Rainwater Filtration System in Timelab's Waterlab

artist Katherine Ball
with
Curd Detaellenaere of Watergenius
Bart De Gusseme & Tom Vandermarliere of Farys
Evi Swinnen, Veronique De Mey & Marieke Maertens of Timelab
Sophie De Somere of Onbetaalbaar
Nqobizitha "Tshaby" Tshabalala of NT Elektriciteitswerken
Wim Vandersleyen Graphic Design
Paul De Braeckeleer of De Muur
Lieven Blancke, Stef De Boeck
Yves Deweerdt of Vito
Biztory
Freja Emilie Kræmmer Nielsen

Summary

This rainwater filtration system filters rainwater collected from the roof of Timelab, an art center in Gent, Belgium. The filtration system makes two qualities of water: drinkable rainwater and sanitary rainwater, which can be used to wash your hands, shower, wash clothes, water the garden, flush toilets, and make art. The filter system is powered by solar panels located on Timelab's roof.

Through a network of tubes and pipes, sanitary rainwater is transported throughout the building to the bathrooms, the washing machine, the Knotfactory, and the garden. Blue and white lines on the floor and ceiling trace the paths that water takes throughout the building. Sanitary rainwater is represented by medium-blue colored lines, city water is represented by white lines, and unfiltered rainwater is represented by dark-blue lines. Roughly half of the water used in Timelab's building is now sanitary rainwater. In Timelab's Waterlab, there is a gold sink with a faucet for drinkable rainwater and a second faucet for sanitary rainwater. Visitors are welcome to drink the drinkable rainwater and wash their hands in the sanitary rainwater.

Sanitary rainwater is made by filtering rainwater through activated carbon, limestone, and UVC light.

Drinkable rainwater is made by filtering rainwater through activated carbon, limestone, UVC light, an ultrafiltration membrane with extruded activated carbon, and reverse osmosis.

Wastewater from the filtration system is pumped to Timelab's garden and the city sewer system. From the garden, the wastewater infiltrates into the groundwater or plants transpire it back into the atmosphere. From the city sewer system, it goes to the Ossemeersen Wastewater Treatment Plant, then into Gent's canals, the Schelde River, the North Sea, and ultimately the Atlantic Ocean.

Costs:

Installation Costs

The filtration system cost €5,735.00 to install inside Timelab's Waterlab, including parts and labor. Including taxes (21% BTW), it cost €6,939.35 to install. A breakdown of the individual costs: submerged pump in the cistern (€1,370), activated carbon and limestone filter (€1,210), UVC light (€400), ultrafiltration membrane with extruded activated carbon (€155), reverse osmosis filter (€695), water counter (€55), labor for installation and start up (€1,850). All of this was coordinated with the company Water Genius. The taps for water testing were provided for free by Farys Water Utility and designed by Tom Vandermarliere. The cistern, rooftop rainwater collection system, and water collectors were installed earlier during the renovation of Timelab's building.

Maintenance Costs

Some parts of the filters need to be replaced and maintained periodically. This is estimated to cost €650 per year. The parts that need to be replaced each year are: UVC bulb (€120), activated carbon and limestone for the first filter (€250), ultrafiltration membrane (€85), and reverse osmosis pre-filter made of activated carbon (€85). The reverse osmosis membrane needs to be replaced (€180) every three to five years. Internal parts in the valve of the first filter (activated carbon & limestone) need to be replaced (€80) every four years. The UV ballast needs to be replaced (€150) every five years. The estimated yearly average cost, on a five-year cycle, based on 2023 prices for parts, is €650.

Water test results

On 8 June 2023 and 31 July 2023, the rainwater filtration system was tested by Farys, the water utility for Gent. In total we sampled the rainwater at seven points: before filtration, at every step in the filtration process, the sanitary rainwater, the drinkable rainwater, and also the wastewater from the reverse osmosis concentrate. We also tested the city drinking water in Timelab that Farys distributes. The test results showed the drinkable rainwater (the final water after the reverse osmosis filter) is microbiologically safe to drink and to use. The full results and more information about the results are at the end of this document. The idea is to continue testing the system periodically and make the results publicly accessible with information about all the parts in the system and how it is put together.

Team

The rainwater filtration system at Timelab was a team effort bringing together artist Katherine Ball with Curd Detaellenaere of Watergenius and Nqobizitha “Tshaby” Tshabalala of NT Elektriciteitswerken, who installed the system and made it flow through the building; Bart De Gusseme and Tom Vandermarliere of Farys, who advised how to integrate water testing and regulations into the system design, including making custom water test taps; Evi Swinnen, Veronique De Mey, and Marieke Maertens of Timelab, who provided support and vision on multiple levels; Sophie De Somere of Onbetaalbaar, who staged the sink and water collectors; and Paul De Braeckeleer of De Muur, who created gold metal elements. Wim Vandersleyen Graphic Design in coordination with Katherine Ball; Jan Floré of Karakters. Lieven Blancke, Stef De Boeck, and Bizstory are working on data collection and data visualization to track how much water the system filters and how much energy it uses. Artist Freja Emilie Kræmmer Nielsen contributed care, discourse, and ongoing reflection.

How does life change as we become participants in water filtration, supply management, and urban hydrology?

How might our relationship to water change as we transition from being consumers of water to stewards of water?

Technical Data

Technical Data for the different filters and the budget is available here:

Filter 1 & 2: Technical Data - Activated Carbon, Limestone Remineralization, and UV Light - Water Genius - Timelab - Rainwater Filtration System
https://drive.google.com/file/d/1JQvTbJssmsZHUC6Jg1TiQ9vsNkWk1K3e/view?usp=sharing

Filter 3: Technical Data - Ultrafiltration Membrane and Extruded Activated Carbon - Water Genius - Timelab - Rainwater Filtration System
https://drive.google.com/file/d/1qREGF6sSARQ_Naxd0vHm7pfZ2EM44Nr7/view?usp=drive_link

Filter 4: Technical Data - Reverse Osmosis - Water Genius - Timelab - Rainwater Filtration System
https://drive.google.com/file/d/17f9EAEW5YmZLuve7Eh4DtnvqMwhSLcG3/view?usp=drive_link

Description and Cost of Filtration System Parts and Installation Costs - Water Genius - Timelab - Rainwater Filtration System
https://drive.google.com/file/d/14C4izQctKEDEkO7EF4uA0Np7LDb-oaXZ/view?usp=drive_link

Parts of the rainwater filtration system and how they work.

The text is organized graphically. The basic information is at the top of each heading, and more detailed information is tabbed inwards.

Rain & Cistern

Rainwater lands on the roof of Timelab and flows into a cistern, which can hold up to 7,500 liters of water. Some rain droplets form around pollution that is in the air, and rainwater contacts bacteria, other microorganisms, organic matter, and sediment on the roof and in the cistern. The rainwater filtration system must filter these out before rainwater can be used for drinking and washing. Twice a year, the cistern is treated with 250 ml of chlorine to kill algae. The activated carbon in the first filter will remove the chlorine.

> The cistern is made out of concrete, which is preferable to plastic for several reasons. Concrete buffers the water with calcium carbonate so the water becomes less corrosive to plumbing and fixtures.[1] In theory, the relatively rough, porous surface of the concrete provides a larger surface area for bacteria to grow than on a smooth plastic surface. In both concrete and plastic cisterns, some of the bacteria and other microorganisms in the water form a biofilm on the surface of the cistern; the biofilm can help filter and clean the water.[2] [3] Harmful pathogenic bacteria in the water can be neutralized when they attach to biofilms in the cistern and die naturally because of competition for nutrients with the biofilm's indigenous microbial communities.[4] Rainwater cisterns can support functional ecosystems comprising complex communities of environmental bacteria, which may have beneficial implications for the quality of harvested rainwater.[5]

---

[1] Younos, T., Bohdan, R., Anderson, E., Ramsey, K., Cook, N., Ross, B., & Dillaha, T. (1998). *Special Publication SP3-1998: Evaluation of Rooftop Rainfall Collection Cistern Storage Systems in Southwest Virginia*. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University.
https://vtechworks.lib.vt.edu/bitstream/handle/10919/49478/VWRRC_sp199803.pdf?sequence=1

[2] Li, N., Li, X., & Fan, X.Y. (2022). Storage tank as a pretreatment unit for rainwater cleaner production: Role of biofilm bacterial communities and functional genera in water quality improvement. *Journal of Environmental Management*, 303, 114118. https://doi.org/10.1016/j.jenvman.2021. Pdf accessible at: https://www.researchgate.net/publication/51811450_Comparing_the_microbial_characteristics_of_rainwater_in_two_operating_rainwater_tanks_with_different_surface-to-volume_ratios

[3] Augustyniak, A., Sikora, P., Grygorcewicz, B., Despot, D., Braun, B., Rakoczy, R., Szewzyk, U., Barjenbruch, M., & Stephan, D. (2021).Biofilms in the gravity sewer interfaces: making a friend from a foe. *Rev Environ Sci Biotechnol* 20, 795–813. https://doi.org/10.1007/s11157-021-09582-0

[4] Kim, M., & Han, M. (2016). Role of Biofilm in Rainwater Tank. In D. Dhanasekaran & N. Thajuddin (Eds.), *Microbial Biofilms - Importance and Applications.* InTechOpen. https://doi.org/10.5772/63373

[5] Evans, C., Coombes, P.J., Dunstan, R.H., & Harrison, T. (2009). Extensive bacterial diversity indicates the potential operation of a dynamic micro-ecology within domestic rainwater storage systems. *The Science of the Total Environment,* 407 19, 5206-15.

Underwater pump

Inside the cistern is a submersible pump, meaning it is located underwater. It pumps rainwater from the cistern into Timelab. The rainwater enters the building through a pipe that runs under the floor of the Timelab Eatery, a culinary cultural space with a kitchen, bar, and spacious seating area. The rainwater travels under the Eatery into the Waterlab and resurfaces on the wall of the Waterlab.

> Submersible pumps are more efficient than normal surface pumps. They require less power because they push water to the surface instead of pulling it. They are also quieter since the water absorbs the noise.
>
> The pump automatically shuts on and off. There is a pressure sensor and a flow sensor inside the pump. The pump will turn on if the pressure drops to 1-2 bars in the filter system. Then it will pump water to refill the pressure tank in the filter system. The pump also has dry-run protection, which means if there is no water the pump will automatically stop.

Main switch

The pump's power is connected to the main switch inside the electricity board. The power cable runs from the main switch in the electricity board, to a small electricity junction box inside the cistern, to the pump. Switching off the main switch will turn off the pump. If there is a problem in the filter system, switching off the main switch will stop water flowing in from the pump to the filter system.

EA check valve

Inside the Waterlab, the first things the rainwater passes through is an EA check valve and a pressure gauge. The check valve prevents water from flowing backwards in the system. EA means "controllable anti-pollution valve," in accordance with European standards DIN EN1717[6] and EN13959.[7] [8]

> Backflow is caused by the differences in pressure in parts of the system. It occurs from backsiphonage or backpressure. Backsiphonage is caused by negative pressure in the distribution piping. It can occur when a pump is operated or a pipe bursts. Backpressure is caused by downstream pressure that is greater than upstream pressure. Devices, such as washing machines or heating systems, may create higher pressure than the source of the water. This can lead to a reversal in the direction of flow.

---

[6] Deutsches Institut für Normung e.V. (2023). *DIN EN 1717*. https://www.din.de/de/mitwirken/normenausschuesse/naw/entwuerfe/wdc-beuth:din21:367908315

[7] Deutsches Institut für Normung e.V. (2004). *DIN EN 13959*. https://www.din.de/de/mitwirken/normenausschuesse/naa/veroeffentlichungen/wdc-beuth:din21:71538012

[8] DIN standards are set by DIN, the German Institute for Standardization [Deutsches Institut für Normung e.V.]. A DIN standard is a document that specifies requirements for products, services and/or processes to assure quality and efficiency. They can be downloaded for a fee on the DIN website or accessible via public libraries. https://www.din.de

Pressure gauge
The pressure gauge helps monitor pressure in the water system, which has an ambient pressure of ~3.0 bars. If there is no pressure in the system, it means the pump is not working. The pressure is needed to transport water through the filter system and building and create a proper amount of water pressure when you use rainwater to turn on a faucet, flush the toilet, or run the washing machine.. When someone uses the water, the pressure will drop slightly, to about 2 bars. When the pump turns on, the pressure will go up momentarily, to around 3.5 bars. When the pump turns off, the system will return to its ambient pressure.

Pressure tank
After the rainwater passes through the check valve and the pressure gauge, the water is pumped into a pressure tank. This creates a buffer or reservoir so the pump does not have to turn on every time someone uses the water (turns on the faucet, flushes a toilet, etc.). The pressure tank holds 35 liters of rainwater. As the amount of water in the pressure tank goes down, the air pressure in the tank drops until it hits a pre-set minimum (1-2 bar); then the pump turns back on and refills the tank.

> There are three things inside the pressure tank: water at the bottom, compressed air at the top, and a membrane separating them. The membrane is like a balloon filled with water rather than air. The underwater pump in the cistern pumps rainwater into the pressure tank. As the rainwater comes in, the membrane expands and presses on the compressed air in the tank. When maximum pressure is reached, typically 3-4 bar, the pump shuts off. As the water is used, the membrane shrinks, and the compressed air forces water out of the tank. When the pressure drops to 1-2 bar, the pump turns back on.

From the pressure tank, the water flows up and over a door to Timelab’s kitchen and then down to the center of the wall where the filters and water testing taps are located.

Shutoff valve 1
There is a shutoff valve at the bottom of the pressure tank. The shutoff valve can turn off the pressure tank if it is malfunctioning or if the pump or any of the pipes surrounding it need to be maintained, repaired, or replaced.

Water test tap 1
The rainwater flows past a water test tap. This is the first of six points for testing the quality of the rainwater. If you turn on this water test tap, you can take a sample of the rainwater coming directly from the cistern, before it has been filtered. The water test tap was customized by Tom Vandermarliere of Farys. It has a long metal stem, which channels a precise flow of water into the sampling bottles. The long stem can be easily sterilized with a flame. Sterilization is important because if you don’t properly sterilize your test tap, bacteria on the tap can contaminate the water sample. The precise flow is helpful because otherwise it is easy to drip water onto the floor and make the sampling process unnecessarily wet and messy.

We made tests of the water on 8 June 2023 and 31 July 2023 with Tom Vandermarliere. The test results were processed at Farys Laboratory in Gent. Total cell count tests were run with flow cytometry by the Farys Research & Development Team (Bart De Gusseme and Tom Vandermarliere). All test results are published in the Waterlab and available at the end of this document.

Shutoff valve 2

After the first test tap there is a shutoff valve. This gives a second point where the whole system can be shut off to enable maintenance or part replacement, or in the case of failure or emergency. If there is a problem, turning this shutoff valve will prevent water coming from the cistern and the pump. It does not matter whether you turn off the main switch or the shutoff valve first, whichever is nearest at hand.

> The shutoff valve is used to shut off the water before any maintenance is done on the system, otherwise water would go everywhere when you disconnect one part. Although the chances of a system failure like a broken pipe are very slim, almost like winning the lottery, it is important to have a solid backup plan and safety protections at multiple intervals.

Water meter 1

A water meter measures the amount of rainwater coming into the filter system. This is the total amount of rainwater filtered by the system and used in Timelab, in cubic meters.

Filter 1: Activated carbon and limestone remineralization

The first filter contains activated carbon and limestone in a pressurized container. The top 90 percent of the filter is granular activated carbon (0.42 - 1.2 mm grain size). A layer of limestone at the bottom 10 percent of the canister remineralizes the water (0.8 - 1.2 mm grain size). Twenty-five liters of water can be filtered each minute.

Through mechanical filtration, activated carbon removes sediment and anything larger than 50 microns (also called micrometers, represented as μm). To put that into perspective, human hair is about 75 microns in diameter;[9] bacteria are typically around 1 micron in diameter.[10] Through a process called adsorption, activated carbon filters pesticides;[11] chemicals; heavy metals

---

[9] Alaska Department of Environmental Conservation, Division of Air Quality. (n.d.). *Particulate Matter - Background Information*. https://dec.alaska.gov/air/anpms/particulate-matter/background/

[10] Buchanan, M. (2014). Sizing up bacteria. *Nature Physics*, 10, 788. https://doi.org/10.1038/nphys3149

[11] Seyhi, B., Drogui, P., Gortares-Moroyoqui, P., Estrada-Alvarado, M.I., & Alvarez, L.H. (2014), Adsorption of an organochlorine pesticide using activated carbon produced from an agro-waste material. *J. Chem. Technol. Biotechnol.*, *89*: 1811-1816. https://doi-org.yale.idm.oclc.org/10.1002/jctb.4256

(including mercury,[12] lead,[13] chromium,[14] copper,[15] zinc,[16] nickel,[17] and cadmium[18]); some medications;[19] chlorine;[20] polychlorinated biphenyls (PCBs);[21] hydrocarbons, including polycyclic aromatic hydrocarbons (PAHs);[22] per- and polyfluorinated substances (PFAS);[23]

---

[12] Chen, Y., Liu, H., Guo, X., Wu, F., Zhao, Y., & Zhang, J. (2020). Performance of CuCl2-Modified Activated Carbon on Mercury Capture after Injection in an Entrained Flow Reactor. *Industrial & Engineering Chemistry Research, 59*(13), 5557-5565, https://doi.org/0.1021/acs.iecr.9b06189

[13] Abdulrazak, S., Hussaini, K.,& Sani, H.M. (2017). Evaluation of removal efficiency of heavy metals by low-cost activated carbon prepared from African palm fruit. *Applied Water Science* 7, 3151–3155. https://doi.org/10.1007/s13201-016-0460-x

[14] Landrigan, R. B., & Hallowell, J. B. (1975). *Removal of chromium from plating rinse water using activated carbon.* Cincinnati, Ohio: National Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency.

[15] Abdulrazak, S., Hussaini, K., & Sani, H.M. (2017). Evaluation of removal efficiency of heavy metals by low-cost activated carbon prepared from African palm fruit. *Applied Water Science* 7, 3151–3155. https://doi.org/10.1007/s13201-016-0460-x

[16] Zhang X, Hao Y, Wang X, & Chen Z. (2017). Rapid Removal of Zinc(II) from Aqueous Solutions Using a Mesoporous Activated Carbon Prepared from Agricultural Waste. *Materials (Basel),* 10(9):1002. https://doi.org/10.3390/ma10091002. PMID: 28846650; PMCID: PMC5615657.

[17] Abdulrazak, S., Hussaini, K., & Sani, H.M. (2017). Evaluation of removal efficiency of heavy metals by low-cost activated carbon prepared from African palm fruit. *Applied Water Science* 7, 3151–3155. https://doi.org/10.1007/s13201-016-0460-x

[18] Abdulrazak, S., Hussaini, K. ,& Sani, H.M. (2017). Evaluation of removal efficiency of heavy metals by low-cost activated carbon prepared from African palm fruit. *Applied Water Science* 7, 3151–3155. https://doi.org/10.1007/s13201-016-0460-x

[19] Chowdhury, Z., Summers, R., Westerhoff, G., Leto, B., Nowack, K., Corwin, C., & Passantino, L. (2013). *Activated Carbon - Solutions for Improving Water Quality - 1.2.1 Batch Adsorption Kinetics.* American Water Works Association (AWWA) . Retrieved from https://app.knovel.com/hotlink/pdf/id:kt011O8OF3/activated-carbon-solutions/batch-adsorption-kinetics

[20] Snoeyink, V. L. (1983). *Reaction of activated carbon with aqueous chlorine and chlorine dioxide.* Cincinnati, OH: U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory.

[21] United States Environmental Protection Agency, Office of Solid Waste and Emergency Response. (2012). A Citizen's Guide to Activated Carbon Treatment, EPA 542-F-12-001. United States Environmental Protection Agency. https://www.epa.gov/sites/default/files/2015-04/documents/a_citizens_guide_to_activated_carbon_treatment.pdf

[22] Lamichhane, S., Bal Krishna, K.C., & Sarukkalige, R. (2016). Polycyclic aromatic hydrocarbons (PAHs) removal by sorption: A review. *Chemosphere*, 148:336-53. https://doi.org/10.1016/j.chemosphere.2016.01.036

[23] United States Environmental Protection Agency. (2018). Reducing PFAS in Drinking Water with Treatment Technologies. https://www.epa.gov/sciencematters/reducing-pfas-drinking-water-treatment-technologies

cyanide,[24] atrazine;[25] hydrogen sulfide;[26] some volatile compounds that cause odors;[27] and organic matter that can affect taste, odor, and color. The water leaving the filter should be fairly clear. Activated carbon does not remove hard water minerals (calcium and magnesium);[28] [29] most metal ions,[30] or nitrate[31] to a significant degree. It removes some but not all fluoride.[32] [33]

Limestone adds minerals to the water, mainly calcium, making the water less acidic and more alkaline. This helps keep the water's pH stable by buffering the water from shifts in pH when acids or bases enter the rainwater. Rainwater is typically soft water, meaning it has relatively low concentrations of calcium, magnesium, and other ions, and therefore has a relatively unstable pH, which can corrode pipes and filters. Remineralization improves water quality and protects the filters and pipes from corrosion.

The pressure vessel is a cylinder made out of polypropylene and/or polyethylene with fiberglass reinforcement. The rainwater flows into the top of the pressurized through an inlet valve. It flows down through the filter media to the bottom of the tank. Then the rainwater enters a pipe in the center of the pressure vessel and goes back up to the top of the tank. It exits the tank out of the outlet valve at the top. The function of the pressure vessel is to retain the filter media inside

---

[24] Depci, T. (2012) Comparison of activated carbon and iron impregnated activated carbon derived from Gölbaşı lignite to remove cyanide from water,
Chemical Engineering Journal, 181–182, 467-478, ISSN 1385-8947,
https://doi.org/10.1016/j.cej.2011.12.003.

[25] Tan, G., Sun, W., Xu, Y., Wang, H., & Xu, N. (2016). Sorption of mercury (II) and atrazine by biochar, modified biochars and biochar based activated carbon in aqueous solution,
Bioresource Technology, 211, 727-735, ISSN 0960-8524, https://doi.org/10.1016/j.biortech.2016.03.147

[26] Le Cloirec, P., & Faur, C. (2006) Chapter 8. *Adsorption of organic compounds onto activated carbon — applications in water and air treatments*, Editor(s): Teresa J. Bandosz, Interface Science and Technology: Elsevier*, 7*, 375-419, ISSN 1573-4285, ISBN 9780123705365,
https://doi.org/10.1016/S1573-4285(06)80017-7.

[27] Chowdhury, Z., Summers, R., Westerhoff, G., Leto, B., Nowack, K., Corwin, C., & Passantino, L. (2013). *Activated Carbon - Solutions for Improving Water Quality - 1.2.1 Batch Adsorption Kinetics.* American Water Works Association (AWWA) . Retrieved from
https://app.knovel.com/hotlink/pdf/id:kt011O8OF3/activated-carbon-solutions/batch-adsorption-kinetics

[28] Saha, U., Turner, P., Hawkins, G., & Burnsed, J. (2021). *Household Water Treatment Techniques and Devices: Activated Carbon Filtration*. UGA Cooperative Extension Bulletin 1542.
https://secure.caes.uga.edu/extension/publications/files/pdf/B%201542_3.PDF

[29] Kamrin, M., Hayden, N., Christian, B., Bennack, D., & D'Itri, F. (n.d.). *Home Water Treatment Using Activated Carbon*. Purdue University Extension, WQ-13.
https://extension.purdue.edu/extmedia/WQ/WQ-13.html

[30] Kamrin, M., Hayden, N., Christian, B., Bennack, D., & D'Itri, F. (n.d.). *Home Water Treatment Using Activated Carbon*. Purdue University Extension, WQ-13.
https://extension.purdue.edu/extmedia/WQ/WQ-13.html

[31] EPA United States Environmental Protection Agency. (2012). *Frequently Asked Questions About Nitrate and Drinking Water.*
https://www.epa.gov/sites/default/files/2017-12/documents/lower-yakima-valley-groundwater-faq-october-2012.pdf

[32] Konno, H., Yaegaki, K., Tanaka, T., Sato, T., Itai, K., Imai, T., Murata, T., & Herai, M. (2008) Neither hollow-fibre membrane filters nor activated-charcoal filters remove fluoride from fluoridated tap water. Journal *Canadian Dental Association*, 74(5), 443. https://www.cda-adc.ca/jcda/vol-74/issue-5/443.pdf

[33] Senewirathna, D.S.G.D., Thuraisingam, S., Prabagar, S., & Prabagar, J. (2022). Fluoride removal in drinking water using activated carbon prepared from palmyrah (Borassus flabellifer) nut shells. *Current Research in Green and Sustainable Chemistry*, 5, 100304. https://doi.org/10.1016/j.crgsc.2022.100304.

while letting the water flow through it. The pressure vessel must be strong enough to hold the pressure from the pump.

The top layer of the activated carbon is where sediments are retained. Sediment that collects in the top layer is removed from the carbon when the filter backwashes. The filter backwashes every 14 days. The backwash lasts about 30 minutes and has a flow rate of 20 liters per minute; in total, around 600 liters of water are backwashed. The backwash removes sediment and resettles the filter media to remove channels, which renews the filter and extends its lifespan. Backflushing does not remove the materials that were adsorbed by the activated carbon, which is why the activated carbon becomes saturated over time and must be replaced each year. The backflush wastewater is pumped to the city sewer system through a transparent tube at the bottom of the canister. Backflushing creates a large quantity of wastewater in a short amount of time, so that wastewater is pumped to the city rather than to the garden.

The activated carbon and limestone need to be replaced every year.

Activated carbon

Activated carbon is filled with tiny pores the size of molecules.[34] It adsorbs substances in these pores.

Adsorption—the adhesion of a substance (atoms, ions, or molecules from a gas, liquid, or dissolved solid) onto a surface—occurs because the pores or voids in activated carbon are surrounded by carbon atoms.[35] Molecules that are adsorbed are constantly in flux. Each molecule that is adsorbed is replaced with another molecule about every trillionth of a second.[36] A carbon particle can have more than six trillion pores and is constantly adhering, releasing, and exchanging molecules. A carbon particle is about 1 mm^3 and has one trillion pore entrances per 1 mm^2.[37] One teaspoon of activated carbon has a surface area the size of a football field.[38]

Activated carbon can be made from wood, coconut shells, nut shells, fruit pits, coals, peat, and synthetic organic polymers.[39] The carbon in the filter has been "activated" by a specific process, often heating with steam to 800˚C (1472˚F) (following standard DIN EN

---

[34] Marsh, H., & Rodríguez, R. (2006). Activated carbon. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org,
[35] Chowdhury, Z., Summers, R., Westerhoff, G., Leto, B., Nowack, K., Corwin, C., & Passantino, L. (2013). *Activated Carbon - Solutions for Improving Water Quality - 1.2.1 Batch Adsorption Kinetics.* American Water Works Association (AWWA) . Retrieved from https://app.knovel.com/hotlink/pdf/id:kt011O8OF3/activated-carbon-solutions/batch-adsorption-kinetics
[36] Marsh, H., & Rodríguez, R. F. (2006). *Activated carbon*. Amsterdam, Boston: Elsevier. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org
[37] Marsh, H., & Rodríguez, R. F. (2006). *Activated carbon*. Amsterdam, Boston: Elsevier. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org
[38] Engber, Daniel. (2005). How does Activated Carbon Work? *Slate*. Retrieved May 29, 2021 from https://slate.com/news-and-politics/2005/11/how-does-activated-carbon-work.html
[39] Marsh, H., & Rodríguez, R. (2006). Activated carbon. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org,

12915[40]). During activation, voids form because of a structural disorder.[41] Most carbons order themselves into a graphite lattice when heated, but certain carbons do not.[42] These non-graphitizable carbons are disordered but not disorganized; when activated, they form a maze of voids. The properties of activated carbon depend on this disorder.[43]

The pores in activated carbon are not infinite. They can become saturated. Once all the pores are occupied, in order to adsorb any new molecules, the pores must release the molecules they already have, and these molecules go back into the water. This is why the activated carbon in the filter needs to be replaced approximately once each year (depending on use), before the pores become saturated.

Activated carbon is not a single chemical entity but a generic name for a class of substances, which adsorb different molecules depending on what they are made from and the process used to activate them. One type of activated carbon may be better for purifying water, while another type may be better for purifying sugar.[44]

Limestone Remineralization

Remineralizing the water with limestone adds minerals to the water, mainly calcium, and makes the water more alkaline and less acidic. The limestone increases the water's pH level to between 7.0 and 8.2.

Limestone contains three main elements: calcium, carbon, and oxygen, primarily in the form of calcium carbonate ($CaCO_3$). When the rainwater filters through the limestone and carbon dioxide is added to the water, it dissolves the calcium carbonate into calcium bicarbonate ($Ca(HCO_3)_2$), which increases water's alkalinity, pH, and hardness. The calcium ions (Ca^{2+}) increase the water's hardness, and the carbonate ions (CO_3^{2-}) increase alkalinity. Carbonate ions bond with the lone hydrogen ion (H+) to produce bicarbonate. Bicarbonate ions neutralize both hydrogen (H^+) and hydroxide (OH^-) ions, and therefore provide a buffer to pH shifts in both directions.

---

[40] Deutsches Institut für Normung e. V. (2009). *DIN EN 12915-1*. https://www.din.de/de/mitwirken/normenausschuesse/naw/wdc-beuth:din21:117012039

[41] Marsh, H., & Rodríguez, R. F. (2006). *Activated carbon*. Amsterdam, Boston: Elsevier. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org

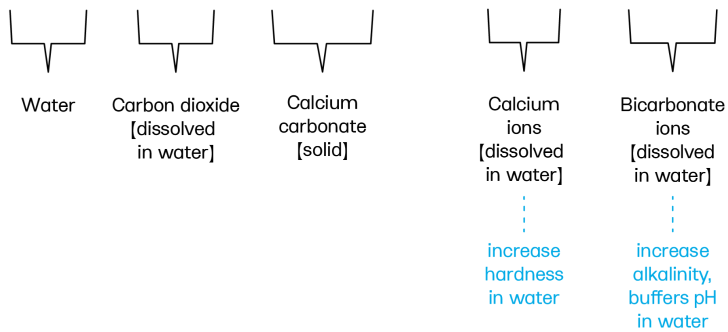
[42] Marsh, H., & Rodríguez, R. F. (2006). *Activated carbon*. Amsterdam, Boston: Elsevier. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org

[43] Marsh, H., & Rodríguez, R. F. (2006). *Activated carbon*. Amsterdam, Boston: Elsevier. ProQuest Ebook Central https://ebookcentral-proquest-com.yale.idm.oclc.org

[44] Hassler, J. W. (1963). *Activated carbon.* [Rev. ed.]. New York: Chemical Pub. Co..

Calcium carbonate increases water's alkalinity, pH and hardness

$$H_2O + CO_2 + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$



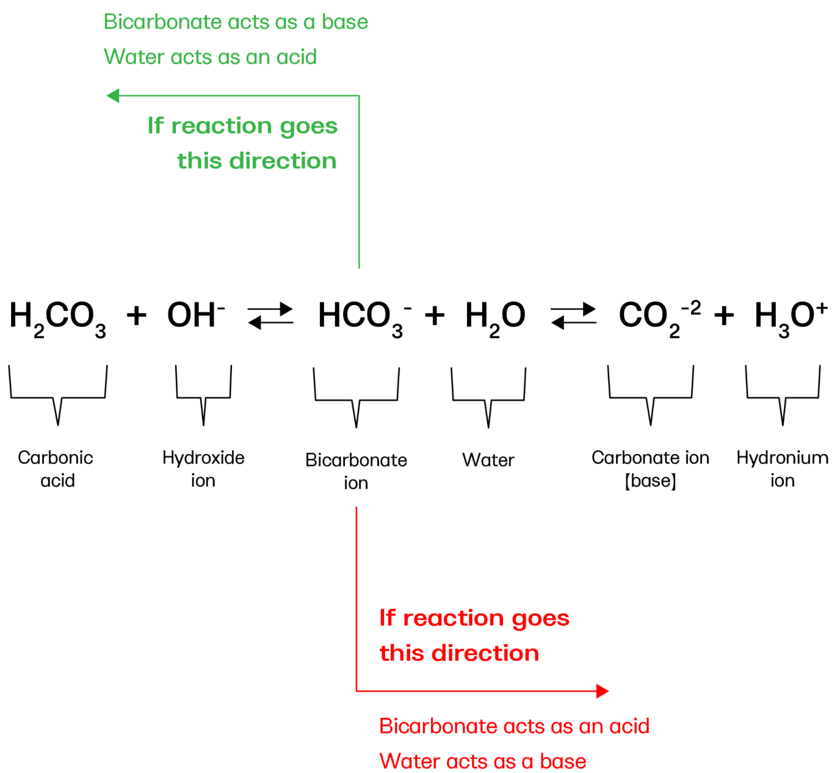
[45]

Alkalinity is a measurement of water's ability to resist changes in pH by buffering or neutralizing acids and bases that enter the rainwater in the air, on the roof, or in the cistern. Alkaline water typically has a pH greater than 7.0. Alkalinity helps water maintain a stable pH. The more alkaline water is, the more buffering capacity it has, meaning the more acid or base it can neutralize without changing pH. Large fluctuations in pH level could impact water quality, damage the filters, or cause corrosion in the pipes. Just as you can never step in the same river twice, the filter system will never filter the same water twice; it is always filtering a novel combination of pure water, minerals, ions, chemicals, acids, bases, living organisms, and organic matter. Limestone remineralization helps soften how pH shifts in response to variation in this mixture.

Rainwater can be acidic because it interacts with carbon dioxide (CO_2) in the atmosphere, and it has very few minerals which can buffer, or neutralize, the acid that forms when carbon dioxide dissolves in water. When carbon dioxide dissolves in water, it becomes carbonic acid (H_2CO_3). Carbonic acid dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+). A high concentration of hydrogen ions leads to a low, acid pH. Continued dissociation results in hydronium ions (H_3O^+), the strongest acid that can exist in water. This decreases the pH of water further. The pH of normal rain is around 5.6. The pH in most streams and lakes is 6.0 - 9.0. The pH of most city drinking water ranges from 6.5 - 8.5. Pure water (H_2O) has a pH of 7.0.

[45] Equation illustration based on: Breslyn, W. (2021). *Equation for CaCO3 + H2O (Calcium carbonate plus Water)*. YouTube. https://www.youtube.com/watch?v=yuFTlnRTFJA

Carbonic acid equilbrium



[46]

Rainwater may become more acidic if it encounters nitric and sulfuric acids in the atmosphere. These strong acids are highly soluble and dissolve in water droplets within clouds. Most of the nitrogen and sulfur oxides in the atmosphere come from human activities, including fossil fuel electricity generation, industrial combustion, industrial processes, and petroleum-powered transportation.

In this way, we begin to understand the rainwater flowing through the filter system not as pure water (H_2O) but as a liquid solvent, an aqueous solution that includes other molecules, which give the water different qualities and capacities. Certain molecules, elements, and organisms in water are beneficial for humans and the functioning of the rainwater filtration system, others are not. In Timelab, the rainwater filtration system is designed to try to maintain the beneficial additives and remove the rest. This is easier said than done, due to the relatively indiscriminate nature of the filter media and mechanisms currently available.

[46] Equation illustration based on: Marks, R. (2020). Acids and Bases II. Visionlearning Vol. CHE-5 (1) https://www.visionlearning.com/es/library/Qumica/1/Acids-and-Bases-II/272

Rainwater is typically soft water, meaning it has relatively low concentrations of calcium, magnesium, and other ions. Rain forms through a process of evaporation, condensation, and precipitation; it cannot carry many minerals and ions during these processes, nor does it encounter many of them in the air. Groundwater and river water (the main sources of city drinking water) are typically hard because they encounter more minerals, for example, when water moves over or through rocks. Groundwater and river water can carry many more minerals on their journeys.

Ions are minerals or elements with a positive or negative charge (cations or anions) that can bond with water molecules, mainly because water is a bipolar molecule that is liquid (rather than solid or gas) on much of the earth's surface. Water molecules have a positive charge on the side where the hydrogen atoms are located and a more negative charge on the side where the oxygen atom is located. Atoms and ions are attracted to these different sides of water molecules depending on their own charge and reactivity. This interaction with water molecules can split atoms and ions apart, dissociating them and dissolving them in water, creating an aqueous solution.

Limestone contains calcium, which is an alkaline-earth metal. Calcium is the most common mineral and most abundant inorganic element in the human body and needed for almost every single process. It is also the most abundant element in the Earth's crust. Calcium makes up 2 percent of the human body and 3 percent of the earth's crust. It can be found all over the body as a structural element in cell membranes, bones and teeth, and as a signal transducer and enzyme cofactor in muscle and heart contraction, necessary blood clotting, hormone regulation, and nervous system functioning.

Limestone is a biological sedimentary rock composed mainly of calcium carbonate. Many limestone deposits were at one time living organisms. Marine animals like molluscs and corals accumulate calcium in their shells and skeletons. Limestone is also formed through a chemical sedimentary process where calcium ions suspended in water sink down to the bottom and accumulate. Fish and other aquatic life require a pH range of 6.0 to 9.0.[47] Humans can tolerate a pH range of 4.0 - 10.0.[48] Because alkalinity buffers against rapid pH changes, it protects living organisms that require a specific pH range.

Water test tap 2
After the activated carbon filter, there is a sampling point. Samples here make it possible to understand the effect the activated carbon and limestone have on the rainwater.

Filter 2: UV light
Next the rainwater filters through the UV light, which does not filter out microorganisms but alters their DNA and destroys their ability to reproduce.

[47] Fondriest Environmental Learning Center. (n.d.) pH of Water. https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/
[48] Fondriest Environmental Learning Center. (n.d.) pH of Water. https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

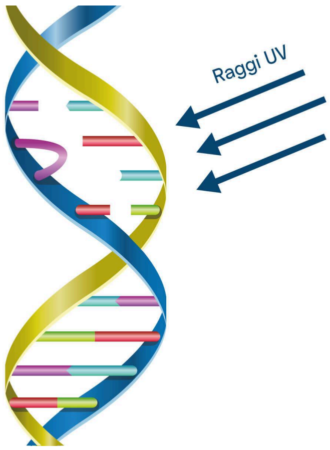
UV light shines onto rainwater through a quartz glass tube suspended inside a stainless steel tube. It emits 254 nanometers of UVC light. This is a short wavelength of UV light that carries a significant amount of energy. UVC light penetrates microorganisms' cell walls and destroys the molecular bonds that hold their DNA together.[49] High energy photons break and change the DNA of bacteria, viruses, protozoa, cysts, fungi, and algae, destroying their ability to reproduce. Bacteria need to reproduce to cause disease in human bodies. If bacteria are unable to reproduce, they cannot harm humans when they are ingested, and they are effectively killed.

The UV light bulb is protected in a glass tube made of quartz, a very transparent type of glass. The bulb is not in direct contact with the water. The lamp is controlled by a ballast inside the stainless steel tube. The ballast provides the high voltage the bulb needs to turn on. The ballast transforms 220 volts into 400 - 1000 volts to ignite mercury gas inside the bulb. Then, the ballast reduces the voltage to a lower working level that keeps the bulb illuminated. Without the ballast, the current would increase rapidly until the bulb blew out.

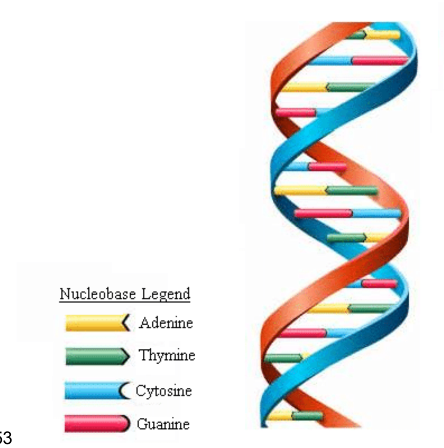
UVC light

UVC light is absorbed by nucleic acids in DNA, causing microorganisms to disintegrate at the cellular level. High energy photons break chemical bonds in DNA and cause mutations. One mutation forms a pyrimidine dimer. In DNA's double helix, there are two strands of DNA connected by bases located on opposite strands. A dimer is formed when the bases on one strand of DNA bind to each other, forming a loop, rather than binding to bases across from them, on the other DNA strand, forming a line.[50] When UVC light hits bases made out of thymine and cytosine, it breaks their connection to bases on the opposite strand.[51] [52]. Then they connect to each other, making a loop on the same strand. This crosslink destroys the normal base-pairing, double-strand structure in that area. These changes in chemical structure of the helix ultimately prevent transcription and replication of DNA. The bacteria cannot reproduce, and the population of microorganisms diminishes rapidly.

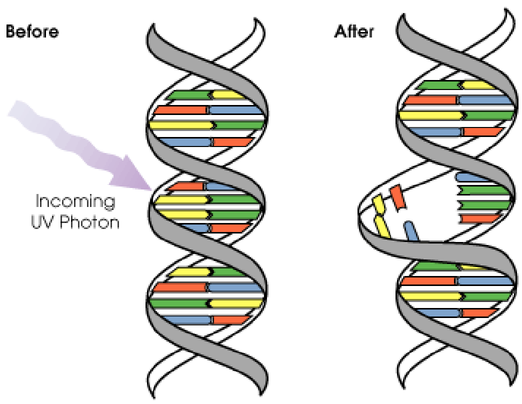
[49] Fondazione Mutagens ETS. (2022). *Gli agenti mutageni*. https://mutagens.it/informati/gli-agenti-mutageni/
[50] Fondazione Mutagens ETS. (2022). *Gli agenti mutageni*. https://mutagens.it/informati/gli-agenti-mutageni/
[51] Rammelsberg, M. and Baxter, B.K. (1998). *How does ultraviolet light kill cells?* Scientific American. https://www.scientificamerican.com/article/how-does-ultraviolet-ligh/
[52] Allen, J. (2001) *Ultraviolet Radiation: How it Affects Life on Earth*. Nasa Earth Observatory. https://earthobservatory.nasa.gov/features/UVB



53



54



55

UV hour counter

The UV light's ballast has an hour counter that counts every hour it is running. The bulb is good for about 8,000 hours. There are 8,760 hours in a year, so the bulb must be replaced every year. It will still be giving light after 8,000 hours, but the bulb has deteriorated in quality, and the light it gives is insufficient for reliably destroying microorganisms' DNA and ability to reproduce. Inside the hour counter, there is a green light and a red light. The green light will be on if the UV lamp is working properly. If there is a problem, the red light will go on, and the UV hour counter will start to buzz.

Sanitary rainwater

---

[53] Fondazione Mutagens ETS. (2022). *Gli agenti mutageni*. https://mutagens.it/informati/gli-agenti-mutageni/

[54] Grimes, David. (2011). Development of a radiation computation dose model for use in ultraviolet phototherapy. [Doctoral dissertation, Dublin City University. DORAS DCU Online Research Access Service. https://doras.dcu.ie/16474/]

[55] Herring, D. (2001). Ultraviolet (UV) photons harm the DNA molecules of living organisms. [Illustration]. In J. Allen, *Ultraviolet Radiation: How it Affects Life on Earth*. Nasa Earth Observatory. https://earthobservatory.nasa.gov/features/UVB

After rainwater has been filtered by the activated carbon, limestone, and UV light, it is now sanitary rainwater. Sanitary rainwater can be used for showering, washing hands, washing clothes, and flushing toilets. In Belgium, any tap point with sanitary water must be marked with a “not for drinking” sign.[56]

At this point, the filtration system splits in two directions. Sanitary water is piped upwards and out to the water collectors and distributed throughout the building. A small portion of the sanitary water continues on in the Waterlab to be filtered by two more filters. This water becomes drinkable rainwater.

Water test tap 3
The third water test tap enables sampling of the sanitary rainwater. Tests made here show the quality of the sanitary rainwater created by the filtration system.

Water meter 2
The second water meter measures all the sanitary water used in the building. About half of the building uses sanitary rainwater.

EA check valve 2
The EA check valve prevents water from flowing backwards from the building into the filtration system.

Pressure gauge 2
The pressure gauge helps monitor pressure in the system, ensuring there is adequate pressure through the filters and leading to the water collectors.

Water collectors
The water collectors are the central hub of the building’s water system. They are located in the room adjacent to the Waterlab. All water tubes in the building connect here. They can be fed with two types of water: sanitary rainwater or city drinking water. The pipes leaving the water collectors, transport water throughout the building.

Sanitary rainwater is transported to the first floor bathroom sink and toilets, washing machine, wheelchair-accessible bathroom sink and toilet, Timelab Eatery bathroom sink and toilet, Waterlab sink, garden, and Knotfactory. In the future, it will be used to water Timelab’s indoor vertical garden.

City drinking water is transported to the ground floor kitchen, first floor kitchen, and Timelab Eatery bar sink.

The top and middle sections of the water collectors connects water tubes to sanitary rainwater. The bottom section of the water collectors connects water tubes to city drinking water. The

---

[56] AquaFlanders vzw. (2018). *Belangrijke tips bij het bouwen van je waterinstallatie*. https://www.aquaflanders.be/public/downloads/Belangrijke-tips-bij-het-bouwen-van-uw-waterinstallatie.pdf

sanitary rainwater and the city drinking water is kept separated. The system never mixes sanitary rainwater and city drinking water.

Water meter 3
The third water meter measures the amount of rainwater filtered into drinking rainwater.

Shutoff valve 3
The third shutoff valve makes it possible to turn off the drinking rainwater section of the filtration system, if there is a problem or if maintenance is needed.

CA check valve
CA is a double check valve that prevents water from flowing backwards in the system. CA means "non-controllable backflow preventer with reduced pressure zones," in accordance with European standards DIN EN1717[57] and EN13959.[58] It has two single check valves separated by a chamber communicating with the atmosphere. This enables the upstream and downstream circuits to be separated if backflow occurs and provides a failsafe backup if one of the check valves fails for any reason. Double check valves have screws on each side so that the valve port can be opened and cleaned if debris builds up over time.

Filter 3: Ultrafiltration membrane with extruded carbon
The third filter contains an ultrafiltration membrane and a cylinder of extruded activated carbon.

The rainwater first passes through the extruded carbon, which removes anything larger than 0.5 microns. The extruded carbon looks like a black tube with a thick wall and open inner core. In addition to a multitude of small pores capable of adsorption, it contains very small silver ion particles in the carbon mix. Nanosilver inhibits growth and reproduction of microorganisms. Silver ions penetrate the cell membranes of microorganisms, and their reproductive abilities are halted. Nanosilver adversely affects microorganisms' cellular metabolism and inhibits cell growth

[57] Deutsches Institut für Normung e.V. (2023). *DIN EN 1717*.
https://www.din.de/de/mitwirken/normenausschuesse/naw/entwuerfe/wdc-beuth:din21:367908315
[58] Deutsches Institut für Normung e.V. (2004). *DIN EN 13959.*
https://www.din.de/de/mitwirken/normenausschuesse/naa/veroeffentlichungen/wdc-beuth:din21:71538012

by suppressing respiration,[59] [60] basal metabolism,[61] electron transfer across cell walls,[62] and transport of substrate in the microbial cell membrane.[63]

Then the rainwater filters through an ultrafiltration membrane, which traps anything smaller than 0.1 microns. The ultrafiltration membrane is located at the top of the filter and is made out of hollow, asymmetric polymeric fibers. These appear like white, spaghetti-like plastic straws. They are attached in a "U" shape to the top of the filter's container. At a microscopic level, these straws look more like sponges.[64] They are filled with tiny pores arranged in a maze-like structure that the water can pass through, but anything larger than 0.1 microns is trapped.[65] [66] [67] The rainwater flows through the pores into the hollow insides of the tubes; anything smaller than 0.1 microns gets stuck in the maze-like walls of the tube. Most bacteria are larger than 0.1 microns,[68] including the three bacteria commonly tested for in drinking water. *Escherichia coli* bacteria is about 1.0 micron in diameter and 1.0-2.0 microns long.[69] *Enterococcus faecalis*

---

[59] Holt, K.B., & Bard, A.J. (2005). Interaction of Silver(I) Ions with the Respiratory Chain of Escherichia coli: An Electrochemical and Scanning Electrochemical Microscopy Study of the Antimicrobial Mechanism of Micromolar Ag+. *Biochemistry*, 44(39), 13214–13223. https://doi.org/10.1021/bi0508542
[60] Feng, Q. L., Chen, G. Q., Cui, F. Z., Kim T. N., & Kim, J. Q., (2000). A Mechanistic Study of the Antibacterial Effect of Silver Ions on Escherichia Coli and Staphylococcus Aureus. *Journal of Biomedical Materials Research*, 52(4), 662-668. https://doi.org/10.1016/j.resmic.2011.04.009
[61] Wen, H., Shi, H., Jiang, N., Qiu, J., Lin, F., & Kou, Y. (2023). Antifungal mechanisms of silver nanoparticles on mycotoxin producing rice false smut fungus. *iScience*, 26, 1, 105763. https://doi.org/10.1016/j.isci.2022.105763.
[62] Feng, Q. L., Chen, G. Q., Cui, F. Z., Kim T. N., & Kim, J. Q., (2000). A Mechanistic Study of the Antibacterial Effect of Silver Ions on Escherichia Coli and Staphylococcus Aureus. *Journal of Biomedical Materials Research*, 52(4), 662-668. https://doi.org/10.1016/j.resmic.2011.04.009
[63] El-Badawy, A., Feldhake, D., & Venkatapathy, R. (2010). Scientific, Technical, Research, Engineering and Modeling Support Final Report State of the Science Literature Review: Everything Nanosilver and More. *US EPA*, Contract No. EP-C-05-057, Task Order No. 95. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EJJS.txt
[64] Mitsubushi Chemical Cleansui. (n.d.). *Hollow Fiiber Membrane*. https://mitsubishicleansui.com.vn/en/hollow-fiber-filter/
[65] Younas, M., & Mashallah Rezakazemi, M. (2022). Introduction to Membrane Technology. In M. Younas and M. Rezakazemi (Eds.), *Membrane Contactor Technology: Water Treatment, Food Processing, Gas Separation, and Carbon Capture* (First Edition). Wiley VCH GmbH. https://application.wiley-vch.de/books/sample/3527348611_c01.pdf
[66] Muthumareeswaran, M., Alhoshan, M. & Agarwal, G. (2017). Ultrafiltration membrane for effective removal of chromium ions from potable water. *Sci Rep* 7, 41423. https://doi.org/10.1038/srep41423
[67] Wang, X., Lyu, Q., Tong, T., Sun. K., Lin, L., Tang, C.Y., Yang, F., Guiver, M.D., Quan, X., & Dong, Y. (2022). Robust ultrathin nanoporous MOF membrane with intra-crystalline defects for fast water transport. *Nature Communications*, 13, 266.. https://doi.org/10.1038/s41467-021-27873-6
[68] Staley, J.T. (1999). Correlates of Smallest Sizes for Microorganisms. In National Research Council (US) Steering Group for the Workshop on Size Limits of Very Small Microorganisms (Eds.), Size Limits of Very Small Microorganisms: Proceedings of a Workshop. National Academies Press. https://www.ncbi.nlm.nih.gov/books/NBK224752/
[69] Riley, M. (1999). Correlates of Smallest Sizes for Microorganisms. In National Research Council (US) Steering Group for the Workshop on Size Limits of Very Small Microorganisms (Eds.), *Size Limits of Very Small Microorganisms: Proceedings of a Workshop*. National Academies Press. https://www.ncbi.nlm.nih.gov/books/NBK224751/

bacteria is 1.0-1.7 microns in diameter and 1.15-1.80 microns in length.[70] *Clostridium perfringens* bacteria is 1.0-15.0 microns in diameter[71] and 3.0-9.0 microns in length.[72]

Given Timelab's typical water use, this filter's cartridge will need to be replaced once per year. If water use were higher, or if there were no reverse osmosis filter following the ultrafiltration membrane, it would be advisable to replace the cartridge twice a year.

In addition to removing bacteria, the ultrafiltration membrane and extruded activated carbon capture small particles of sediment. This protects the final filter, the reverse osmosis filter, from being quickly clogged and increases its longevity. The ultrafiltration membrane and extruded activated carbon can be thought of as a pre-filter for the reverse osmosis filter.

Water test tap 4

The fourth water test tap enables sampling after the ultrafiltration membrane, to see the effect it has on the rainwater. Tests can show how the ultrafiltration membrane may improve the quality of the sanitary rainwater and how that sanitary rainwater compares to the drinking rainwater produced after the reverse osmosis system.

Filter 4: Reverse Osmosis

Reverse osmosis is the final filter in the system. After reverse osmosis, the rainwater is drinkable water. Reverse osmosis filters apply pressure to push water through a semipermeable membrane filter in the opposite direction that osmosis would flow naturally. Reverse osmosis membranes have tiny pores of around 0.0001 micrometers (0.1 nanometers or 1/10,000th of a millimeter) that can trap the tiniest contaminants. The system's reverse osmosis filter is an ultralow-pressure spiral membrane module, thin film composite that yields a maximum total dissolved solids of 1500 ppm and removes more than 90 percent of ions. It substantially removes per- and polyfluoroalkyl substances (PFAS);[73] microplastics; heavy metals, such as cadmium, arsenic, lead, and copper; volatile organic compounds; sodium; nitrates; phosphate; fluoride; cysts; agrochemical and petrochemical contaminants; some pharmaceutical contaminants; and various microbial, viral, and biological contaminants larger than 0.0001

[70] Signoretto, C., Lleò, M.M., Tafi, M.C., & Canepari, P. (2000). Cell wall chemical composition of Enterococcus faecalis in the viable but nonculturable state. *Applied and Environmental Microbiology*, 66(5),1953-9. https://doi.org/10.1128%2Faem.66.5.1953-1959.2000

[71] ANSES French Agency for Food, Environment and Occupational Health & Safety. (2010). *Clostridium perfringens*. https://www.anses.fr/en/system/files/MIC2010sa0235FiEN.pdf

[72] Japanese Society of Chemotherapy Committee on guidelines for treatment of anaerobic infections; Japanese Association for Anaerobic Infection Research. (2011). Chapter 2-12-6. Anaerobic infections (individual fields): food poisoning due to *Clostridium perfringens*. *Journal of Infection and Chemotherapy* 17(Suppl 1), 135–136. https://doi.org/10.1007/s10156-010-0159-0

[73] Cserbik, D., Redondo-Hasselerharm, P.E., Farré, M.J., Josep Sanchís, S. , Bartolomé, A., Paraian, A., Herrera, E.M., Caixach, J., Villanueva, C.M., & Flores, C. (2023). Human exposure to per- and polyfluoroalkyl substances and other emerging contaminants in drinking water. *npj Clean Water,* 6, 16. https://doi.org/10.1038/s41545-023-00236-y

microns.[74] [75] [76] [77] Viruses are typically smaller than bacteria. The typical virus size is about 0.1 microns in diameter; this is the size of the influenza virus.[78] The smallest viruses are 0.02 microns in diameter. The size of coronavirus (SARS-CoV-2) ranges from 0.07 microns to 0.09 microns.[79] [80] Reverse osmosis removes almost everything in the water—this is as far as one can go with the currently available technology.

After reverse osmosis, there are very few minerals in the water; this makes the pH of the water unstable. The smallest quantity of a base or acid can change the pH completely. Reverse osmosis water is more likely to leach heavy metals from pipes, which is why the reverse osmosis filter is connected directly to the gold sink in the Waterlab, so there are no pipes between the filter and the faucet where you can access the drinkable rainwater.

Since reverse osmosis also removes beneficial minerals,[81] remineralization could be added after the reverse osmosis filter via an inline cartridge that costs around 20 euros. People obtain more minerals from food than water.

How do reverse osmosis membranes not become quickly clogged? Because there are several filter stages before water reaches the reverse osmosis membrane that have a higher micron rating and are designed to remove larger particles that could quickly clog the membrane's pores. In the rainwater filtration system, there are three filters before the reverse osmosis filter, and the filter itself has an activated carbon pre-filter. Additionally, because of the high-pressure operation of a reverse osmosis system, impurities like

---

[74] Wimalawansa, S. J. (2013). Purification of contaminated water with reverse osmosis: effective solution of providing clean water for human needs in developing countries. *International Journal of Emerging Technology and Advanced Engineering,* 3, 75–89. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=14777e52b5efa8ff94e529051b24fad15808df6a

[75] EPA United States Environmental Protection Agency, Office of Water. (March 2023). *Work Breakdown Structure-Based Cost Model for Reverse Osmosis/Nanofiltration Drinking Water Treatment*. 31. https://www.epa.gov/system/files/documents/2022-03/ronf-documentation-.pdf.pdf

[76] EPA United States Environmental Protection Agency. (2022). *Point-of-Use Reverse Osmosis Systems fact sheet.* https://www.epa.gov/system/files/documents/2022-12/WS-Products-Specification-RO-Systems-factsheet.pdf

[77] Pooi, C.K., & Ng, H.Y. (2018). Review of low-cost point-of-use water treatment systems for developing communities. npj *Clean Water,* 1, 11. https://doi.org/10.1038/s41545-018-0011-0

[78] Louten, J. (2016). Virus Structure and Classification. *Essential Human Virology*, 19–29. https://doi.org/10.1016/B978-0-12-800947-5.00002-8

[79] Lee, B. (2020). Minimum Sizes of Respiratory Particles Carrying SARS-CoV-2 and the Possibility of Aerosol Generation. *International Journal of Environmental Research and Public Health*, 17(19), 6960. MDPI AG. Retrieved from http://dx.doi.org/10.3390/ijerph17196960

[80] Park W.B., Kwon N.J., Choi S.J., Kang C.K., Choe P.G., Kim J.Y., Yun J., Lee G.W., Seong M.W., Kim N.J., Seo, J.S., & Oh, M.D. (2020). Virus isolation from the first patient with SARS-CoV-2 in Korea. J. Korean Med. Sci., 35:e84. https://doi.org/10.3346/jkms.2020.35.e84

[81] Younas, M., & Mashallah Rezakazemi, M. (2022). Introduction to Membrane Technology. In M. Younas and M. Rezakazemi (Eds.), *Membrane Contactor Technology: Water Treatment, Food Processing, Gas Separation, and Carbon Capture* (First Edition). Wiley VCH GmbH. https://application.wiley-vch.de/books/sample/3527348611_c01.pdf

minerals are likely to bounce back after hitting the membrane. In the reverse osmosis concentrate chamber, they are drained away with the wastewater, or concentrate.

Two qualities of water flow out of the reverse osmosis system: permeate water and concentrate water. Permeate water is the drinkable water; it flows out of a white tube and is connected to the drinking water faucet. Concentrate water is the wastewater; it flows out of a red tube and drains to the garden. For every glass of drinkable rainwater that flows out of the reverse osmosis filter, there is one glass of concentrate wastewater that gets pumped to a tank in Timelab's garden to use for watering the plants and replenishing the groundwater supply. The concentrate water from filtering the rainwater likely includes calcium, magnesium, sulfate, nitrate, and some organic matter.

Gold sink
The gold sink in the Waterlab has two faucets, one for drinkable rainwater and the other for sanitary rainwater. The gold sink is accessible to visitors of Timelab.

Water test tap 5
The fifth water test tap samples the permeate rainwater after reverse osmosis filtration. This is the drinkable rainwater. The test tap is used to confirm the drinkable rainwater is safe for drinking. Test tap 5 is the same as the faucet for drinkable rainwater in the gold sink.

Water test tap 6
The sixth water test tap samples the concentrate wastewater after reverse osmosis filtration. It is used to identify what reverse osmosis removes from the rainwater. Test tap 6 is the same as the red tube flowing out of the reverse osmosis system, before it empties into a funnel and is pumped to the garden.

Water tests results

On 8 June 2023 and 31 July 2023, the rainwater filtration system was tested by Farys. The test results showed that the final water after the reverse osmosis filter is microbiologically safe to drink and to use. They also showed that the sanitary water is safe to use for all sanitary water uses (handwashing, showering, clothes washing, toilets).

Pdfs of the tests are available here:
8 June 2023 - Water Test Results - conducted by Farys Gent Lab - Rainwater Filtration System at Timelab
https://drive.google.com/drive/folders/1XETa77TIYUZtTgWaSBQJyVtW3nrGGTvd?usp=drive_link

8 June 2023 - Flow Cytometry Test Results - conducted by Farys Research and Development (Bart De Gusseme and Tom Vandermarliere) - Rainwater Filtration System at Timelab
https://drive.google.com/drive/folders/1IV4PyUbb8d_t7SHaAAUIOb7WokTRo54q?usp=sharing

31 July 2023 - Water Test Results - conducted by Farys Gent Lab - Rainwater Filtration System at Timelab
https://drive.google.com/drive/folders/1exnGxor5fSaW5mKdUy6UT_w8zOKixIwp?usp=drive_link

31 July 2023 - Flow Cytometry Test Results - conducted by Farys Research and Development (Bart De Gusseme and Tom Vandermarliere) - Rainwater Filtration System at Timelab
https://drive.google.com/drive/folders/1mbrIIMy3dCm648VpLQmcwVgQbvIGYrsx?usp=drive_link

Of the 35 parameters tested after reverse osmosis (test tap 5), on 8 June 2023, 33 met the maximum permitted concentration for drinking water according to the Decree of the Flemish Government dd. 20/01/2023 [Maximum toegelaten concentratie volgens het Besluit van de Vlaamse Regering dd. 20/01/2023[82]]; on 31 July 2023, 34 met the maximum permitted concentration. The deviations from the Flemish drinking water standards include:

1. The maximum permitted concentration according to the Decree of the Flemish Government (20/01/2023) is 0.10 mg/l of nitrite (NO2). In the first test on 8 June 2023, the nitrite concentration in the drinking rainwater was a little bit too high, with 0.14 mg/l. In the second test on 31 July 2023, the nitrate concentration went down to 0.015 mg/l, well below the maximum permitted concentration.

[82] Vlaamse Milieumaatschappij. (2023). Algemeen Waterverkoopreglement: Maximum toegelaten concentratie volgens het Besluit van de Vlaamse Regering dd. 20/01/2023. https://www.vmm.be/wetgeving/algemeen-waterverkoopreglement.pdf

2. Both test results showed the reverse osmosis water is very low in mineral content, which is also shown in the absence of residual hardness and low and negative Langelier Saturation Index. This is considered a “comfort parameter” (Group C and D) and does not pose a health risk, as long as this water is not the sole intake of minerals during the day. It is therefore recommended to drink other water or beverages as well, and (obviously) to eat and thus take up the necessary minerals through your food, a far higher source of minerals than water. To resolve this, remineralization could be added after the reverse osmosis filter via an inline cartridge that costs around 20 euros.

Further information about nitrite:

The nitrite comes from the raw rainwater in the cistern. When the sample was taken on 8 June 2023, the water level in the cistern was quite low because it had not rained for a while. When the sample was taken on 31 July 2023, the nitrate level went down, presumably after it had rained and the rainwater cistern had been replenished. A level of 0,14 mg/l of nitrates does not pose an immediate risk to healthy adults, but it is not recommended for infants and young children to drink water with this level of nitrates. Farys will continue to follow the nitrate concentration in future sampling and analyses of Timelab’s water.

The Flemish Government’s standard for nitrite is lower than the standards set by the EU (0.5 mg/l) and the US EPA (1 mg/l). The EU Drinking Water Directive (DWD, EU/2020/2184, revision of 98/83/EC and 80/778/EEC) water quality standard for nitrite is 0.5 mg/l for water intended for human consumption (DWD, Annex I, Part B).[83] The EPA’s maximum contaminant level in drinking water for nitrites is 1 mg/l (Phase II, January 1991 (56 FR 3526) Effective:1992).[84]

Nitrate and nitrite are naturally occurring ions that are part of the nitrogen cycle. Nitrate is a byproduct of a bacteria called Nitrosomonas, which eats ammonia and produces nitrite. Nitrobacter bacteria then convert the nitrites into nitrates. Nitrate also comes from fertilizers, agricultural runoff, manure, and liquid waste discharged from septic tanks.

High levels of nitrate and nitrite are most serious for infants. The conversion of nitrate to nitrite in the body reduces the ability of red blood cells to carry oxygen. According to the Washington State Department of Health,[85] nitrite can interfere with the oxygen-carrying capacity of an infant's blood. Red blood cells rapidly return to normal in most adults and children, but not in babies, which can cause methemoglobinemia, sometimes called blue baby syndrome.

---

[83] European Union. (2020). Drinking Water Directive 2020/2184. Retrieved from https://eur-lex.europa.eu/eli/dir/2020/2184/oj

[84] US Environmental Protection Agency. (n.d.) *Chemical Contaminant Rules: Background Information on Nitrate and Nitrite*. https://www.epa.gov/dwreginfo/chemical-contaminant-rules

[85] Washington State Department of Health. (2022). *Fact Sheet Nitrate in Drinking Water 331-214*. https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs//331-214.pdf