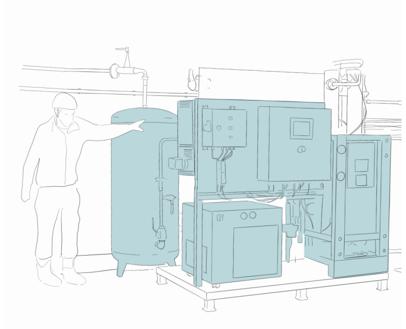
TARGET OUTPUTS

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.

Circular Sanitation TOOLBOX | 2025 | © Eawag
References and further information available at www.eawag.ch/en/wh/toolbox

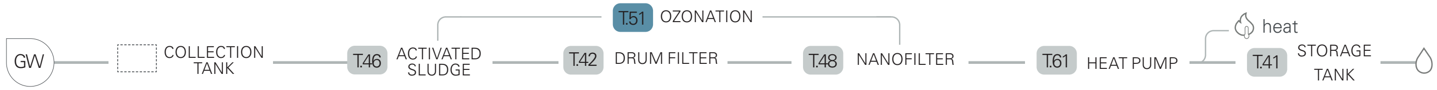
SELECTED CASE STUDIES

OCEANHAMNEN
Helsinborg, Sweden | 2021

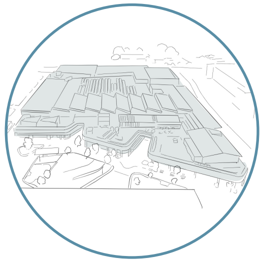
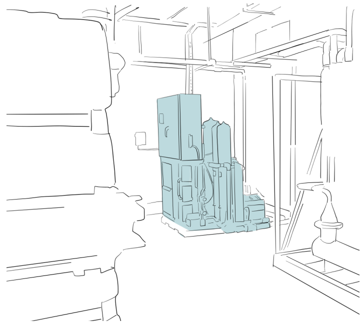



Ozonation for micropollutant removal

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).



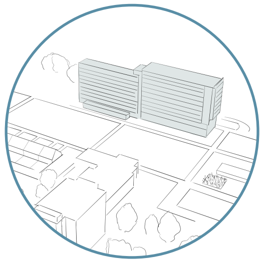
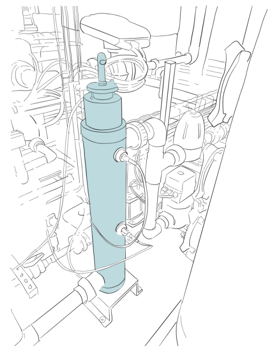
BURWOOD BRICKWORKS
Melbourne, Australia | 2019

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).