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Natural treatment based on willows for concentrate of reverse osmosis

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A B S T R A C T

Aquaduin started reusing wastewater effluent for infiltration, *Cf.* managed aquifer recharge (MAR), in its dune water catchment St-André in 2002. The treatment train at the Water Production Centre Torreele is based on multiple barrier approach with submerged ultrafiltration prior to reverse osmosis (RO). The project not only resulted in enhanced ecological values of the dunes but during the recent longer periods of drought, the combination of reuse/MAR proved to be a robust and safe way to ensure drinking-water production and thus is a potential solution to mitigate the impact of climate change [1]. Concentrate disposal is an issue when using RO. However, as Aquaduin operates in a coastal area, disposal could be managed; the concentrate was discharged in a canal that drained to the sea. To mitigate the impact of this discharge, treatment of RO concentrate using willows has been tested since 2007. This research resulted in the full-scale implementation of a willow field or marsh, that is based on the concept of a horizontally constructed wetland combined with short rotation coppice using willows (*Salix*). The construction started in 2021 and early 2022 the willow marsh became operational. In 2022 a total volume of 538.446 m^3 was treated by the willow marsh, 85% of the total volume of RO concentrate produced. This paper will present the preliminary research, construction and initial results of the treatment.

Keywords: Water reuse; Membranes; Concentrate disposal; Natural treatment; Managed aquifer recharge; Climate change

1. Introduction

Aquaduin, formerly the Intermunicipal Water Company of the Veurne Region (IWVA), started in 2002 with reusing wastewater effluent at Water Production Centre (WPC) Torreele combined with managed aquifer recharge (MAR) in its dune water catchment St-André, situated in Koksijde, Belgium [2]. The treatment train for reuse is based on multiple barrier approach with submerged ultrafiltration (UF) prior to reverse osmosis (RO).

The project resulted in enhanced ecological values of the dunes. But also, the combination reuse/MAR proved to be a robust and safe way to ensure drinking-water production during the recent years with longer periods of droughts maintaining the groundwater levels and could thus be considered a solution to mitigate the impact of climate change.

The reverse osmosis technology used at WPC Torreele proved its excellent capacity of rejecting organic pollutants, bacteria, viruses, dissolved organic matters and inorganic salts [3]. However, everything that is removed in the effluent of the RO, ends up in its concentrate. In early 2022 a nature-based solution (NBS) was taken into operation to treat the concentrate. NBS employ natural resources and systems that predominantly involve living organisms for the water treatment and can be used as an alternative or alongside engineering solutions. This NBS consists of a willow marsh

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of 7.500 m^2. The concept is a horizontally constructed wetland combined with short rotation coppice using willows. The willow species used, *Salix x rubens*, was selected based on its salt tolerance. Based on the experience with pilot testing substantial removal of nitrogen is expected.

2. Preliminary research

Very soon after the start-up of WPC Torreele in 2002, Aquaduin performed tests using NBS to treat its discharge water.

From 2003 until 2009 a 9 m^2 subsurface flow constructed wetland with *Phragmites australis* was used to investigate the possibility to reduce the nutrient content of the mixed discharge water, thus both UF backwash water and RO concentrate. The nitrogen content reduced by 30%; organic content (total organic carbon, chemical oxygen demand) was only partially removed (10%–20%) and phosphorous content did not change [4]. On 26 samples taken in 2006–2007, total organic carbon content decreased by 11.8% on average.

Since 2007 willows (*Salix*) have been tested. *Salix* is a fast-growing tree species and has several advantages over herbaceous species, such as a deeper root system, high productivity and transpiration activity; it represents a promising resource in mitigating impacts of environmental degradation [5]. The objective was not only impact mitigation and reduction of costs (discharge fee) but also biomass production by short rotation coppice (SRC). SRC, referring to biomass production systems for energy purposes using fast-growing tree species, have the ability to resprout from their stumps after being harvested at short intervals (2–4 y) [6]. They are considered an energy-efficient carbon conversion technology to reduce greenhouse gas emissions [7].

In February 2011 a test field of 28.6 m^2 containing 70 willows of 9 different species was installed. This field was approximately 3 m wide and 9.5 m long. It contained iron coated filter sand; the sand bed being 70 cm thick [8]. The willow stools were placed in rows at 45 cm distance each; rows lying 70 cm apart. The initial feed flow was 500 L/h. Based on the results of biomass production, resistance to salinity and experience with resprouting after harvesting, since the beginning of 2014 only 3 species were used. In 2013 the length of the field was reduced to 8.7 m and the flow was 250 L/h. The test was part of the DEMOWARE project (European Union's 7th Framework Programme for Research, Technological Development and Demonstration, Theme ENV.2013.WATER INNO&DEMO-1 (Water Innovation Demonstration Projects) Under Grant Agreement No 619040).

The conclusion after the DEMOWARE experiment [9] was that the use of willows to treat RO concentrate is technically feasible. Two specimens of *Salix x rubens var. Basfordiana* were salt tolerant and proved to resprout and grow. Based on the experiences with the test and other experiences, a production of 20-ton·dry·matter/ha/y seemed feasible.

A minimum of 30% of the total phosphorous and nitrogen was removed from the concentrate, benefiting the receiving water body and reducing the cost for discharge (estimated at 30.000 euro/y). Based on these results full-scale implementation was assumed to be economically feasible.

3. Full-scale implementation

In 2019 Aquaduin entered a new project, FRESH4Cs (Interreg 2 Seas Programme 2014–2020 Co-funded by the European Regional Development Fund Under Subsidy Contract No 2S06-028), which funded the construction and demonstration of the full-scale willow marsh. This was based on the experiences from the previous experiments.

The design of the subsurface wetland implemented consisted of (Fig. 1):

- Construction of a basin with a height of 80 cm using an impermeable layer at the bottom and sides to avoid water leaking into the soil;
- A construction for feeding the influent into coarser gravel on one side of the basin; it longed the whole length of the basin;
- Drainage pipes at the other side of the basin, over the whole length and also based in coarser gravel, to extract the effluent; the drainage pipes were connected to a collection pipe entering a reservoir from where the water was pumped to the existing discharge facility;
- The rest of the basin filled with gravel, except for a small zone where wood chips were used;
- 20.000 willow stools of *Salix x rubens var. Basfordiana* planted in the gravel in rows.

The total surface of the NBS using willows amounted to 7.500 m^2. In the reservoir it is possible to adjust the water level in the gravel. By the end of 2021 the construction was finished, and first tests started. Early 2022 the system became fully operational.

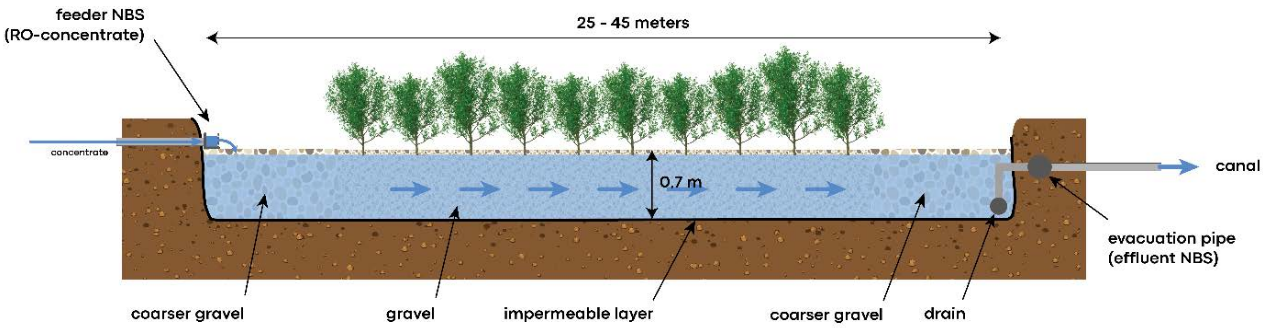

Fig. 1. Cross-section of the nature-based solution using willows.

4. Full-scale results

The results are based on 24 h sampling using a CSF33 sampler from Endress. Results from the influent at day *X* are compared with the samples of day *X* + 1, 24 h being the average calculated residence time of the concentrate in the willow field. This was a good estimate based on conductivity measurements.

All samples were analysed by the accredited lab ECCA.

The most abundant ion in the effluent water (RO concentrate) is chloride which had an average concentration of 1,406 mg/L in 2022 whilst the average electrical conductivity (EC) was of 5.38 mS/cm.

Fig. 1 shows the composition of the water before and after passing through the willow field, compared to the specific discharge limit for that site. As chloride is not removed by the willows, it is not included in Fig. 2.

The biological oxygen demand (BOD) is mostly removed and the chemical oxygen demand remains at a similar concentration. This is expected as BOD stands for the organic matter that is biologically degraded, which is the process that occurs in a willow treatment. It is expected that this removal increases in the future, as it can take some time until the suitable microorganisms grow on the willow's roots [10].

Regarding the nutrients, they were both partially removed. Phosphorus, as total phosphorus (TP), had an average removal of almost 10%. In these types of systems, phosphorus is mostly removed through physical and chemical processes; it can accumulate and be adsorbed by the field substrate and also be taken up by the plant [10]. Chemical precipitation can also occur depending on the water composition. These processes do not lead to high phosphorus removal; the obtained values were also in accordance with literature (10%–20%) [11].

Total nitrogen (TN) had an average removal of 33%. Just like phosphorus, it can also be removed by plant uptake and be adsorbed in the soil, however it is not the most significant part of the process, and it is a temporary solution. There's a limited quantity of nutrient that the soil can hold, and the plant needs to be harvested, as otherwise, the nutrients are eventually released during the plant decomposition [11]. Therefore, the most important nitrogen removal in a willow field is through biological processes: nitrification and denitrification reactions. The removal of different constitutes of nitrogen is shown in Fig. 3. Although 33% of TN was removed, ammonium (NH_4^+) and nitrite (NO_2^-) had a removal percentage of 68% and 76%, respectively. This is expected in an aerobic system, meaning that more nitrification reactions took place and that the NH_4^+ and NO_2^- were converted to NO_3^-. According to Dotro et al. [11], a system that is mostly aerobic typically removes little TN but has high concentrations of nitrate in the effluent. This is a positive point, as ammonium can be toxic for the receiving water body [10].

The results from 2022 were confirmed by monthly samples taken in 2023 (Table 1). Total nitrogen was removed by 31.7% on average and total phosphorous by 6.6%.

5. Future research

Aquaduin will continue to take monthly samples. Also, the difference in removal efficiency for total nitrogen will be investigated between the part of the system where wood chips were used compared to the area with gravel. The evolution of oxygen content through the willow field will also be monitored.

With tracer tests Aquaduin will investigate more in detail how water flows through the willow field. In this way it will be possible to precisely evaluate the residence time of the NBS. In the future, once the root system will be more developed, Aquaduin will also investigate the effect on the removal of different micropollutants. In 2006–2007 7 samples were taken in the *Phragmites* wetland: atrazine (9.3%), simazine (21.5%) and diuron (19.9%) were partially removed, so there is a potential for general improvement of the quality. Also, the plant uptake will be observed. This is fundamental to investigate possible use of the willows after harvesting. This can be for construction or agricultural purposes or for local production of baskets or chairs based on willow tails.

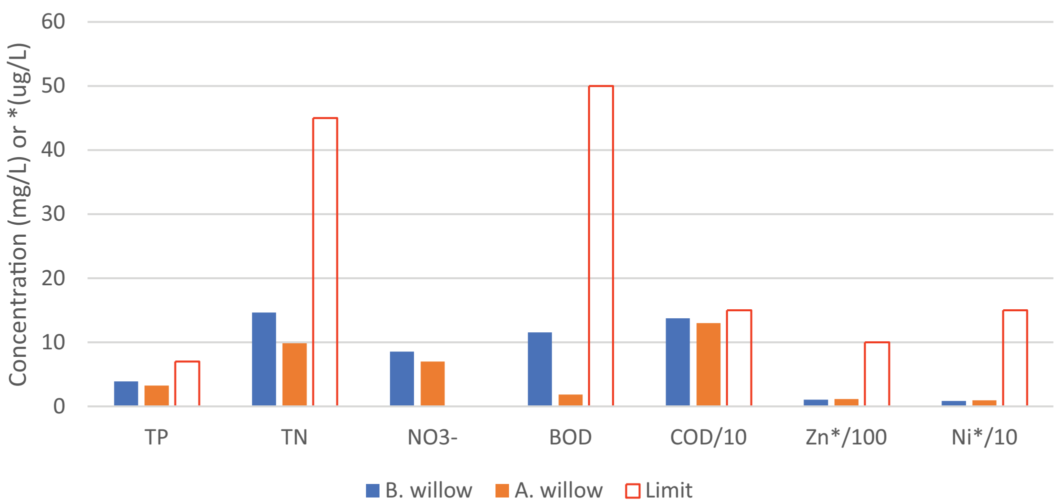

Fig. 2. 2022 average results of reverse osmosis effluent treatment at Aquaduin's nature-based solution. Notes: B. willow: before willow. A. willow: after willow. Limit: maximum concentration for discharge [10].

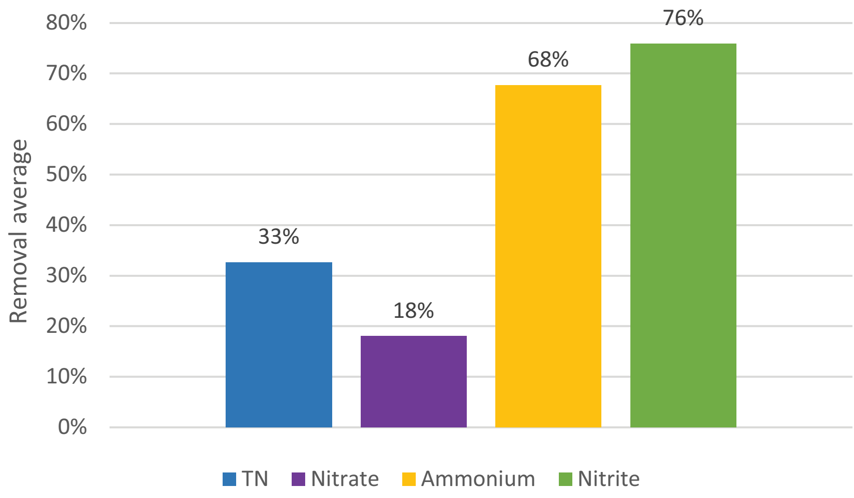

Fig. 3. Average nitrogen removal in 2022 [10].

Table 1
Results based on monthly sampling in first half of 2023

<=1/01/2023–<=1/07/2023	Unit	Average IN	Average OUT	Removal rate based on average	Number of samples	Average removal rate
Biological oxygen demand	mg·O_2/L	2.9	1.3	54.5%	5.0	49.0%
Chemical oxygen demand	mg·O_2/L	126.4	120.5	4.7%	5.0	5.4%
Total nitrogen	mg·N/L	13.2	9.0	31.7%	5.0	31.0%
Total phosphorous	mg·P/L	3.0	2.8	6.6%	5.0	1.4%
Zinc	µg/L	117.0	97.2	16.9%	5.0	15.7%

In 2024 some alternative plants like *Typha*, *Cannabis* and *Miscanthus* will be planted, and the effect will be compared to the willows (*Salix*).

Aquaduin will also investigate the best way to treat the effluent of the willow field in order to reuse it in the WPC Torreele and hence increase overall recovery of the reuse plant.

6. Conclusion

It is concluded that for the period of 2022, the nature-based solution based on willows used by Aquaduin could improve the quality of the RO concentrate, having a positive impact on the receiving water body. However, more growing seasons are necessary for the system to fully develop. On top of this, Aquaduin aims to incorporate the effluent of the willow field back to the RO system, this would mean that more water will be recovered from the wastewater, enabling its reuse as potable water.

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