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Sustainable groundwater management using reclaimed water: the Torreele/St-André case in Flanders, Belgium

Emmanuel Van Houtte and Johan Verbauwhede

ABSTRACT

The Torreele facility produces infiltration water for indirect potable re-use through artificial recharge of the dune aquifer of St-André. The secondary wastewater effluent is treated by ultrafiltration (UF), using the submerged ZeeWeed system, prior to reverse osmosis (RO), using brackish water low energy membranes. The Torreele experience showed that combining UF and RO enables the treatment of wastewater effluent in an effective and reliable way; RO being the major and ultimate barrier against both microbial and chemical contamination. The produced filtrate is of excellent quality and enables sustainable groundwater management in an area with high ecological interest. The biggest challenges for the Torreele facility are the changing conditions, based on the meteorological and seasonal variations, the scaling and fouling problem and the concentrate. Bio-fouling is prevented by monochloramination and scaling by dosing of antiscalant combined with pH adjustment. The Intermunicipal Water Company of the Furnes Region (IWVA) studied alternative treatment, mainly using natural systems, with the objective to mitigate the impact of the concentrate disposal into surface water and to reduce the charges set for this disposal. Concerning groundwater recharge, IWVA is studying alternatives to optimize the infiltration capacity.

Key words | concentrate treatment, managed aquifer recharge, membranes, sustainable groundwater management, water re-use

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INTRODUCTION

As the water demand expanded from 526,000 m³ in 1950 to 5,500,000 m³ in 1990, the three dune water catchments at the western part of the Flemish coast (Belgium), where fresh groundwater is pumped from the unconfined aquifer by the Intermunicipal Water Company of the Furnes Region (IWVA), could no longer expand production. Additional pumping could negatively affect the quality of the aquifer by salt intrusion as salt water is present both north (North Sea) and south (the polder area) of the dunes (Van Houtte & Vanlerberghe 1998). Alternative exploitation methods were studied to remediate decreasing water levels and to guarantee current and future water extraction possibilities. This resulted in the project for artificial recharge of the unconfined dune aquifer. As in the area no other sources were available all year round, IWVA adopted advanced/highly reclaimed water as the supply source for aquifer recharge.

HISTORY OF THE PROJECT

Ten years of research preceded the start of the project:

– an ecological study of the water catchment of St-André was performed by the Flemish Institute of Nature Conservation resulting in a delineation of the infiltration area, the indication of ecological conditions (Kuijken *et al.* 1993) and an ecological management plan for this area;

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- two infiltration tests, using groundwater from sewage works, gave valuable information about the hydrogeological parameters of the dune aquifer in St-André (Lebbe *et al.* 1995);
- the impact of artificial recharge in St-André was simulated using MODFLOW (Van Houtte & Vanlerberghe 1998);
- from 1996 until 1999 pilot tests were performed on surface water and wastewater effluent using different microfiltration (MF) and ultrafiltration (UF) systems for the pre-treatment (Van Houtte *et al.* 1998, 2000) and two types of reverse osmosis (RO) membranes for water demineralization and dissolved organic carbon removal (Van Houtte & Vanlerberghe 2001);
- from 1994 until 2000 procedures for getting necessary permits were followed;
- construction started in 2001.

The choice for combining UF/RO was based on examples in the USA (Leslie *et al.* 1996).

The key elements considered were as follows:

1. The drinking-water should be supplied without any disinfection.
2. Due to the ecological values of the dunes high quality standards (e.g. low nutrient and salt content) were set for infiltration water.
3. The space for buildings is restricted.

Public involvement was a key factor in achieving success. The project and the results of the pilot tests were presented to the public in the visitors' center that was built in 1996:

- from 1997 on a temporary exhibition presented the plans for the project of water re-use/recharge and during the permitting procedure the public was able to comment or object to the plans;
- press notes were released regularly, e.g. when permits were obtained, when the project was tendered, at the opening, etc.;
- an 'open day' at Torreele and the recharge area was organized at the opening in 2002, in 2007 (after 5 years of operation) and was renewed in October 2012 after 10 years of operation;
- since 2003 the results are presented annually to the public through a temporary exhibition in the visitors' center;
- for some years during vacation periods there has been a weekly guided walk to the infiltration area.

THE TORREELE FACILITY

The Torreele facility produces infiltration water for indirect potable re-use through artificial recharge of the dune aquifer of St-André.

The treatment facility was built beside the wastewater treatment plant (WWTP) of Wulpen (operated by Aquafin) and came into operation at the beginning of July 2002. Based on the experience of the pilot tests the following treatment steps were implemented (Figure 1):

- a 1 mm prescreen to remove bigger particles from the effluent before entering the buffer reservoir;
- a submerged UF system using ZeeWeed® element cassettes containing chlorine resistant membranes with pore sizes of maximum 0.1 μm performing outside-in filtration to remove suspended solids and bacteria;
- a cartridge filter;
- two identical RO skids (20 cm diameter in pressure vessels (PV) of 6 meter length), in a two-stage configuration; currently 21 PV in the first stage contain 20 cm low-energy, brackish water RO membrane elements (DOW 30 LE-440) and 10 PV in the second stage contain 20 cm low-energy, brackish water RO membrane elements (DOW LE-440i);
- UV disinfection.

RO is the major and ultimate barrier against both microbial and chemical contamination.

The UF ZeeWeed® modules (ZW500C), work at a maximum design flux of 36 L/h/m². The filtration time is 480–600 s, while backwash is 30 s. Every 30 to 35 backwashes an extended backwash is performed using chlorinated UF filtrate. Aeration on the UF system has been reduced from initially 50% of the time to 30% resulting in reduced energy costs. UF filtrate enters a holding reservoir after monochloramines are dosed to prevent biofouling of RO

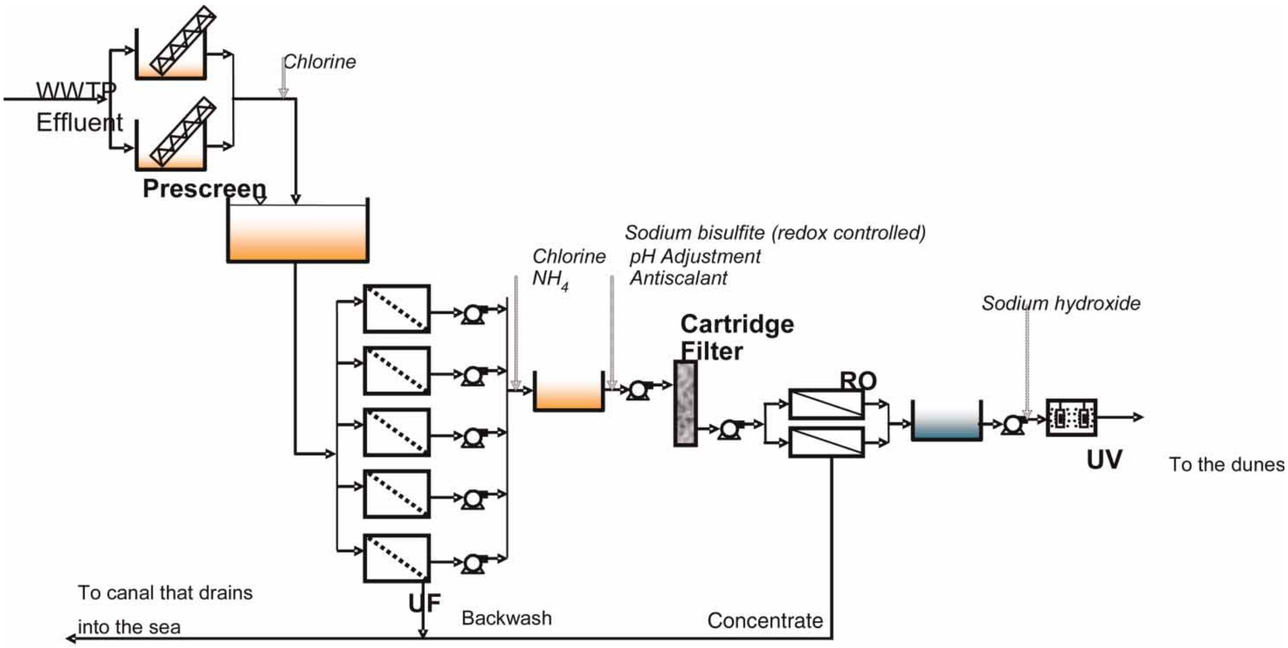

Figure 1 | Process scheme of the Torreele plant.

membranes. The average recovery amounted to 89% in 2011.

The UF filtrate is then pumped to the RO system. Both antiscalant and sulfuric acid are injected to control scaling. A third pump can dose $NaHSO_3$ to neutralize free chlorine. The RO permeate enters a reservoir.

The recovery is controlled by a valve at the concentrate outlet of the second stage. The average recovery (RO) was increased, without dosing more chemicals, as recovery was related to conductivity: when the electrical conductivity is lower, this means less risk for scaling, and a higher recovery is allowed. This is called 'recovery control'. The average recovery in 2011 amounted to 76.7% (initial recovery 75%); the maximum design flux was 20 L/h/m². Additionally, especially during the colder periods, chloramination is no longer constant saving chemical consumption (Van Houtte & Verbauwhede 2008).

The water quality at Torreele is shown in Table 1. Water re-use intended for drinking-water production, either direct or indirect, is not possible without intensive quality monitoring. Both UF and RO produced filtrate as was expected. Levantesi *et al.* (2010) found that in secondary effluent *Escherichia coli*, Enterococci, *Clostridium* spores and somatic coliphages were present at very similar levels (Figure 2) but only somatic coliphages were present in the UF permeate (range from 10 to 2.6 10^2 PFU/ 100 mL). UF, being capable to produce water free of bacteria and suspended solids, proved to be a good pretreatment for RO.

Based on three sampling campaigns in 2007, Tandoi *et al.* (2012) concluded that UF seemed to be a useful barrier to remove protozoa as *Giardia* cysts and *Cryptosporidium* cysts, still present in the secondary effluent.

Replacement of UF membranes started in October 2009; the last set was replaced in January 2012. The average lifetime thus was around 8 years. RO membranes were all replaced between 6 and 7 years of operation.

The concentrate is drained in the nearby canal together with the part of the effluent that has not been treated at 'Torreele'.

In Torreele RO is the major and ultimate single barrier against both microbial and chemical contamination of drinking water and the aquifer alike. Observations show that RO offers complete removal of all pathogenic agents (Table 1) and can be considered as good practice for the removal of trace contaminants (e.g. pesticides). Three campaigns performed in 2007

Table 1 | Overview of water quality at Torreele in 2011

Parameter	UF filtrate	RO filtrate	Infiltration water
Conductivity (μS/cm)	1,126 (454–1,385)	19.5 (8–39)	24 (8–66)
pH	8.02 (7.58–8.23)	5.69 (5.35–6.07)	6.67 (6.25–6.92)
Total organic carbon (mg/L)	9.2 (6.0–11.9)	0.3 (0–1.2)	0.3 (0.1–0.6)
Total hardness (mg/L as $CaCO_3$)	27.5 (11–38)	<0.5	<0.5
Chlorides (mg/L)	213 (70–300)	2.7 (2–9.1)	2.4 (1–3.3)
Fluorides (mg/L)	0.06 (0.00–0.15)	0.00 (0.00–0.05)	<0.2
Sulfate (mg/L)	64 (29–85)	0.2 (0–2)	0.1 (0–0.3)
Nitrate (mg NO_3/L)	19 (6–53)	1.5 (0.3–5.8)	1.1 (0–5)
Ammonia (mg NH_4/L)			0.18 (0.02–0.51)
Phosphate (mg PO_4/L)	4.2 (1.0–9.3)	0.00 (0.00–0.07)	0.00 (0.00–0.03)
Total trihalomethanes (μg/L)			2.8 (1.0 – 6.6)
Aluminum (μg/L)	35 (3–69)	0.91 (0–18.4)	2.6 (0–6)
Chromium (μg/L)	0.05 (0–1.2)	0.15 (0–1.6)	<2.5
Copper (μg/L)	1.1 (0–2.5)	0.3 (0–1.7)	<5
Iron (μg/L)	3.5 (21.3–52.8)	0.15 (0–6)	1 (0–11)
Lead (μg/L)	0.3 (0–11)	<5	<5
Manganese (μg/L)	45 (21–87)	0.05 (0–0.3)	<10
Mercury (μg/L)		<0.2	<0.2
Nickel (μg/L)	1.04 (0–5.2)	0.5 (0–3.5)	<3
Sodium (μg/L)	141 (38–200)	3 (0–6)	4.8 (1.9–6.2)
Zinc (μg/L)	14.3 (0–31)	<20	<20
Total coliforms (MPN/100 mL)	0	0	0
E. coli (MPN/100 mL)	0	0	0
HPC 22 °C (CFU/mL)	22 (2–50)	<1 (0–3)	<1 (0–3)

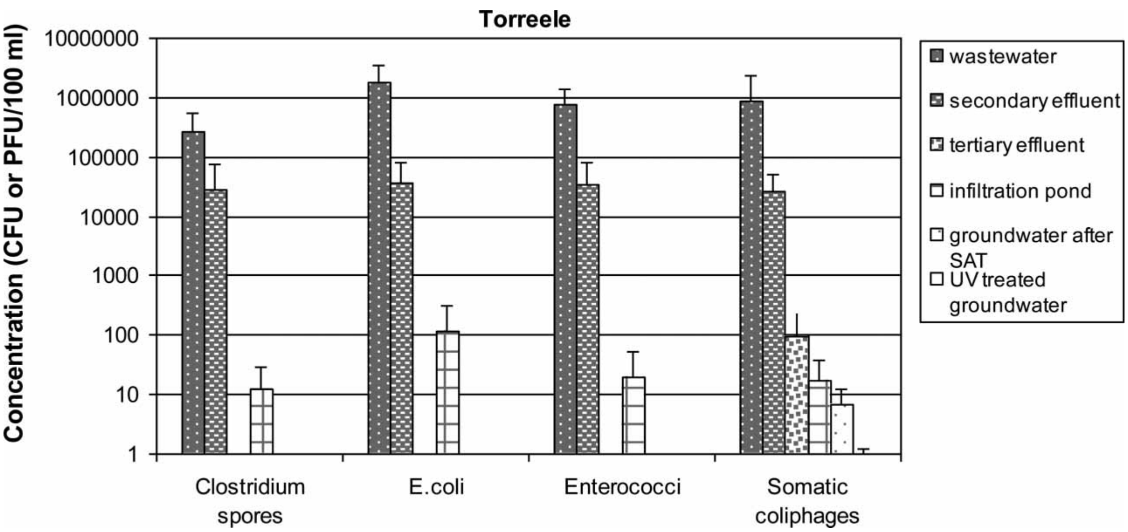

Figure 2 | Microbial indicators concentration in the pathogen sampling campaigns (Levantesi *et al*. 2010).

Table 2 | Operating conditions during sampling

	Quality of UF-filtrate	Recovery	Salt removal based on online conductivity measurement
29/01/2007	1,265 μS/cm 10.9 °C	75.8% (RO1) 76.2% (RO2)	97.5% (RO1) 97.2% (RO2)
23/07/2007	1,134 μS/cm 19.7 °C	76.0% (RO1) 76.3% (RO2)	95.9% (RO1) 95.5% (RO2)
15/10/2007	1,267 μS/cm 16.6 °C	75.6% (RO1) 76.0% (RO2)	96.2% (RO1) 95.9% (RO2)

(Table 2) to quantify the occurrence for pharmaceuticals (PhACs) and endocrine disruptor chemicals (EDCs) (analysis by German Federal Institute of Hydrology, BfG, in Koblenz) showed no presence of these compounds above detection limit (which varied between 0.5 and 10 ng/L according to the substance) after RO despite the presence of these compounds in the effluent and consequently the UF filtrate (Kazner *et al.* 2011). This investigation showed that a number of compounds are substantially lowered in concentration in the WWTP itself, but most of the compounds are unaffected by the WWTP as for the UF treatment.

One control analysis for carbamazepine, an anti-epilecticum, at the beginning of June 2009, prior to the membrane replacements, thus with old membranes, showed values below detection limit (10 ng/L) for RO filtrate of the separate skids, despite presence in the UF filtrate (465 ng/L). These analyses were done by the lab of Antwerp waterworks and confirmed the 2007 results.

In May 2010 and April 2011 'Technologiezentrum Wasser' (TZW) in Karlsruhe screened 89 pharmaceutical residues in the RO filtrate, performing high performance liquid chromatography (HPLC) to a tandem of mass spectrometer (MS/MS) analysis (Sacher *et al.* 2001, 2008), and EDCs, performing gas chromatography–mass spectrometry (GC-MS) analysis (Sacher *et al.* 2001, 2008). None of the PhACs or EDCs could be detected.

Nitrosamines, often a concern with RO when chloramination is performed, tend to be very low in concentration, never exceeding 10 ng/L for *N*-nitrosodimethylamine (NDMA) and 5 ng/L for *N*-nitrosomorpholine (NMOR) (Ernst *et al.* 2012). RO rejected about 50% of NDMA, while NMOR was rejected to a larger extent resulting in NMOR levels below the limit of quantification (1 ng/L) (Krauss *et al.* 2010). The results from different campaigns showed that the probability of significant human exposure to nitrosamines from the reclaimed water was low and that low levels of NDMA, when present in the RO filtrate, are removed in the aquifer (Krauss *et al.* 2010).

CONCENTRATE DISPOSAL

Besides the changing conditions due to the meteorological and seasonal variations, and the scaling and fouling problem, concentrate treatment is an important challenge for the near future. In accordance with the permit, both UF backwash water and RO concentrate have been discharged in the adjacent canal that drains to the sea. The discharge is subject to taxes. It is based on the load of organics, heavy metals and nutrients and amounts annually to 120,000 euro on average or 0.06 €/m³ of produced infiltration water. Studies show that the impact on the quality of this brackish canal is limited. However, since 2003 the IWVA has studied alternative treatment, mainly using natural systems, with the objective to mitigate the impact of the discharge on the canal and to reduce the charges set for concentrate disposal (Van Houtte *et al.* 2012).

From 2003 until 2009 a 9 m² subsurface flow constructed wetland (*Phragmites*) was used to investigate the possibility to reduce the nutrient content of the discharge water; nutrients having the greatest impact on the charge. The nitrogen content reduced by 30%; organic load (total organic carbon (TOC) and chemical oxygen demand (COD)) was removed only partially and phosphorus content did not change (Van Houtte *et al.* 2011).

Willows, by short rotation coppice (SRC), have been tested as an alternative for *Phragmites* as they produce biomass, which can be used for heating or power generation.

After two preliminary tests, in 2010 10 different species were tested for their salt tolerance. As in the short term UF backwash water will be reused after treatment using sand filtration, only RO concentrate would be fed to the willows.

In February 2011 a test field of 28 m² containing 70 willows of nine different species was installed. A quartz sand (0.7–1.2 mm with a porosity of 0.39) layer 70 cm thick, was used (Berquin 2011). The willows were put in rows. The distance between the plants in the row was 45 cm; each row was 70 cm from the next. The feed flow was 500 L/h in the first months of testing but was lowered to 250 L/h in April 2012.

As most of the cost for discharging the concentrates of Torreele is due to the volume itself and the content of COD, total nitrogen and total phosphate, the focus was mainly on these parameters. From May 2011 until December 2011, water samples were taken by IWVA and analyzed by the laboratory of the Vlaamse Maatschappij voor Watervoorziening.

The conclusions for the tests are as follows (Van Houtte *et al.* 2012):

- It was observed that with one exception, COD content after the water passed the willows was lowered. On average the reduction amounted to 14.4%; the median being 12.8%.
- For total nitrogen there were three exceptions but generally the content was lowered by the willows; on average 4.6% with a median of 9.8% (if we do not consider the exceptions the nitrogen was reduced by 12% on average).
- The phosphate level lowered 43.4% on average with a median level of 49% and the removal reduced gradually, probably partly due to the presence of iron on the sand grains.

Based on visual inspection, weighing and evaluating biomass and growth, four (species from *Salix viminalis*, *nigra* and × *rubens* var *basfordiana*) of the 10 tested species were considered to perform the best. These species already performed best in a pot test, so this can be considered a valuable and inexpensive way of evaluating plant performance. The test is being continued.

Using natural systems to treat concentrate will not only mitigate the effects of discharging this water into the environment but will, by the production of biomass, contribute to the climate problem. The willows, by taking up the nutrient, organics and other elements from the concentrate, will harvest the energy out of this concentrate. This energy, in the form of biomass, can be used for heating or power production in a CO_2 neutral way (Van Houtte *et al.* 2012). The investment costs have not been calculated so far. The annual reduction of discharge taxes would be a minimum of 20,000 euros yearly.

Ghyselbrecht *et al.* (2012) performed a test using electrodialysis (ED) to further treat the effluent of the willow test field. ED is a widely applied desalination technology for moderately saline streams. ED is an electromembrane process in which ions are transported through ion exchange membranes from one aqueous solution to another using an electric field as the driving force. The ion exchange membranes used are cation and anion exchange membranes, which basically means that either positive ions or negative ions will flow through. These membranes are placed alternately in an ED stack. This allows the separation of the target water into a desalinated (diluate) stream and brine (concentrate) stream (Hell *et al.* 1998).

The ED concentrate stream was acidified to pH 6.0 by continuous dosing of concentrated HCl. The acid addition is very effective in preventing the precipitation of $CaCO_3$ because it removes one of the reactants, namely CO_3^{2-}, necessary for $CaCO_3$ precipitation. At pH 6.0, the migrated carbonate is converted into bicarbonate that does not cause scaling.

At the end of the feed-and-bleed experiment, a sample was taken of the ED effluent (diluate). The ion composition of the diluate (expressed in mg/L) was compared to the ion composition of the ED feed which was the effluent of the willow field (Table 3).

As can be seen the ED feed was successfully desalinated. All common anions and cations are significantly reduced, except for phosphate and TOC. This implies that these compounds do not migrate to the ED concentrate but are kept at

Table 3 | Comparison of the ion composition between the ED feed (effluent willow field) and the ED effluent (diluate) (Ghyselbrecht *et al.* 2012)

	TOC	TIC	Cl^-	NO_3^-	PO_4^{3-}	SO_4^{2-}	Na^+	K^+	Mg^{2+}	Ca^{2+}
ED feed	37.0	139	501	50	11	366	492	96	37	330
ED effluent	33.8	81.2	192	14	10	257	248	27	15	104

the diluate side. The ED effluent is thus sufficiently desalinated to be re-inserted into the biological unit of the WWTP without salinization of the water cycle. However, the high TOC value of the ED effluent (only 10% was removed from the ED feed) can be a potential obstacle and in order to enhance the biodegradability of the ED effluent extra treatment should be performed. This is an obstacle to the implementation of ED for the treatment of RO concentrate. Additional tests should be performed.

Zhang (2011) calculated that implementation of ED for the treatment of RO concentrate would result in an extra cost of 0.06 €/m³ of produced infiltration water. In this calculation discharge costs were not integrated. As both ED diluate and concentrate are subject to taxes and discharge to sewers, thus WWTP is more expensive, ED does not seem a good option from the economical point of view (Table 4).

Additional treatment of RO concentrate will not be economically feasible unless discharge cost could be lowered substantially or the overall recovery rate could be increased.

MANAGED AQUIFER RECHARGE (MAR) OR INFILTRATION AT ST-ANDRE

The reclaimed water, RO filtrate with an increased pH (>6.5) by dosing of sodiumhydroxide, is transported to the recharge/extraction site of St-André, in Koksijde, by a 2.5 km long pipeline. The water feeds an artificial pond with a surface area of 18,200 m².

In the first 10 years of operation 19.5 million m³ was recharged in the unconfined sandy aquifer. This water is recovered with 112 wells at varying distances from the pond; the filter elements are situated at between 8 and 12 m depth (Van Houtte & Verbauwhede 2005). An additional amount of 'natural' groundwater is extracted as the infiltration project was developed for an extraction/infiltration ratio of 1.4 (2.5 Mm³/year of infiltration and 3.5 Mm³/year of extraction is permitted). Analysis of residence times has indicated that 50% of the water recharged at the same point in time reaches extraction wells in less than 60 days. It takes up to almost 5 years for the last water recharged at the same point in time to reach the extraction wells. These calculations are confirmed by the results of a tracer test (Vandenbohede *et al*. 2008).

Isotope studies (Kloppmann *et al*. 2008) lead to a similar conclusion: infiltration water is mainly confined to the shallow aquifer within the limits of the injection ponds and the pumping wells. Immediately downstream of the recovery wells, the typical signature of the infiltration water (low Cl/B ratios, δ11B close to 0‰, low δ7 Li, evaporative enrichment in 18O, 2H) cannot be evidenced, and the infiltration water fraction, calculated on the basis of boron isotopes, is below 4%. This indicates high recovery efficiency for the MAR system of St-André.

As Table 5 shows, recontamination occurs in the infiltration pond and this is due to the presence of birds. However, the underground passage ensured elimination as bacterial indicators and pathogens, present in the infiltration water, were never detected in the ground water after the MAR (Levantesi *et al*. 2010).

In recent years the infiltration capacity has reduced and it is thought that this is partly because the dynamic equilibrium has already occurred. As can be seen in Figure 3, the surplus defined as the extra infiltrated volume according to the designed ratio of 1.4, gradually accumulated between 2003 and 2007. Then there was a correction and in the last years a stable situation established. Colder water temperatures in winter result in a lower infiltration capacity (Figure 3) causing a negative surplus. When temperatures increase, hydraulic conductivity augments and the monthly surplus gradually increases.

The yearly infiltration rate, 2.2 Mm³/year in the first years of operation, stabilized around 1.8 Mm³/year. The infiltration capacity in summer can be as high as 1.5 to 2 times the infiltration capacity in winter.

Table 4 | Calculation of discharge taxes in different scenarios using ED as an extra treatment step for RO concentrate

Scenario's	Discharge cost per m³ of produced infiltration water
Discharge of RO concentrate and UF BW water	0.057 €
Discharge of RO concentrate (re-use of BW water)	0.043 €
Discharge of ED diluate (to WWTP)	0.040 €
Discharge of ED concentrate into canal	0.022 €

Table 5 | Overview of quality in 2010 at St-André[a]

Parameter	Infiltration water (open pond)	Extracted groundwater	Drinking-water[b]
Conductivity (μS/cm)		344 (271–409)	391 (326–472)
pH	6.98 (6.28–8.02)	7.58 (7.50–7.69)	7.80 (7.73–7.87)
Total organic carbon (mg/L)		2.1 (1.8–2.5)	2.0 (1.7–2.3)
Total hardness (mg/L as $CaCO_3$)		15 (14–17)	16 (14–18)
Temperature		13.4 (11–16.4)	13.4 (11.2–15.9)
Chlorides (mg/L)		20.5 (19–24)	24.5 19–27)
Fluorides (mg/L)		<0.2	<0.2
Sulfates (mg/L)		25 (23–30)	28 (25–34)
Nitrate (mg NO_3/L)		2.0 (0.0–5.3)	2.2 (1–3.4)
Ammonia (mg NH_4/L)		0.30 (0.21–0.36)	0.1 (0.01–0.15)
Phosphate (mg PO_4/L)		0.37 (0.3–0.4)	0.02 (0–0.04)
Total trihalomethanes (μg/L)			5.0 (2.03–6.74)
Aluminum (μg/L)		23 (18–29)	4.8 (4–5)
Chromium μg/L)		<10	<2.5
Copper (μg/L)		<20	<5
Iron (μg/L)		1,126 (864–1,446)	35 (26–46)
Lead (μg/L)		<20	<5
Manganese (μg/L)		42 (34–48)	21 (19–23)
Mercury (μg/L)		<20	<0.2
Nickel (μg/L)		<3	<3
Sodium (mg/L)		18 (16–21)	20 (18–23)
Zinc (μg/L)		<20	0.2 (0–1)
Total coliform bacteria (counts/100 mL)	0–8,164	0	0
E. coli (counts/100 mL)	0–644	0	0
Enterococci (counts/100 mL)	0–118	0	0
HPC 22 °C (counts/mL)	4–520	6 (0–50)	13 (0–150)

[a]Mean values are presented with minimum and maximum values provided in parentheses.
[b]The drinking-water is a mixture of extracted groundwater after recharge and 'natural' groundwater uninfluenced by infiltration.

Two alternatives were studied for increasing the infiltration capacity (Pantoula 2012) and IWVA will start the procedures for permitting within the next few months.

Extracted groundwater is conveyed to the potable water production facility at St-André which consists of an aeration step, rapid sand filtration, a reservoir and UV disinfection prior to distribution. Dosing with chlorine is possible as a preventive action to prevent re-growth and recontamination in the distribution network.

The quality of the drinking-water has improved thanks to the water re-use scheme. The hardness is substantially lower and the color is better due to decreased organic content in the water. The results of the internal inquiry that the IWVA has organized since March 2006 show that the public is generally satisfied with taste, odor and color. The rate of satisfaction concerning the hardness of the water is better in the area where water is distributed from the St-André area, thus coming from the water re-use/aquifer recharge scheme.

The combination water reuse/artificial recharge enabled sustainable groundwater management of the dunes of St-André. The groundwater levels increased resulting in a greater groundwater flow from the dunes to the sea and the polders preventing seawater ingress. The limitation of the infrastructure to a smaller part of the area, together with ecological management, resulted in enhanced natural values in the dunes.

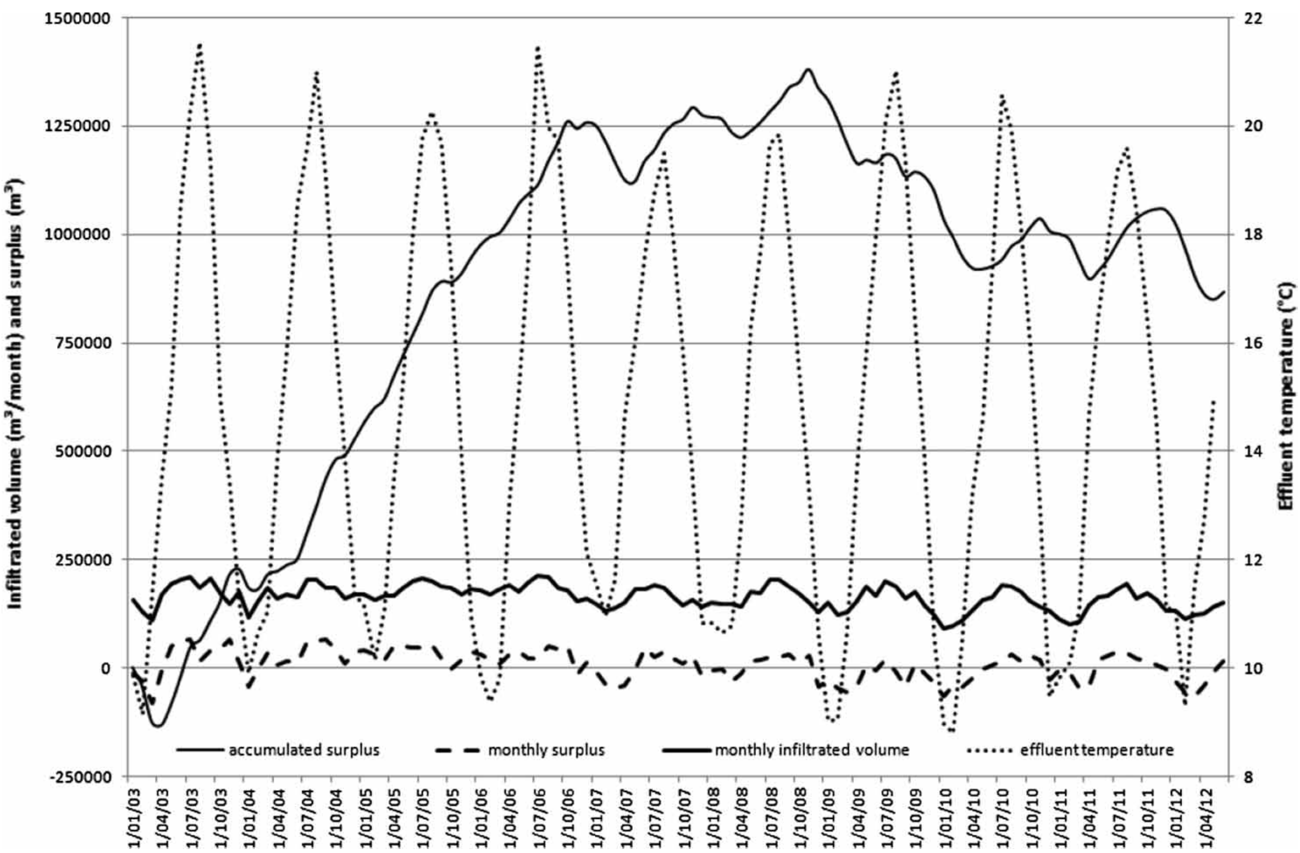

Figure 3 | Evolution of infiltrated volume and surplus since 2003.

ECONOMICAL ASPECTS OF WATER RE-USE

The IWVA had enough capital to fund the project. It decided to opt for a 10 year maintenance contract. The total investment cost amounted to 7 M€.

As both the infiltration capacity and the drinking-water demand decreased, the production of infiltration water declined and consequently the operation and investment cost increased over recent years. In 2005 (2.17 Mm^3 produced) it cost 0.46 €/m^3 to produce infiltration water and this included 0.15 €/m^3 for both operational and investments costs (Van Houtte & Verbauwhede 2008). In 2011, for a production just under 1.8 Mm^3, the cost amounted to 0.62 €/m^3. The maintenance cost (chemicals, energy, personnel, lab) amounted to 0.20 €/m^3 and the part of the maintenance contract and investment cost increased to respectively 0.16 and 0.18 €/m^3. To this cost 0.02 €/m^3 should be added for infiltration but the total of 0.64 €/m^3 is still substantially lower than the average cost to purchase drinking-water from neighbors which amounted to 0.79 €/m^3 in 2011.

Despite this project the drinking-water price for IWVA customers, 1.75 €/m^3 in 2012, is still moderate. According to the website of the Flemish Environmental Agency (VMM 2012) in 2012 prices in the 334 communities of Flanders varied from 1.26 to 2.47 €/m^3 with an average of 1.82 €/m^3.

CONCLUSIONS

Re-use of highly reclaimed water at Torreele via managed aquifer recharge at St-André resulted in a sustainable groundwater management of the Flemish dunes. The combination of UF and RO enabled the re-use of wastewater effluent in an effective and reliable way, as the 10 years of operational experience demonstrated. Bacteria and pathogens were never found, either in the infiltration water or the extracted groundwater. The RO filtrate complies with all requirements of drinking-water guidelines.

Both UF and RO membranes performed for a long period without any quality problems. The lifetime of RO membranes was over 6 years; UF membranes were replaced after a minimum of 8 years of operation. The treatment is economically feasible but, as the production of infiltration water decreased in recent years, in 2011 the production cost amounted to 0.62 €/m³ compared to 0.46 €/m³ in 2005. However, this is still lower than the average cost of 0.79 €/m³ to buy drinking-water from neighbors.

The decreased infiltration capacity is due to the dynamic equilibrium that established in the aquifer. The infiltration capacity is influenced by water temperature and therefore the infiltration rate in winter is 1.5 to 2 times lower compared to summer.

Concentrate treatment is a challenge for the near future. Natural systems seem to be an attractive alternative, not only mitigating the impact of concentrate discharge, but by the production of biomass they could add a positive contribution to the climate problem. Further economic evaluation is needed. Tests of ED showed that it would result in an extra cost of 0.06 €/m³ of produced infiltration water without taking into account discharge costs.

Throughout all tests IWVA has taken great care to inform the public correctly and this public involvement has proved to be a key factor in achieving success.

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