Archives of Environmental Protection
Vol. 51 no. 3 pp. 74–84

PL ISSN 2083-4772
DOI:10.24425/aep.2025.156010

Cost analysis of recirculating pre-treated backwash water from sand filters into drinking water treatment: trial results

Małgorzata Wolska[1]*, Juan Tomás García Bermejo[2], Antonio Vigueras Rodríguez[2], Francisco Javier Pérez De La Cruz[2], Małgorzata Kabsch-Korbutowicz[1], Halina Urbańska-Kozłowska[1], Agata Rosińska[3]

[1]Wrocław University of Technology, Poland
[2]Politecnic University of Cartagena, Spain
[3]Czestochowa Technical University, Poland

* Corresponding author's e-mail: malgorzata.wolska@pwr.edu.pl

Keywords: ultrafiltration, water treatment plant, capital cost, UV disinfection, operation cost

Abstract: Effective water resource management and reduction of water consumption require water utilities to minimize losses during the treatment process. As a result, backwash water produced during filtration is often the subject of research focused on its reuse within the water treatment system. This study was conducted at two large water treatment facilities, each with a capacity of 100,000 m^3/day. The research focused on backwash water produced during the cleaning of sand filters. Before being reintroduced into the treatment process, the backwash water underwent pre-treatment involving UV disinfection followed by ultrafiltration. The effectiveness of various processes, including coagulation with sedimentation, microfiltration, ultrafiltration, and UV disinfection was assessed under optimal conditions, based on their ability to remove organic matter and microorganisms, which pose health risks when backwash water is recirculated. Additionally, the operational and capital costs of selected pre-treatment approaches were evaluated. The findings revealed that pre-treating backwash water with ultrafiltration membranes (UF), followed by UV disinfection, and reusing it in the treatment systems can reduce environmental impacts.

Introduction

The world's freshwater resources are diminishing, causing water stress to affect an increasing number of countries. At the same time, the demand for water for agricultural and drinking purposes is growing (Kang et al. 2021). Due to the increasing global water deficit, it is necessary, on one hand, to seek new or alternative sources and, on the other hand, to manage water resources rationally. Therefore, ensuring a sufficient quantity of water of appropriate quality for people, by means of water supply companies, is becoming an increasingly challenging task. The actions undertaken by these companies aim to find new water sources and reduce losses, both in distribution systems and in treatment processes (Khilchevskyj and Karamushka 2021). The greatest water losses during its treatment result from the need to flush filters, which are used in the vast majority of drinking water treatment plants worldwide (Cescon and Jiang 2020). It is estimated that up to 10% of abstracted water is used during backwashing, which is why research is being conducted worldwide on the reuse of this water (Jibhakate et al. 2017). Recycling backwash water can contribute not only to reducing the amount of wastewater generated, but also to lowering energy consumption and, thus, reducing operating costs.

The reuse of backwash water is recommended in the guidelines of many countries around the world. Possible methods of its utilization include irrigation, use in greywater systems, and application as process water for industrial purposes (Messe et al. 2021, Australian Water Association, Israel Water Authority). Increasingly, treated backwash water is being used to augment treated water resources. For example, in Berlin, recirculated backwash water forms the basis of water resource management and helps ensure supply reliability (Diwakar et al. 2020). Similarly, in Singapore, the reuse of treated backwash water through microfiltration and UV disinfection aims to reduce the demand for drinking water (NEWater 2023).

The method of managing backwash water depends primarily on its composition, which is influenced by the type of filter media, the type of water being treated, and the parameters of the backwashing process (Jibhakate et al. 2017). A large number of microorganisms, which are detected regardless of the type of water being treated (Turan 2023), as well as the presence of organic substances, are the most typical contaminants in backwash water. Liang et al (2018) reported that the organic carbon content in backwash water from surface water treatment plants ranged from 8.5 to 60.0 gC/m^3, whereas in intake water it ranged from 2.1 to 5.0 gC/m^3.

The amount of organic substances in backwash water depends on the backwashing procedure used (Malhabi et al. 2017). Backwash water from sand filters contains various types of microorganisms, including pathogenic species (Studziński et al. 2021), which pose a serious health risk if the water is reused for drinking purposes. In addition to bacteria, backwash water may contain fungi, rotaviruses, and other microorganisms (Chaudhry et al. 2015). Therefore, pre-treatment is essential before reusing backwash water, particularly by subjecting it to disinfection (Arendze and Siliya 2014).

Coagulation and sedimentation processes are the most commonly employed processes for pre-treating filter backwash water (Cheng et al. 2020). However, low-pressure membrane separation techniques are increasingly being adopted to enhance pre-treatment efficiency (Alhussaini et al. 2023). Pressure-driven membrane processes are now widely used to treat water from various sources for both drinking and industrial purposes (Hofs et al. 2011).

The recirculation of backwash water into the main water treatment train is possible after it has been pre-treated, and requires the selection of pre-treatment methods as well as the evaluation of backwash water pre-treatment costs. Coagulation is the most inexpensive method of backwash treatment, allowing for the removal of suspended contaminants, organic compounds, and the reduction of microorganisms (Li 2018). The effectiveness of backwash treatment largely depends on the composition of raw water, with coagulation being the most efficient method for removing low molecular weight compounds. (Zhou et al. 2015). The pre-treatment of sand bed backwash through coagulation with PAFCI and $FeCl_3$ has shown greater effects on colloid destabilization at lower doses for PAFCl (Ebrahimi 2017), along with higher effectiveness in limiting membrane fouling.

Due to the high presence of microorganisms, disinfection is an essential step in recycling backwash water, particularly through UV radiation and chlorination (Mosati et al. 2011). Given the significant amount of suspended solids in backwash water, disinfection should be carried out after the sedimentation process.

Because of backwash water contamination. chlorination results in the creation of large amounts of disinfection by-products, the quantity of which depends on the characteristics of the organic matter present in backwash water (Qian et al. 2023). Heavily contaminated water is more commonly subjected to UV light as a physical disinfection method, since harmful disinfection by-products are not produced with this approach (Luo et al. 2022).

The effectiveness of microfiltration membranes in water and wastewater treatment depends on various factors, including membrane type, pore size, the composition of the treated medium, and specific process conditions (Konieczny et al. 2019). Although microfiltration is widely applied in water and wastewater treatment, including industrial wastewater, its efficiency in the pre-treatment of sand filter backwash water remains insufficiently studied. Microfiltration is typically combined with flocculation and is most commonly employed for the removal of particles and microorganisms (Anis et al. 2019), which represent the key contaminants in both types of backwash water.

Ultrafiltration, known for its ability to enhance the biostability of treated liquids, is frequently used for the pre-treatment of sewage prior to reuse (Silva et al. 2022). In urban wastewater reclamation, ultrafiltration has been shown to remove over 90% of *E. coli* bacteria and achieve 94% reduction in total organic carbon, while enabling the reuse of 70.7%–94.5% of the treated water (Yang et al. 2022). However, complete elimination of *E. coli* was not achieved in a bioreactor equipped with a PVFD ultrafiltration membrane during sewage pre-treatment (Arevalo et al. 2012). Therefore, a multi-barrier approach is recommended when reintroducing backwash water into the treatment process.However, the use of multiple unit pre-treatment processes can increase both operational and investment costs associated with recirculation. For example Ebrahimi et al. (2017) showed that, depending on the type of coagulants used, the costs of sedimentation, flocculation and ultrafiltration can vary by up to a factor of five.

The capacity of a water treatment plant and the waste water management generated during purification are the most important factors affecting recirculation costs. Given the limited information available on the cost of implementing full-scale backwash water recirculation, further study is warranted to estimate the expenses of optimized pre-treatment. The cost of installing water reuse systems plays an important role in justifying their implementation, yet a significant research gap remains in estimating the capital costs of water reuse. Various methods are used to estimate investment and operating costs (Ruiz-Rosa et al. 2016, Xie et al. 2022).

Although backwash water generated in water treatment plants is increasingly being reused, insufficient knowledge about effective and universal pre-treatment methods remains limited , and reliable data on implementation costs are lacking. Conducting research and cost analyses of backwash water pre-treatment and recycling for various types of water can enable the development of universal solutions for water utility companies. The aim of the present research was therefore to determine the potential of using pre-treated backwash water to increase drinking water resources and to carry out an economic analysis of the feasibility of such an approach.

Methodology and subject of study

Subject of study

The research focused on an economic analysis of the costs of implementing a pre-treatment system for backwash water generated at two water treatment plants, with the aim of returning it to the water treatment process. The analysis covered various unit water treatment processes, whose effectiveness and optimal operational parameters had been determined in previous studies. The characteristics of the plants included in the analysis, as along with the optimal parameters of the individual backwash water pre-treatment processes, are presented below. The selection of solution for implementation was based on the effectiveness of removing contaminants critical for both types of water, ensuring a universal approach that guarantees the safety of the treated water.

The study was carried out in two water treatment plants (WTP), which treat surface water and infiltration water, respectively. The water treatment trials are shown in Figure 1.

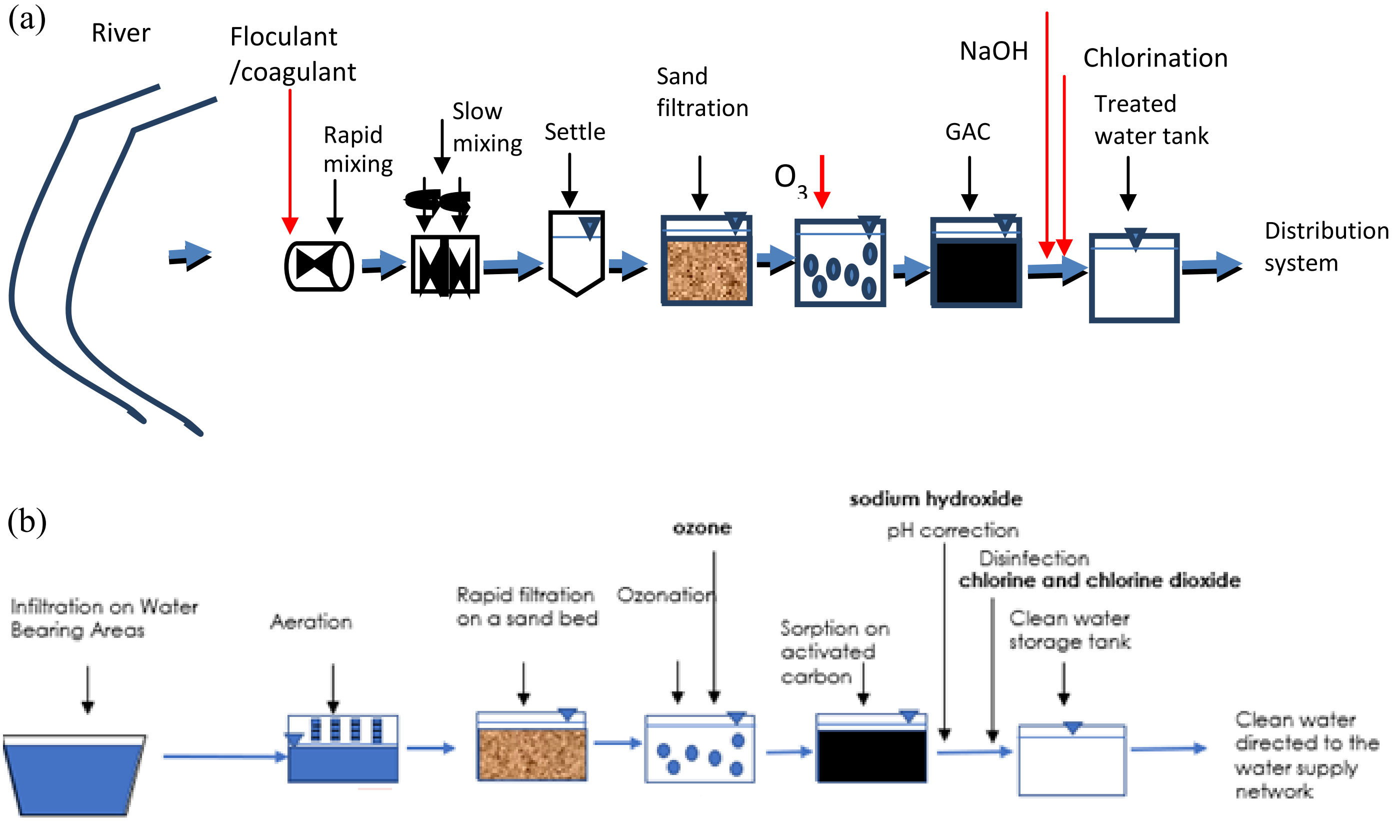

Figure 1. Water treatment plant technology a) surface water treatment b) infiltration water treatment

The average capacities of WTPs are 120,000 m^3/d and 98,000 m^3/d of treated water for surface water and infiltration water, respectively. In both WTPs, the subject of study was sand filtration backwash water. Each plant generates up to 100,000 m^3 of washings per month, with minimum monthly volumes of 50,000 m^3 and 70,000 m^3 for the surface water and infiltration water treatment plant, respectively. In both cases, the backwash water in the WTP is discharged into the river as wastewater after sedimentation in settler tank. The current management infrastructure in both WTPs is presented in Figure 2.

In the studies conducted at both WTPs, the backwash water was subjected to coagulation, disinfection, and low-pressure membrane filtration, the effectiveness of which was reported in earlier work (Wolska et al. 2024 a, b, c). To evaluate the suitability of these processes for pre-treating backwash water, optimal parameters were applied, including the most effective reagent types and doses, as well as ideal conditions for process implementation. This approach ensured a fair comparison of the efficiency and effectiveness of each pre-treatment method. Coagulation and sedimentation were carried out under flow conditions. The installation operated at a capacity of 150 L/h, with a contact time of 90 seconds in the rapid mixing tank, a flocculation time of 15 minutes, and a sedimentation time of one hour in a lamellar settler.

For coagulation, the most effective coagulant in both WTPs was PAX XL3 (Kemipol Ltd.), with an optimal dose of 5 gAl/m^3, which was considered in the optimization of implementation costs.

Test of physical disinfection effectiveness were conducted under flow conditions using a low-pressure UV lamp

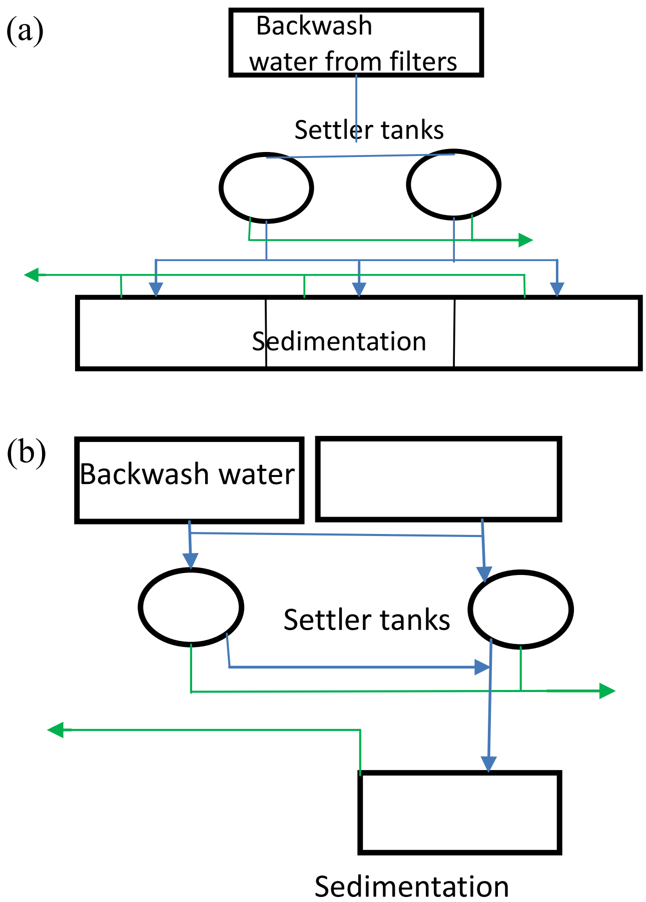

Figure 2. Backwash water management infrastructure in a) surface b) infiltration WTP

Table 1. Characteristics of microfiltration and ultrafiltration membranes

	Microfiltration	Ultrafiltration
Module configuration	spiral	capillary
Membrane material	Polyvinylidene fluoride (PVDF)	Polyethersulfone (PES)
Producer	PolymemTech	
Membrane cut-off / pore size	0.2 μm	80 kDa
Maximum operating temperature (°C)	45	45
Maximum operating pressure (bar)	1.0	4
Membrane surface (m^2)	1.8	2

(Chemtech Ltd.). The cost assessment included disinfection with a UV dose of 600 J/m², which ensured the removal of all analyzed groups of microorganisms to levels lower than those found in the intake waters.

The backwash water was subjected to microfiltration or ultrafiltration tests in a pilot flow installation. In the case of microfiltration, as shown in previous studies (Wolska et al. 2025), the PVDF microfiltration membrane (Table 1) showed the highest permeate flux stability and the highest psychrophilic bacteria. Therefore, this membrane was included in costs estimation and optimization.

The quality of the permeate obtained after ultrafiltration with the 80 kDa membrane (Table 1) was sufficient to allow its reintegration into the water treatment process, where it could be blended with raw surface or infiltration water. This particular membrane was selected for the recirculation process and for the cost analysis.

Backwash water quality parameters analysis

The analysis of backwash water composition before and after unit processes included measurements of pH, color, turbidity, UV_{254} absorbance, the concentration of dissolved organic carbon, the number of psychrophilic bacteria, the number of bacteria (*Escherichia coli, Enterococci, Clostridium perfringens*), and the molecular weight distribution of organic compounds. Size exclusion chromatography (SEC) was used to assess the molecular weight distribution.

pH was measured using a Hach HQ440D multi-parameter meter, turbidity with a Hach TU5200 turbidimeter, and DOC concentration with a Shimadzu TOC-L analyzer. Color and absorbance measurements were performed in samples filtered through 0.45 μm filters using a Shimadzu UV-Vis UV-1200 spectrophotometer.

Microbiological analyzes were performed using seeding methods in accordance with applicable standards: PN-EN ISO 6222:2004 - total number of microorganisms, PN-EN ISO 9308-2:2014-06 (coliform bacteria and *Escherichia coli*), PN-EN ISO 7899-2: 2004 (*Enterococci*), and PN-EN ISO 14189:2016-10 (*Clostridium perfringens*).

The molecular weight distribution was determined using an UltiMate 3000 Dionex liquid chromatograph equipped with a DAD detector. Calibration was conducted with polystyrene sulfonate sodium salts (PSS, American Polymer Standards Corporation) of molecular masses 891, 1600, 3420, 7420, 15,650, and 29,500 Da. The relationship between particle size, retention time, and concentration (g/m³) was then established for the following specific particle molecular weight ranges: 3.2–2.5 kDa, 1.8–2.0 kDa, 0.7–0.9 kDa, and <0.1 kDa.

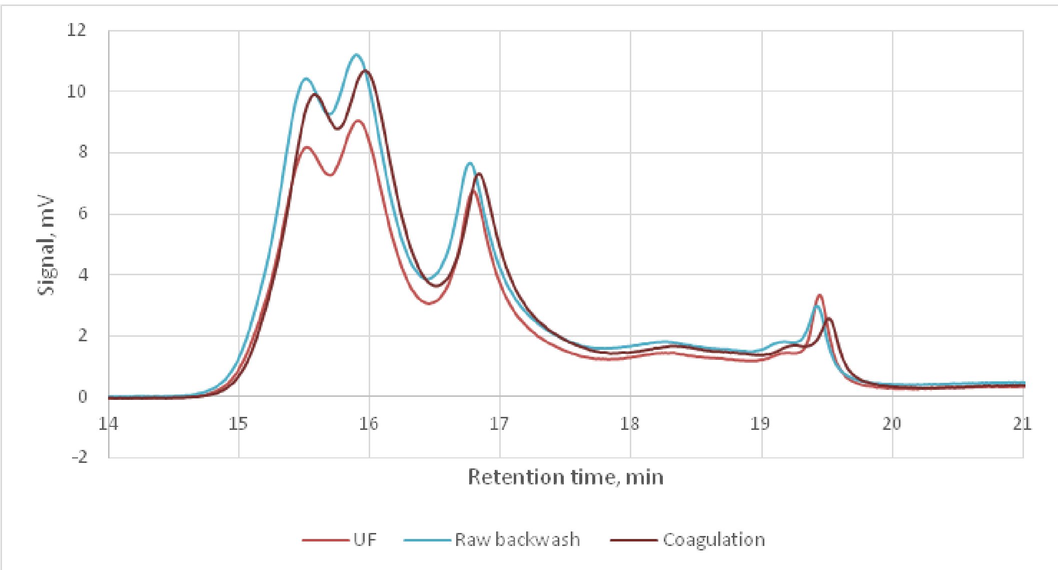

Figure 3. Molecular weight distribution of organic substances in backwash water before and after pre-treatment

Table 2. Ranges of backwash water from surface WTP quality parameters before and after pre-treatme

Parameter	Unit	Raw water	Raw backwash	After pre-treatment in				Efficiency of removal (%)			
				coagulation	physical disinfection (UV)	UF	MF	coagulation	UV	UF	MF
Turbidity	NTU	2.6-14.0	54 - 143	11.0 - 17.3	15.1 - 18.2	0.3 - 0.32	0.4 - 0.5	84-91	72-84	97-100	84-87
Colour	mg Pt/L	7.0-19.0	8.0 - 11.0	5.89 - 6.39	7.0 - 9.4	2 - 4	4.0 - 7.0	32-48	12-45	14-43	0-32
pH	–	7.5-8.1	7.4 - 7.6	7.3 - 7.5	7.4 - 7.6	7.8 - 8.7	7.5 - 7.8	-	-	--	-
Absorbance UV_{254}	m^{-1}	6.43-15.00	7.99 -11.70	5.68 - 7.01	5.2 - 6.9	2.89 - 3.45	6.07 - 7.67	30-38	14-38	0-14	19-27
DOC	mg/L	3.07-7.79	3.77 - 5.37	3.82 - 4.02	4.20 - 5.10	2.22 - 3.65	3.87 - 4.71	12-22	0-13	17-45	20-44
Total number of psychrophilic bacteria	cfu/mL	$0,12x10^4$-$6,6x10^4$	$3.9x10^4$-$11x10^4$	$3x10^4$-$4.3x10^4$	490 – 6421	4 - 1,600	140 - 4,300	57-69	78-86	64-99	91-99
Escherichia coli	cfu/100mL	0-8	3 - 7	0 - 9	0 - 15	0	0-1	64-100	0-100	100	0-100
Clostridium perfringens	cfu/100mL	10-130	1 - 3	1 - 3	19 - 66	0	0	0-100	-	100	100
Enterococci	cfu/100mL	0-51	0 - 28	0 - 5	0 - 1	0	0	0-81	90-100	100	100

Cost analysis

The evaluation of investment and operating costs for the implemented unit processes and selected trials at each plant was based on contractor quotations and market prices of consumables. The analysis was conducted using 2023cost data. In assessing investment costs, the potential use of the existing sewage and sediment management infrastructure (Fig. 2) at the plants was taken into account.

In both configurations, the investment scope included the purchase of an ultrafiltration (UF) plant with a maximum capacity of 100 $m^3 h^{-1}$ and a UV lamp installed downstream of the UF unit. Both designs also incorporated buffer tanks located before and after the membrane separation stage. Additionally, the existing clarifiers were used for preliminary sedimentation in both cases. The UF installation was fitted with pressure, flow, and temperature monitoring instruments. Implementation costs also covered integration of the new system into the existing SCADA network.

Results and discussion

Assessment of unit treatment processes efficiency

A comparison of the backwash water quality parameter ranges, before and after the pre-treatment processes, is presented in Tables 2 and 3 for the surface and infiltration water treatment plants respectively. Both types of backwash water quality showed seasonal variation, especially in surface water (Torabi et al. 2024). The use of optimal parameters for conducting the unit processes ensured that the contamination of the backwash water was reduced to the levels found in the raw surface or infiltration waters, with the exception of physical disinfection, which primarily influenced changes in the microbiological rather than the physical-chemical composition.

The organic content of backwash water is a key factor in determining the appropriate treatment method. In both water treatment plants, the total organic carbon concentration in raw backwash water was low, leading to dissolved organic carbon (DOC) levels in the pre-treated backwash water that remained below the acceptable limits for drinking water, regardless of the treatment process used. Similar findings on the lower concentrations of organic substances in raw backwash water have been reported in previous studies (Wolska et al. 2024a, 2024 b). The efficiency of organic matter elimination increased in the following order: physical disinfection< coagulation < microfiltration < ultrafiltration. This trend applied to organic substances of different molecular weights (Fig. 3). Compounds with the highest molecular weights (retention time of 15.5-16.0 minutes) were removed most effectively across all analytical processes whereas, those with the lowest molecular weights (retention time of 19.5 minutes) were removed insufficiently, regardless of the pretreatment method.

It is also essential to ensure the effective removal of low molecular weight substances, as these substances are precursors to disinfection by-products and may pose a threat to drinking water quality. This hypothesis has been confirmed by studies conducted on backwash water from 10 water treatment plants (Qian et al. 2023).

Due to the presence of a very large number of microorganisms in the raw backwash water, their elimination formed the basis for selecting the backwash water pre-treatment method.

In the case of backwash water from surface water treatment, characterized by the presence not only of psychrophilic bacteria but also of indicator bacteria posing a health risk to humans. As our earlier studies have shown their effective elimination was ensured by ultrafiltration, followed by physical disinfection. Similarly, Sukanya et al. (2022) demonstrated that the ultrafiltration process combined with UV radiation is the most effective method for pre-treating backwash water for its reuse in potable applications.

For backwash water from infiltration water treatment plants, the microfiltration process effectively reduced the number of microorganisms to levels comparable to those found in the raw infiltration water. However, despite the effective elimination of microorganisms, microfiltration did not provide sufficient reduction of manganese concentration . Therefore, in order to increase the effectiveness of its removal, ultrafiltration must be applied. Research by Jerroumi et al. (2023) has confirmed that conventional processes do not always allow for the effective removal of manganese. In such cases, advanced water treatment systems or membrane separation processes are necessary.

Considering the above observations, ultrafiltration followed by UV disinfection, that provides multibarrier protection against microbial contamination, was considered an effective method for the pre-treatment of backwash water, regardless of its origin.

Assessment of implementation costs

Taking into account the backwash water composition after pre-treatment, ultrafiltration followed by UV disinfection was recommended for implementation in a full-scale recirculation system. The analysis of the pre-treatment installation capacity, corresponding to the minimum quantity of backwash water generated in water treatment plants, showed values of 70 m^3/h and 90 m^3/h in surface and infiltration WTP, respectively (Wolska et al. 2024).

Low-pressure membrane separation processes costs

A cost analysis was carried out for implementing a backwash water pre-treatment system using capillary ultrafiltration modules with an 80 kDa membrane. The assessment of investment costs for integrating this solution into the plant's circular economy considered the reconstruction of the existing wastewater and sludge management system (Fig. 2), the purchase of an ultrafiltration installation, and the construction of a buffer tank and control system.

The total investment cost for the membrane installation, based on market estimates, was approximately €1.5 million. This included the purchase of a containerized ultrafiltration system with a treatment capacity of 70–100 m^3/h of backwash water (permeate). The most significant operating expense was electricity consumption, which ranged from 3.6 to 4.4 kW per cubic meter of treated backwash water. This translated into a cost of €0.25–€0.35 per cubic meter – equivalent to €0.01–€0.02 per cubic meter of purified water in surface and infiltration water treatment plants, respectively.

It should be noted that energy cost estimates may be subject to significant uncertainty due to the scale differences between pilot and full-scale installations. As highlighted by Mazari and Abdessemed (2020), the relationship between

Table 3. Ranges of backwash water from infiltration WTP quality parameters before and after pre-treatment

Parameter	Unit	Raw water	Raw backwash	After pre-treatment				Efficiency of removal			
				coagulation	physical disinfection (UV)	UF	MF	coagulation	(UV)	UF	MF
Turbidity	NTU	7.4-18.0	194-332	69.2-93.8	190-325	0.3	0.1-0.35	52-64	67-89	99-100	99-100
Colour	g Pt/m^3	6.0-12.0	12.3-26.7	10.0 - 7.5	10.2-18.3	7.1-8.3	9-10	37-41	14-48	0-10	0-12
pH	-	6.8-7.0	7.3-7.6	7.3-7.5	7.2-7.6	7.3-7.7	7.6-7.9	-	-	-	-
Absorbance UV_{254}	m^{-1}	6.46-9.25	7.78-12.63	4.84-5.9	5.3-7.2	6.36-7.20	7.35-8.86	32-35	19-42	0-12	9-16
DOC	g/m^3	3.06-5.59	4.18-4.64	3.45-3.77	3.8-4.1	3.01-3.20	3.82-4.16	10-17	4-17	2-24	15-19
Total number of psychrophilic bacteria	cfu/mL	10-90	$3,0 \times 10^4$-5.6×10^4	20.1×10^2-16×10^3	380-2350	8-230	330-2100	51-71	69-91	52-95	98-99
Escherichia coli	cfu/100mL	0	0	0-1	0	0	0	-	-	-	-
Clostridium perfringens	cfu/100mL	0	1- 7	0-1	0	0	0	0-100	100	100	100
Enterococci	cfu/100mL	0-3	0-3	0	0	0	0	0-100	0-100	100	100

Table 4. Capital costs (thousands €)

Cost	Surface WTP	Infiltration WTP
UF installation	1,500	1,500
UV installation	60	60
Pipelines with fittings, flow meters and automation	335	235
Buffer tanks	5	5
total	1,900	1,800

Table 5. Operating costs (€/m³ of pre-treated backwash water)

Cost	Surface WTP	Infiltration WTP
Energy cosumption	0.4	0.45
Consumable	0.27	0.30
Chemical reagents	0.01	0.01
Replacement of membrane	0,03*	0,03*
Total	0.71	0.79

*replacement every 5 years

membrane system capacity and energy consumption is not linear. Similarly, Karimanzira et al. (2021) demonstrated that unit treatment costs in membrane separation processes decrease significantly as system efficiency increases. Therefore, maximizing the flow of treated backwash water is advisable to reduce overall costs.

UV disinfection costs

The investment costs for physical disinfection were estimated at €60,000 for both water treatment plants (WTP), assuming the installation of UV lamps within existing buildings. The unit operating costs for UV disinfection of backwash water were €0.03/m³ in a surface water treatment plant and €0.05/m³ in an infiltration water treatment plant.

The operating costs of UV disinfection are directly proportional to power consumption and illumination time. The required power in the process depends on the transmittance of the backwash water, which is significantly higher in infiltration water due to its physicochemical properties.

Implementation cost

The scheme of the backwash water pre-treatment system for both WTPs is presented in Figure 4. In both plants, existing settling tanks will be used for primary sedimentation. Capital costs include the construction of two buffer tanks, the installation of ultrafiltration (UF) units with bag filters as pre-treatment for membrane separation, UV disinfection, and the pipeline system for transporting backwash water from the settling tank to subsequent pre-treatment stages. Flow meters and an automated system integrated with the WTP management system were also included in the capital cost assessment. A summary of capital costs is presented in Table 4.

Operating costs include energy consumption for both processes, membrane cleaning (involving the purchase of citric acid and sodium hypochlorite), and annual UV lamp replacement. The assessment of energy consumption was based on measurements conducted in a pilot plant with a capacity of 100 L/h. A summary of operating costs is shown in Table 5.

Higher operating costs for pre-treatment of infiltration wash water are due to increased energy consumption during membrane separation, caused by the presence of suspended iron and manganese, and therefore by the higher pump power required to maintain the same transmembrane pressure. In addition, effective physical disinfection of backwash infiltration water requires higher radiation dose .

It is important to note that reintegrating the water reclaimed from backwash into the water treatment system has reduced costs associated with environmental fees, such as water intake and discharged sewage, by approximately €645 per month for each water treatment plant (WTP).

Furthermore, at the surface WTP, the return of pre-treated backwash water contributes to a reduction in coagulant consumption for water purification, amounting to about 100 kg per month. This occurs because less raw water is sourced from the river for treatment. The current cost of the coagulant is €0.03 per cubic meter of purified water, which decreases slightly to €0.028 per cubic meter. Considering the monthly volume of returned backwash water, this translates to savings of €1,680 per month.

When evaluating the increase in water treatment costs due to the recirculation of pre-treated backwash water, a payback period of 10 years was taken into account. This made it possible to determine both the total cost of the pre-treated backwash water and the change in overall water treatment costs associated with its recirculation (Table 6).

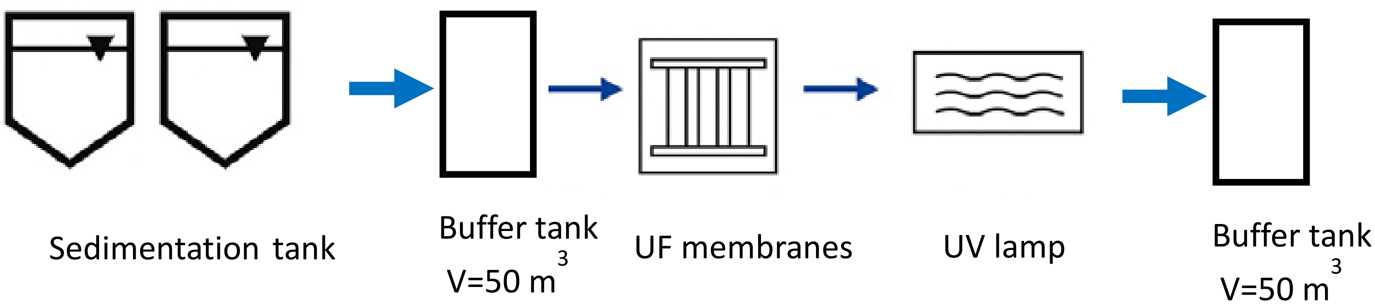

Figure 4. Scheme of backwash water pre-treatment

Table 6. Summary of costs of implementing recirculation of pre-treated backwash water

Costs	Unit	Surface water	Infiltration
Intake and treatments costs before recirculation	€/m³ (treated water)	0.28	0.22
Costs of backwash water pre-treatment	€/m³ (pre-treated backwash water)	3.68	3.73
Intake and treatment costs with recirculation of pre-treatment backwash water	€/m³ (treated water)	0.45	0.40

After accounting for investment and operating costs, as well as the reduction in environmental fees (Table 6), it was estimated that water purification costs would increase by approximately 1.5% in surface WTPs and 4% in infiltration WTPs. This increase is justified from economic and ecological perspectives. The smaller percentage observed in surface water treatment is the effect of greater plant capacity. For comparison, the costs of water treatment using the catalytic oxidation process with UV + TiO_2 followed by membrane separation were estimated by Rani and Karthikeyan (2021) to range from $10.4 to $13.6, depending on system efficiency and the power of the UV lamps used.

Conclusions

The research and analysis carried out showed that:

– Regardless of the type of water treated, it is possible to use pre-treated backwash water generated during the operation of sand bed filters as a complementary source for the main process line at the WTP.
– The most effective pre-treatment method for backwash water, independent of water type, was a combination of preliminary sedimentation, ultrafiltration, and physical disinfection. This ensured the removal of chemical contaminants, all indicator microorganisms, and most psychrophilic microorganisms. To provide multi-barrier protection against microbial contamination, this process should be followed by UV treatment.
– The use of existing infrastructure for wastewater management reduces capital costs for pipelines and connections, or allows the usage of existing settlers.
– In both WTPs, the largest share of operating costs is related to energy consumption, which was higher for infiltration water treatment.
– Due to infrastructure differences, the implementation of this solution increases the cost of treated water, with a greater increase observed in infiltration water treatment plants.

References

Achilli, A. (2023). Analysis of backwash settings to maximize net water production in an engineering-scale ultrafiltration system for water reuse, *J. Water Process Eng.*, 53**,** 103761. DOI:10.1016/j.jwpe.2023.103761

Alhussaini, M.A., Binger, Z.M., Souza-Chaves, B.M., Amusat, O.O., Park, J., Bartholomew, T.V., Anis, S.F., Hashaikeh, R. & Hilal, N. (2019). Microfiltration membrane processes: A review of research trends over the past decade, *J. Water Process Eng.*, 32**,** 100941. DOI:10.1016/j.jwpe.2019.100941

Arendze, S. & Sibiya, M. (2014). Filter backwash water treatment options, *Journal of Water Reuse and Desalination*, 4, 2, pp. 85-91. DOI: /10.2166/wrd.2013.131

Arévalo, J., Ruiz, L.M., Parada-Albarracín, J.A., González-Pérez, D.M., Pérez, J., Moreno, B. & Gómez, M.A. (2012). Wastewater reuse after treatment by MBR. Microfiltration or ultrafiltration?, *Desalination*, 299, 22. DOI:10.1016/j.desal.2012.05.008

Australian Water Association (2023). *Water Reuse in Urban Landscaping*. https://www.awa.asn.au/ (22.09.2024).

Cescon, A. & Jiang, J. Q. (2020). Filtration process and alternative filter media material in water treatment, *Water*, 12, 12, 3377. DOI:10.3390/w12123377

Chaudhry, R.M., Nelson, K.L. & Drewes, J.E. (2015). Mechanisms of pathogenic virus removal in a full-scale membrane bioreactor, *Environmental science & technology*, 49, 5, pp. 2815-2822. DOI: 10.1021/es505332n

Cheng, L.H., Xiong, Z.Z., Cai, S., Li, D.W. & Xu, X.H. (2020). Aeration-manganese sand filter-ultrafiltration to remove iron and manganese from water: Oxidation effect and fouling behavior of manganese sand coated film, *Journal of Water Process Engineering*, 38, 101621. DOI:10.1016/j.jwpe.2020.101621

Cuartucci, M. (2020). Ultrafiltration, a cost-effective solution for treating surface water to potable standard, *Water Practice & Technology,* 15(2), 426-436. DOI:10.2166/wpt.2020.039

Diwakar, A., Rituja, A., Shubhangi, G., Suvarna, A. & Ansari, Y. (2020). Treatment of Sand Filter Backwash Water from Water Treatment Plant, *International Journal of Advanced Science and Technology*, 29, 7, pp. 12130-12137.

Ebrahimi, A., Amin, M.M., Pourzamani, H., Hajizadeh, Y., Mahvi, A.H., Mahdavi, M. & Rad, M.H.R. (2017). Hybrid coagulation-UF processes for spent filter backwash water treatment: a comparison studies for PAFCl and FeCl 3 as a pre-treatment, *Environmental monitoring and assessment*, 189, pp. 1-15. DOI:10.1007/s10661-017-6091-3.

Ebrahimi, A., Mahdavi, M., Pirsaheb, M., Alimohammadi, F. & Mahvi, A.H. (2017). Dataset on the cost estimation for spent filter backwash water (SFBW) treatment, *Data in Brief*, 15, pp. 1043-1047. DOI:10.1016/j.dib.2017.10.040

Hofs, B., Ogier, J., Vries, D., Beerendonk, E.F. & Cornelissen, E.R. (2011). Comparison of ceramic and polymeric membrane permeability and fouling using surface water, *Sep. Purif. Technol*., 79, pp. 365–374. DOI:10.1016/j.seppur.2011.03.025

Israel Water Authority, https://shituf.water.gov.il/#/ (22.09.2024).

Jerroumi, S., Amarine, M. & Gourich, B. (2023). Technological trends in manganese removal from groundwater: A review, *Journal of Water Process Engineering, 56,* 104365. DOI:10.1016/j.jwpe.2023.104365

Jibhakate, M.L., Bhorkar, M.P., Bhole, A.G. & Baitule, P.K. (2017). Reuse & recirculation of filter backwash water of water treatment water, *Int. J. Eng. Res. Appl*, 7, 4, pp. 60-63. DOI:10,9790/9622-0704016063

Kang, J., Hao, X., Zhou, H. & Ding, R. (2021). An integrated strategy for improving water use efficiency by understanding physiological mechanisms of crops responding to water deficit: Present and prospect, *Agricultural Water Management*, 255, 107008. DOI: 10.1016/j.agwat.2021.107008

Karimanzira, D., Went, J. & Neumann, F. (2021). Cleaning Strategies and Cost Modelling of Experimental Membrane-based Desalination Plants, *International Journal*, 9, 1, pp. 6-22. DOI:10.12691/ijefm-9-1-2

Khilchevskyi, V. & Karamushka, V. (2021). Global water resources: distribution and demand, *Clean Water and Sanitation*, pp. 1-11. Cham: Springer International Publishing.

Konieczny, K., Wszelaka-Rylik, M. & Macherzyński, B. (2019) Membrane processes innovation in environmental protection: Review, *Arch. Environ. Protect.*, 45**,** pp**.** 20–29. DOI:10.24425/aep.2019.130238

Liang, W. X., Duan, J., Beecham, S. & Mulcahy, D. (2018). Influence of spent filter backwash water recycling on pesticide removal in a conventional drinking water treatment process, *Environ. Sci.: Water Res. Technol.*, 4, pp. 1057–1067. DOI:10.1039/C7EW00530J

Luo, X., Zhang, B., Lu, Y., Mei, Y. & Shen, L. (2022). Advances in application of ultraviolet irradiation for biofilm control in water and wastewater infrastructure, *Journal of Hazardous Materials*, 421, 126682. DOI:10.1016/j.jhazmat.2021.126682

Mahdavi, M., Ebrahimi, A., Azarpira, H., Tashauoei, H.R. & Mahvi, H.A. (2017). Dataset on the spent filter backwash water treatment by sedimentation, coagulation and ultrafiltration, *Data in Brief*, 15, pp. 916-921. DOI:10.1016/j.dib.2017.10.062

Masotti, L. (2011). *Depurazione Della Acque—Tecniche ed Impianti per il Trattamento Delle Acque di Rifiuto*; Ed. Calderini, Milano, Italy 2011.

Mazari, L. & Abdessemed, D. (2020). Feasibility of Reuse Filter Backwash Water as Primary/Aid Coagulant in Coagulation–Sedimentation Process for Tertiary Wastewater Treatment, *Arabian Journal for Science and Engineering*, 45, pp. 7409-7417. DOI:10.1007/s13369-020-04597-1

Meese, A. F., Kim, D. J., Wu, X., Le, L., Napier, C., Hernandez, M. T. & Kim, J. H. (2021). Opportunities and challenges for industrial water treatment and reuse, *ACS ES&T Engineering*, 2, 3, pp. 465-488. DOI:10.1021/acsestengg.1c00282

NEWater: Turning Wastewater into Safe, Clean Water 2023, https://www.pub.gov.sg/watersupply/fournationaltaps/newater (22.09.2024).

Qian, Y., Shi, Y., Guo, J., Chen, Y., Hanigan, D. & An, D. (2023). Molecular characterization of disinfection byproduct precursors in filter backwash water from 10 drinking water treatment plants, *Science of the Total Environment*, 856, 159027. DOI:10.1016/j.scitotenv.2022.159027

Qian, Y., Shi, Y., Guo, J., Chen, Y., Hanigan, D. & An, D. (2023). Molecular characterization of disinfection by product precursors in filter backwash water from 10 drinking water treatment plants, *Science of The Total Environment*, 856, 159027. DOI:10.1016/j.scitotenv.2022.159027

Rani, C. N. & Karthikeyan, S. (2021). Synergic effects on degradation of a mixture of polycyclic aromatic hydrocarbons in a UV slurry photocatalytic membrane reactor and its cost estimation, *Chemical Engineering and Processing-Process Intensification*, 159, 108179. DOI:10.1016/j.cep.2020.108179

Ruiz-Rosa, I., García-Rodríguez, F.J. & Mendoza-Jiménez, J. (2016). Development and application of a cost management model for wastewater treatment and reuse processes, *Journal of cleaner production*, 113, pp. 299-310. DOI:10.1016/j.jclepro.2015.12.044

Silva, F. , Geraldes, A.M. & Albuquerque, A. (2022). Water reuse in a municipal sports center, *1st International FibEnTech Congress* 10.18502/kms.v7i1.11624 http://hdl.handle.net/10198/26078

Studziński, W., Poćwiardowski, W. & Osińska, W. (2021). Application of the swimming pool backwash water recovery system with the use of filter tubes, *Molecules*, 26, 21, 6620. DOI: 10.3390/molecules26216620

Sukanya, K., Sivarajasekar, N. & Saranya, K. (2022). Spent filter backwash water treatment by coagulation followed by ultrafiltration, *Industrial Wastewater Treatment: Emerging Technologies for Sustainability*, pp. 27-40. Cham: Springer International Publishing. DOI:10.1007/978-3-030-98202-7_2

Suman, S., Singh, N.P., Sulekh, Ch. (2012). Effect of Filter Backwash Water when blends with Raw Water on Total Organic Carbon and Dissolve Organic Carbon Removal, *Research Journal of Chemical Sciences*, 10, 38-42.

Torabi, M.S., Momeni, M., Robati A. & Yazdanpanah, N. (2024). Water quality in the reservoirs of seasonal river dams, *Environment Protection Engineering*, 50, 5. DOI:10.37190/epe240201

Turan, M. (2023). Backwashing of granular media filters and membranes for water treatment: a review, *AQUA—Water Infrastructure, Ecosystems and Society*, 72, 3, pp. 274-298. DOI: 10.2166/aqua.2023.207

Wolska, M., Kabsch-Korbutowicz, M., Rosińska, A., Solipiwko-Pieścik, A. & Urbańska-Kozłowska, H. (2024). The Use of Microfiltration for the Pretreatment of Backwash Water from Sand Filters, *Materials*, 17, 2819. DOI:10.3390/ma17122819

Wolska, M., Kabsch-Korbutowicz, M., Solipiwko-Pieścik, A., Urbańska-Kozłowska, H. & Ferenc, Z. (2024). Assessing the feasibility of using ultrafiltration to recirculatebackwash water in a surface water treatment plant, *Archives of Environmental Protection*, 50, pp. 3-13. DOI:10.24425/aep.2024.150547

Wolska, M., Solipiwko-Pieścik, A. & Urbańska-Kozłowska, H. (2024). Disinfection as a stabilization method for backwash water reuse, *Desalination and Water Treatment*, 317, 100101. DOI:10.1016/j.dwt.2024.100101

Wolska, M., Urbańska-Kozłowska, H. & Solipiwko-Pieścik, A. (2025). An assessment of coagulation process efficiency as a pre-treatment for reusing filtration backwash in water treatment plants, *Archives of civil engineering,*71,1, pp.225-240. DOI:10.24425/ace.2025.153331

Xie, Y., Zeng, L., Wang, P., Wu, X. & Feng, T. (2022). Water cost for water purification: Renewability assessment of a typical wastewater treatment plant in China, *Journal of Cleaner Production*, 349, 131474. DOI:10.1016/j.jclepro.2022.131474

Yang, J., Monnot, M., Eljaddi, T., Ercolei, L., Simonian, L. & Moulin, P. (2022). Ultrafiltration as tertiary treatment for municipal wastewater reuse, *Separation and Purification Technology,* 272, 118921. DOI:10.1016/j.seppur.2021.118921

Zhou, Z., Yang, Y., Li, X., Su, Z., Liu, Y., Ren, J. & Zhang, Y. (2015). Effect of recycling filter backwash water on characteristic variability of dissolved organic matter in coagulation sedimentation process, *Desalination and Water Treatment*, 53, pp. 48-56. DOI:10.1080/19443994.2013.836994

Analiza kosztów wdrożenia recyrkulacji popłuczyn do układu oczyszczania wody do picia

Streszczenie. Głównym celem pracy było określenie możliwości wykorzystania podczyszczonych popłuczyn z zakładów oczyszczania wody powierzchniowej i infiltracyjnej do zwiększenia zasobów wody do picia. Dodatkowymi celami badań były:
- określenie skutecznej metody podczyszczania popłuczyn, niezależnie od rodzaju oczyszczanej wody;
- oszacowanie kosztów wdrożenia w istniejących układach gospodarki wodno-ściekowej zakładów oczyszczania wody.
Badania prowadzono w dwóch zakładach oczyszczania wody, powierzchniowej i infiltracyjnej o wydajności około 100 000 m3/d generujących od 70 do 100 tys. popłuczyn miesięcznie. Badania doboru metody podczyszczania obejmowały procesy koagulacji, dezynfekcji fizycznej, separacji membranowej (MF i UF). Ocena skuteczności została dokonana w zakresie eliminacji substancji zawieszonych, materii organicznej oraz mikroorganizmów. Natomiast ocena kosztów wdrożenia została przeprowadzona na podstawie cen zakupu infrastruktury oraz kosztów eksploatacyjnych. Analiza skuteczności procesów jednostkowych wykazała największą skuteczność procesów MF i UF w eliminacji głównych zanieczyszczeń. Jednak procesy te bez wstępnej sedymentacji oraz drugiego stopnia dezynfekcji (lampa UV) nie mogłyby zostać zawrócone do układu oczyszczania wody. Zaproponowany układ zapewnił wystarczającą skuteczność niezależnie od rodzaju oczyszczanej wody. Analiza kosztów wdrożenia rozwiązania wykazała, że ostateczny koszt oczyszczania wody nie ulegnie znacznemu zwiększeniu, a głównym składnikiem generującym ten wzrost jest zużycie energii. Badania wykazały możliwość wykorzystania podczyszczonych popłuczyn jako dodatkowego źródła wody, jednak po wcześniejszym podczyszczeniu. Zastosowanie wstępnej sedymentacji, procesu UF i dezynfekcji przy użyciu lampy UV zapewnia skuteczne podczyszczenie popłuczyn, niezależnie od poziomu ich zanieczyszczenia oraz niezależnie od rodzaju oczyszczanej wody. Zastosowanie tego rozwiązania zwiększy koszty oczyszczania wody o 1,5 lub 4,0 % odpowiednio dla oczyszczania wody powierzchniowej i infiltracyjnej.