# VINETA
# Innovative low-pressure membrane process as a modular solution for decentralized potable water treatment

## Application guide

# Preface

This application guide was developed by Technische Universität Berlin, Chair of Environmental Process Engineering, Martin Systems GmbH and the University of the South Pacific, School of Information Technology, Engineering, Mathematics and Physics as part of the joint project "VINETA: Innovative low-pressure membrane process as a modular solution for decentralized potable water treatment". The implementation of VINETA would not have been possible without the continuous support of Fiji Water Authority and Palau Public Utilities Cooperation. This project was funded by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection in the Federal Republic of Germany as part of the Export Initiative Environmental Protection.

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# Objectives and target group

This document compiles information on the VINETA project that was collected during the course of the project's implementation. This information can be used by utilities and decision makers to assess whether the project's technological approach is a suitable solution for a site whose water supply is to be overhauled.

# Project VINETA

Water is ubiquitous in the North and South Pacific Islands and an important part of the local culture. As a result of climate change, many people in the Pacific Island Countries are highly affected by the negative consequences associated with rising seawater level and dramatic changes in the rainfall patterns. Droughts become more common, last up to several months, and can severely impact the water supply for many communities.

The aim of VINETA is to analyze and improve drinking water treatment in selected countries of Oceania. A needs assessment serves to select three application cases in three different countries. The assessment considers solar radiation to allow decentralized power supply. Thus, the drinking water treatment can be decoupled from the power grid when sufficient open area for solar energy operation is available. Consecutively, integrated solutions are developed which will be discussed and optimized with local stakeholders. When the conceptual designs are completed, three application cases are selected, and the low-pressure membrane filtration is demonstrated on location. This technology was developed to maturity by Martin Systems GmbH. Subsequently, the Aqua CUBE for continuous treatment of surface water in rural areas was created in a project sponsored by the German Federal Ministry of Economics and Technology. The VINETA project implements research to adapt this technology to the special requirements of decentralized and isolated operation in Oceania. In addition to the demonstration, information material for stakeholders and training materials for local operators are developed in the course of the project. This facilitates sustainable operation in the spirit of the sustainable development goals.

In close cooperation with the Palau Public Utilities Corporation (PPUC) a low-pressure UF membrane filtration system is operated in a Palauan community on Babeldaob. Two systems will provide filtered water in Fiji, one is operated in a community in Viti Levu, and the other one supplies filtered water on the Laucala Campus of the University of the South Pacific.

# Technology

The low-pressure membrane process applied is ultrafiltration. This is a membrane filtration process that is effective in removing suspended solids, bacteria, viruses, and other microorganisms from water. It is often used as a treatment step in drinking water or wastewater treatment, and industrial processes. The relatively low operating pressure and energy requirements make it a cost-effective option for many applications.

## Characteristic Properties

Ultrafiltration systems offer many advantages that facilitate long-term operation and comparatively low operation and maintenance cost:

1. effective removal of contaminants: Ultrafiltration membranes can effectively remove particles, bacteria, viruses and colloids with a size of around 0.01 to 0.1 micrometers. This helps to improve water quality.
2. chemical stability: PES ultrafiltration membranes are generally chemically stable and can be used in different water qualities without any significant degradation of the membrane.
3. low energy consumption: Compared to other filtration methods, such as reverse osmosis, ultrafiltration systems generally require less energy, making them more cost-effective.
4. ease of operation and maintenance: ultrafiltration systems are often easier to operate and maintain as they require less complex technology.
5. high flow rates: ultrafiltration membranes allow for high flow rates, which increases the efficiency of water treatment.
6. minimal chemical treatment: as ultrafiltration removes many microorganisms and particles, the need for chemical disinfectants can be reduced, reducing the environmental impact.
7. flexibility: ultrafiltration systems can be used in various applications, from drinking water treatment to the treatment of wastewater or industrial processes.
8. improved taste and odor: By removing organic matter and microbes, ultrafiltration can help improve the taste and odor of water.

Naturally there are also limitations which have to be considered in the technology selection and in the plant design process. Comparing with other membrane and filter types helps to identify the suitable applications.

## Comparison with other membrane types

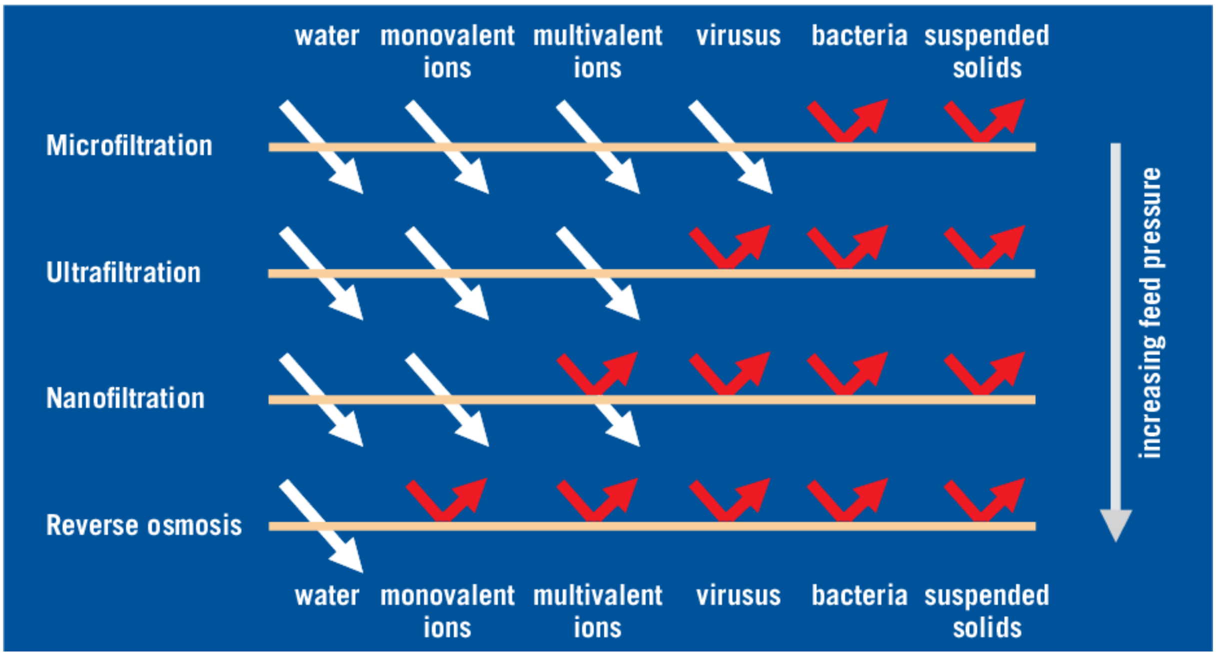


Figure 1: Membrane Types (Farhat 2020)

Ultrafiltration and Microfiltration are both used to remove particles and contaminants from water, but they differ in their pore size, with microfiltration having a larger pore size (0.1-10 µm) and ultrafiltration having a smaller pore size (0.01-0.1 µm). This means that ultrafiltration can remove smaller particles, bacteria, and viruses, while microfiltration is more effective at removing larger particles, but it cannot remove most viruses. Nanofiltration and reverse osmosis can remove a wider range of contaminants, including dissolved solids and heavy metals, but require higher operating pressures and energy. Reverse osmosis is the most effective technology for producing high-quality water but also produces a significant amount of wastewater (often called brine), which is hard to dispose of in a safe way. The choice of membrane technology depends on the specific application, water quality requirements, and operating conditions, and a thorough evaluation is necessary to select the most suitable technology for a particular use case.

Table 1: Membrane characteristics

| **Membrane Type** | **Pore Size** | **Operating Pressure** | **Specific Energy per Cubic Meter** | **Compounds Removed** |
|---|---|---|---|---|
| Microfiltration | 0.1-10 µm | 0.1-5 bar | 0.01-0.5 kWh/m³ | Particles, colloids, some bacteria |
| **Ultrafiltration** | **10-100 nm** | **0.5-10 bar** | **0.1-1.0 kWh/m³** | **Colloids, particles, bacteria, viruses** |
| Nanofiltration | 1-10 nm | 5-20 bar | 1.0-5.0 kWh/m³ | Dissolved solids, heavy metals, pesticides, some dissolved ions |
| Reverse Osmosis | 0.1-1 nm | 10-80 bar | 2.0-10.0 kWh/m³ | Dissolved solids, heavy metals, pesticides, most dissolved ions |

Especially if the power supply is limited or expensive and the source water is not contaminated by seawater, pesticides or heavy metals (e.g. from mining), ultrafiltration offers the best price-performance ratio for water treatment. And even if the water is contaminated, ultrafiltration should be used as a pre-treatment for reverse osmosis to increase the treatment performance and service life of the membrane.

## What sets it apart from cartridge filters?

Ultrafiltration (UF) systems and cartridge filter systems differ in their technology, effectiveness, and maintenance requirements. UF systems use a semi-permeable membrane with tiny pores (0.01-0.1 µm) to remove contaminants from water, while cartridge filter systems use a physical barrier, such as a porous material or a screen, to remove particles and contaminants.

This difference makes UF systems generally more effective at removing a wider range of contaminants, including bacteria, viruses, and parasites, due to their smaller pore size. Cartridge filter systems, on the other hand, may not be as effective at removing smaller particles and microorganisms. Additionally, UF systems typically require less maintenance than cartridge filter systems, as the membrane can be backwashed and cleaned, extending its lifespan. Cartridge filter systems, however, require more frequent replacement of the filter cartridges, which can be costly and inconvenient. When cartridge filter systems are required to reach the same water quality as UF systems, a cascade of different filters is needed.

UF systems are generally more effective and require less maintenance than cartridge filter systems but may have a higher initial investment cost. Cartridge filter systems may not be as effective and require frequent replacement, which leads to constantly high operation costs.

## What sets it apart from slow sand filtration (SSF)?

Both UF and SSF systems can be effective at removing particles, bacteria, and viruses, but SSF systems, if operated correctly, can even be more effective at removing organic substances due to the biological activity that occurs in the sand layer. However, SSF systems operate at a much slower flow rate than UF systems. SSF systems require regular maintenance, including scraping and cleaning the sand surface, and replacing the sand layer periodically. UF systems, on the other hand, require less maintenance, as the membrane can be backwashed and cleaned. According to JICA, slow sand filtration is an adequate treatment process if the raw water is relatively clean and stable but it requires a large area for the facilities. UF systems are often more suitable for larger water treatment applications, where high flow rates are required to supply a whole community or when the raw water quality varies. Considering economics, UF can outperform SSF systems due to the decrease in investment costs in the last decade.

# Application examples

In the frame of the VINETA project, three application examples in two countries started operation in 2023 and 2024. Two systems run in Fiji and the third one operates in Palau. The applications cover surface water treatment of dammed river water and rainwater treatment for long time storage rainwater catchment systems.

## Fiji

In Naimasimasi for the community and the district school tap water is supplied by gravity from a damn above the village.

Figure 2: Aqua CUBE system in Naimasimasi

To secure the water supply in dry periods, a large water storage tank was built on a hill next to the village. The water taken from the river is often contaminated with manure and, in heavy rain events, with sewage as well. As a result, the community relies mostly on rainwater harvesting to meet their daily water needs.

Figure 3: Filtration system with filtered water tank

Utilizing the head pressure from the storage tank on the hill, the Aqua CUBE UF system is gravity driven in Naimasimasi. The solar panels on the system housing supply the energy to pump the water into the filtered water tank. This tank is elevated to enable gravity feeding to the school at the other end of the village and the community.

## Palau

At Ngaraard Elementary School a large rainwater catchment system was built as part of a program to strengthen the typhoon resilience of the community. This system stores large amounts of rainwater for extended periods of time. Given the design of the system and the influence of the hot and humid climate, the water in the storage tanks creates an environment that fosters biological growth. When leaves, bird droppings and debris are washed from the roofs into the storage tanks, bacteria and nutrients enter the tanks. As a result, the water quality is not always high enough for human consumption.

This is one of the ideal applications for ultrafiltration treatment systems. The picture above shows the Aqua CUBE UF system in operation. The energy required to pump the water from the catchment tank into the filtration unit (Figure 5, on the right) is supplied by the solar panels on the unit during daytime and by batteries at night. The filtered water is pumped into the black product water tank. This tank is dimensioned to meet the school’s water demand and to avoid long storage times for the filtered water.

Figure 4: Original rainwater catchment system


Figure 5: Catchment system with filtration extension

## Design options

In addition to the systems shown in the application examples, individual solutions based on the ultrafiltration membrane can also be designed. UF modules can be installed in a variety of configurations, including:

- Inline filtration: where the UF module is installed in the piping system that connects the rainwater tank to the point of use
- Tank-mounted filtration: where the UF module is installed directly in the rainwater tank
- Pre-treatment filtration: where the UF module is used as a pre-treatment step before other treatment processes, such as disinfection or reverse osmosis

Using UF modules in storage tanks can provide several benefits, including:

- Improved water quality and safety
- Reduced risk of waterborne illnesses
- Extended lifespan of downstream treatment systems and appliances
- Reduced maintenance and cleaning requirements for the tank and piping system

However, it's worth noting again that UF modules may not remove all contaminants, such as dissolved solids, heavy metals, or certain chemicals. Additional treatment steps may be necessary to achieve the desired level of water quality when it contains sea/brackish water or is contaminated with organics such as pesticides. It's also important to ensure that the UF filter is properly sized, installed, and maintained to ensure optimal performance and longevity.

## Maintenance needs

For an ultrafiltration system used to clean water from a stream, regular maintenance is crucial to ensure optimal performance, prevent membrane fouling, and provide safe drinking water. The key maintenance steps and their recommended frequencies are:

- **Regularly** clean the area around the plant to prevent debris and dirt from accumulating and potentially entering the system
- **Daily**: inspect treated water for turbidity, staining and odor
- **Daily to weekly**: clean the pre-treatment filter, depending on the (stream) water quality
- **Monthly or after heavy rains**: empty the sludge accumulated in the filter chamber
- **Every 1-3 months**: pump and valve maintenance: including checking for leaks, lubricating moving parts, and replacing worn-out components
- **Every 3 -6 months**: clean ultrafiltration membrane, using a combination of chemical cleaning, scrubbing and flushing
- **Yearly**: Inspect the whole plant for broken and worn parts, leakages, and vegetation intrusion
- **When running on solar energy**, check the charge controller daily to make sure power supply is working well

It's essential to note that the frequency of these maintenance steps may vary depending on the specific system design and the water quality (e.g. stream, surface, rainwater). It's recommended to consult the guidelines for the system in place and develop a customized maintenance schedule to ensure the ultrafiltration system operates efficiently and effectively.

# Decision support

Although many technologies exist to treat water, many of them have either high operational costs in terms of energy or chemical consumption. In addition, a lot of them need good pretreatment to be effective, like UV disinfection, or even to remain operational, like reverse osmosis. Therefore, choices are limited, when looking at the requirements for water supply for small and medium communities.

When deciding on a water filtration system, for example to supply one village of 100 people which cannot be connected to a larger water network, the main technologies to consider are ultrafiltration membranes and slow sand filtration. Each method has its own advantages and disadvantages, which can significantly impact operational efficiency, costs, and water quality.

Slow Sand Filtration is characterized by its simplicity and low operational costs. This method requires minimal energy and maintenance, making it very cost effective. The biological layer that forms on the sand surface helps break down organic matter and pathogens, providing effective filtration. However, slow sand filters have a lower flow rate, which may necessitate multiple units to meet the daily demand of a village. Especially when the filtered water should not be stored for a long time to avoid recontamination in tropical climates, the low flow rate requires large plants. In addition, they are effective against many pathogens, but they do not completely reject bacteria and do not remove viruses. Maintenance involves regular monitoring of water quality and flow rates, with occasional cleaning of the sand layer. The top layer of sand can become clogged and needs to be scraped off periodically, but the sand itself can last for many years, depending on the quality of the source water.

Ultrafiltration membranes offer high-quality filtration, effectively removing suspended solids, bacteria, and viruses. This technology does not require chemical additives, reducing potential health risks. Additionally, ultrafiltration systems provide consistent water quality, regardless of variations in feed water quality, and their compact design makes them suitable for areas with limited space. The flow rate is high compared to slow sand filtration, when the feed water doesn't contain many sediments. And even when the turbidity is higher, high flow rates can be maintained with regular cleaning of the filter chamber. However, the investment cost is higher and although the membranes can last up to 10 years, depending on maintenance and feed water quality, they eventually need replacement. For the operation of the ultrafiltration energy is required for pumping, if the required head can't be supplied by gravity. Regular cleaning is also necessary to prevent fouling, involving chemical agents and additional labor. See Maintenance needs for details.

In conclusion, the choice between ultrafiltration and slow sand filtration depends on specific community needs. If high-quality drinking water is paramount and the budget allows for the initial investment, ultrafiltration is the better option.

The application examples show the potential applications with a filtration capacity of 10 $m^3$/day. However, different design options are possible for many applications. The low-pressure ultrafiltration systems are fully scalable. Very small UF filters can be carried by one person and deployed in emergency response situations. Slightly larger UF filters can be installed within rainwater catchment tanks and large UF systems can be deployed inline to supply whole communities with treated water.

Generally, low pressure UF systems are best applied in situations where one or more of the following needs should be addressed:

- **High-flow applications:** UF is suitable for high-flow applications, such as community water treatment plants, and large-scale municipal applications.
- **Variable water quality:** UF is effective in treating water with variable quality, including water with high levels of suspended solids, bacteria, viruses, and other microorganisms.
- **Space constraints:** UF systems are more compact than SSF systems, making them suitable for applications where space is limited.
- **High-level treatment:** UF can provide high-level treatment, including removal of particles, bacteria, viruses, and other microorganisms.
- **Emergency response:** UF can be used in emergency response situations, such as natural disasters, where rapid deployment and high-flow treatment are required, as ultrafiltration filters can also operate gravity driven without pumps or energy supply.

However, good maintenance is vital to achieve good water quality. Therefore, it is absolutely necessary to train the local operators to follow the simple, yet crucial maintenance protocols. Please refer to the preceding section and the operator's manual used for the application examples.

# Economic potential

In the global context, ultrafiltration systems often serve as water kiosks in rural and urban areas. These are effective solutions for providing clean drinking water, particularly in regions facing water quality and access challenges. Utilizing ultrafiltration technology, these kiosks filter out bacteria, viruses, and larger particles, ensuring safe water for consumption.

In fact, these kiosks often operate as small businesses, charging a nominal fee, making clean water accessible to local communities. These kiosks are prevalent in various parts of the world. In Africa, countries like Kenya, Uganda, and South Africa have implemented water kiosks to serve both urban and rural populations. These initiatives are crucial in areas where access to safe water sources is limited, helping to reduce the incidence of waterborne diseases and improve public health. In Asia, nations such as India and Bangladesh have established water kiosks in densely populated areas, addressing concerns related to water contamination. Similarly, in Latin America, countries like Brazil and Colombia are using these kiosks to tackle water scarcity and quality issues. The Middle East also sees the adoption of ultrafiltration kiosks, where water scarcity is a significant concern. These kiosks not only provide clean water but also create job opportunities within the community, fostering local entrepreneurship. By combining technology with a sustainable business model, ultrafiltration water kiosks represent an innovative approach to addressing water challenges, improving public health, and promoting community development. Their scalability allows for replication in various locations, making them a viable solution for enhancing water access and quality across many regions of the world.

In the Pacific, the supply of clean drinking water is a challenge in rural and remote locations due to the limited accessibility of many communities that either live in locations which are separated from larger urban areas by the ocean or the countries' topography. The WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene reported numbers that clearly show the lower share of people using safely managed drinking water in rural areas.

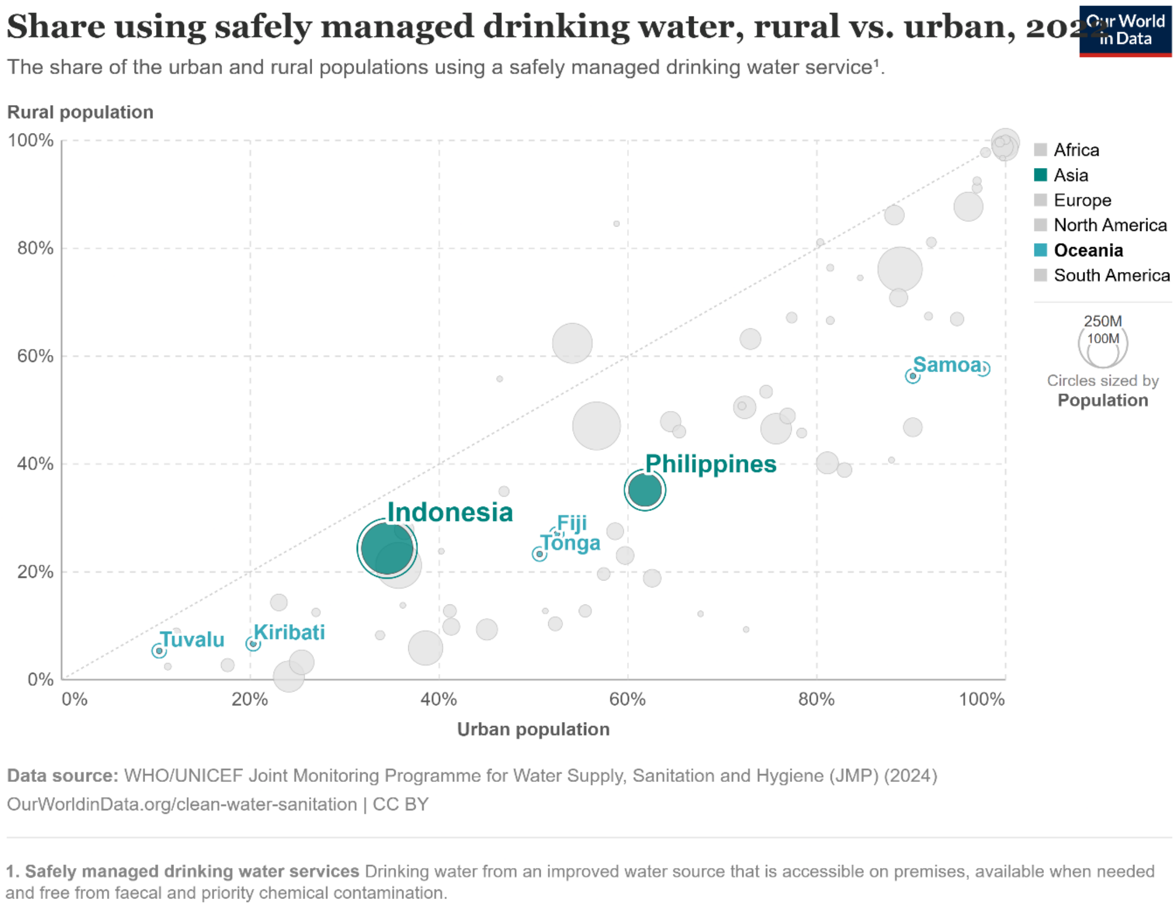


Figure 6: Share using safely managed drinking water

Looking at global development regarding ultrafiltration systems, there are high economic benefits when a community water filtration system is implemented. When communities are well-organized and maintain their water supply together through a water committee, the operational cost is low. That allows governments that work towards SDG 6.1 “Safe drinking water” to support many communities with the allocation of comparatively little resources. The systems can be operated on gravity or solar power in rural areas where centralized treatment plants are out of reach. While the treatment of water for the whole community is much more cost efficient for the individuals than household filtration systems or buying bottled water, it helps to avoid a lot of solid waste like cartridge filters, plastic bottles and packaging.

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