

## What to do after nutrient removal?

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**Abstract** In the Netherlands, interest in advanced treatment is increasing now that almost all wastewater treatment plants apply full biological treatment and nutrient removal. The resulting effluents have an excellent quality which can be improved further by applying advanced treatment processes like flocculating filtration, membrane filtration, UV or activated carbon, and others. The treated effluent can be re-used for various purposes, as process water, household water, urban water, for groundwater suppletion and drinking water. Nowadays many applications are investigated. In order to confirm the applicability pilot test investigations are done at various WWTPs. The results are promising; the cost estimations show increasing prospects. This will finally lead to the maturity of the advanced treatment. It will certainly contribute to a more sustainable water cycle.

**Keywords** Effluent; advanced treatment; further treatment; flocculating filtration; membrane filtration; costs; sustainability; re-use; urban water cycle; process water; household water; infiltration water

### Introduction

For many decades wastewater has been treated in the Netherlands. The first plants were built at the beginning of the twentieth century. Due to industrialisation and increased water consumption, pollution problems increased considerably causing many odour and water quality problems of the surface waters.

After the 1970 law on water pollution many wastewater treatment plants were built especially designed to remove oxygen-consuming substances. In the last 15 years attention has also been paid to eutrophication of surface waters; this led to the introduction and implementation of nutrient removal techniques, such as phosphorus and nitrogen removal.

Today we are thinking about water problems in a more integrated way and sustainability has become a major issue. One of the items that receives increasing attention is the possibility to use or reuse the effluents of wastewater treatment plants. Why throw it away? Can effluent be or become a valuable resource? Is further or advanced treatment necessary? Can we close the water cycle? These are questions that gradually confuse the minds of the Dutch water managers.

### Present situation in the Netherlands

In the Netherlands almost all wastewater (> 95%) is treated in wastewater treatment plants (WWTP). These plants nowadays include full mechanical and biological treatment. Typical data on capacity and effluent quality are summarised in Table 1 (CBS, 1999).

In the near future all WWTPs will include nutrient removal. The biological nitrification/denitrification concept is applied to remove nitrogen. Full nitrification is guaranteed by a high sludge age (or low sludge loading) even at low temperatures (in winter: 5–10°C) resulting in large aeration tanks. Denitrification is carried out by the simultaneous process (especially in oxidation ditch systems) or by the predenitrification concept; sometimes addition of methanol or another carbon source will be necessary. Phosphorus may be removed in various ways. If possible, biological removal is preferred. It mainly deals with the mainstream process; a few examples of the side-stream process are available. There are

**Table 1** Data on capacity and effluent quality of wastewater treatment plants in the Netherlands (1997)

Type	Number	capacity	× 1,000 p.e. effluent concentrations in mg/l				
			CZV	BZV	KjN	Ntot	Ptot
mechanical	2	11	412	145	46	47	5.4
trickling filter	18	852	83	15	18	35	3.3
aeration tank	59	9.762	59	9	11	23	2.1
oxidation tank	59	1.810	46	6	6	13	1.8
oxidation ditch	218	7.987	44	5	5	10	1.8
two stage	32	3.623	62	9	11	23	3.6
various	24	766	72	10	10	19	4.5
total	412	24.790	57	9	9	16	2.4

also many applications of chemical precipitation; simultaneous precipitation (in combination with the activated sludge process) as well as preprecipitation (in the primary sedimentation tank) are applied. A combination of biological P removal and simultaneous precipitation is also applied. Special processes for N or P removal are applied in only a few WWTPs. Examples of special N removal are: the treatment of rejection water from sludge treatment and the denitrification of effluent in a compact filtration bed unit (Dynasand). The pellet reactor (fluidized bed crystallization) is an example of special P removal.

As to disinfection, applications have been limited so far (< 10 WWTPs). Only in a few situations do health reasons (recreation, mussel banks) require disinfection of the effluent. Until recently disinfection was carried out by adding sodium hypochlorite, but due to fear of halogenated toxic by-products, application of other techniques, such as UV, is preferred. So far there has been little need for disinfection in the Netherlands because, generally, effluents are discharged into surface waters with a great dilution capacity.

It is remarkable that further or advanced effluent treatment is not applied in the Netherlands at the moment. Sand or dual media filtration especially, which is widely applied in other European countries (Germany, Switzerland and England), has not yet been used in the Netherlands. Neither is there any practical experience with other advanced treatment systems, such as membrane filtration, at this moment.

### Effluent quality

The quality of treated urban wastewater (effluent) has been strongly improved during the last decades; in the near future further improvements can be expected. Table 2 illustrates this effect showing the average effluent quality of wastewater treatment plants in the Netherlands (CBS, 1999; Van der Graaf, 1999).

As to oxygen-consuming substances (COD < 40 mg/l, BOD < 5 mg/l, KjN < 4 mg/l) the oxygen balance will be hardly disturbed by the discharges of effluents. Also eutrophication problems will be less due to the low content of nutrients (total-N < 5 mg/l, total phosphorus < 0.5 mg/l and ortho-phosphate < 0.1 mg/l).

The effluent still contains approximately 5 mg/l of suspended solids. Probably, this may

**Table 2** Average quality of WWTP-effluent in the Netherlands

Parameter		1981 <sup>(a)</sup>	1997 <sup>(a)</sup>	future <sup>(b)</sup>
COD	mg O <sub>2</sub> /l	112	57	<40
BOD	mg O <sub>2</sub> /l	29	9	<5
N-Kjeldahl	mg N/l	18	9	<4
P-total	mg P/l	10	2.4	<0.5
Suspended solids	mg DS/l	–	9 <sup>(c)</sup>	5

<sup>(a)</sup> CBS, 1999; <sup>(b)</sup> van der Graaf, 1999; <sup>(c)</sup> estimation

not cause harmful situations in the surface waters; nevertheless the removal of suspended solids, which is relatively easy to apply, will result in a considerable improvement of quality – COD to < 30 mg/l, BOD to < 2–3 mg/l, total P to < 0.2 mg/l – and also in a reduction of heavy metals (see Table 3).

Although wastewater treatment plants remove a considerable amount of pathogens and viruses, the numbers in the effluent of these organisms are still very high. Until now the removal or reduction has not yet received any attention in the Netherlands. It may be expected that this will change in future. Relatively simple techniques such as ultrafiltration, chlorination or ultraviolet treatment can be applied to achieve disinfection.

Due to local circumstances and changing conditions such as temperature, dry weather flow, rainwater flow, daily fluctuations and seasonal changes, the quality and quantity of the effluents will fluctuate strongly and continuously. Also the composition of the wastewater with respect to industrial discharges and the conditions in the sewerage system as well as the type of treatment process will influence the treatment results. These variations may create bottlenecks for the practical application of treatment processes applied for advanced effluent treatment.

### Sustainability

In the Netherlands an interdepartmental research programme, called Sustainable Technological Development (STD), has been set up to try to find new ways to achieve a sustainable society. As a part of the programme a study has been made into the “Sustainable Technological Development for urban water cycles” (Van der Graaf, Meester-Broertjes *et al.*, 1997). This study has investigated the (un)sustainability of the urban water cycle, from drinking water production to effluent discharge. Based on the present situation in the Netherlands further improvements can be achieved by various and numerous measures and optimisations. Improvement of the effluent quality can produce considerable results. In this respect the reductions of heavy metals and organic micro-pollutants are especially important. It was suggested that new techniques, such as membrane technology, selective ion exchange, pertraction and selective micro-organisms should be developed.

### Reuse

In this respect the reuse of effluent has to be considered. In the past the basic assumption in wastewater treatment in the Netherlands was the discharge of the effluent into the surface water in such a way that nuisance or degradation were avoided.

For the future we have to examine other ways of using the effluent.

- *Process water for industries.* In the near future the industries have to decrease or optimise the consumption of water. Especially the usage of groundwater will be further restricted. Sometimes the present quality of the used drinking or groundwater is too high for specific applications as process water. Effluent may be considered as a (cheap) alternative as process water or even as boiler feed water; however several additional treatment steps will be necessary.
- *Household water.* New housing schemes introduce the division of water usage into a

**Table 3** Concentrations of heavy metals in effluent in the present and near future (Van der Graaf, 1999)

heavy metals in µg/l	As	Cd	Cr	Cu	Hg	Pb	Ni	Zn
present, average	1.5	0.2	4	12	0.1	6	10	55
future	1.0	0.1	2	5	0.05	3	5	50
, after filtration	1.0	0.05	1	2	0.05	2	2	50
, after ultrafiltration	1.0	0.05	0.5	1	0.05	1	2	50

drinking water section and a less quality household section (for toilet flush, washing machines, gardening). Next to drinking water, water of a different quality will be supplied separately. Effluent may be used as household water after further treatment.

- *Agricultural water.* The need for water for agricultural purposes is still growing, especially in advanced situations (green houses). This results in specific quality requirements. In some cases effluent can meet these standards after treatment.
- *Dehydration.* The theme of dehydration of the wetlands gets much attention in the Netherlands. In the first instance this seems to be merely a water quantity problem. In looking for solutions effluent may play a role.
- *High quality surface water.* In several situations the quality of the surface water is dominantly determined by the quality of the effluent. If higher standards have to be reached, the effluent needs to be treated further.
- *Urban water.* New concepts for urban areas include changes in water management. The role of water and water quality will be more important. Solutions can be either local or centralised. More and more the reuse of effluent will be envisaged.
- *Groundwater supplementation.* The groundwater balance becomes critical. Increasing or even continuing extractions will demand simultaneous addition of water by infiltration. For this purpose effluent can be used as is done in other situations (Orange County, USA).
- *Drinking water.* Although it is technically possible to convert effluent into drinking water, this route still will be limited to very specific situations. Nevertheless, as the processes will become more reliable, the applications will increase.

Although the possibilities for effluent reuse are increasing, the boundary conditions still have to be developed. Due to the sectoral division of responsibilities, quality requirements do exist in some fields, but with respect to process water and household water good references are still lacking. Nevertheless the willingness to explore intersectoral activities (between drinking water companies and wastewater boards) is increasing.

### Advanced treatment techniques

For the further treatment of effluent many processes can be applied. Table 4 gives an overview of various options (STOWA, 2000). It shows the great variety in process results. Therefore the processes will all find their typical field of application.

In the Netherlands the market for advanced treatment is in a starting and developing phase. Special aspects are the typical effluent quality, the various alternatives for reuse of the treated effluent and the lack of experience with various processes. Also experiences and know-how from other places cannot be transferred or translated to the actual situation in the Netherlands. So there is a high need for pilot experiments in order to develop processes and applications that really fit the actual needs and requirements. During the last 5 years several interesting experiments were done; also scientific research (especially at Delft University of Technology) aims at improving the know-how in this field.

From evaluations on applicability not all processes show the same perspectives. At this moment most of the interest is focused on filtration processes as deep bed filtration, flocculating filtration and membrane filtration (Van der Graaf, Kramer, *et al.*, 1999). An inventory showed that more than 25 feasibility studies were done so far; at more than 10 WWTPs pilot tests were done in order to get more information on the applicability. In the next paragraphs three examples are presented.

### Pilot project WWTP Ede

In the neighbourhood of the WWTP Ede a new housing area will be developed. For these houses the distribution of household water is under investigation. It may be an attractive

**Table 4** Various processes for further treatment of effluent

Process	Main principle	Removal	Applications	Status	Costs	Prospects
coagulation/flocculation sedimentation	chemical precipitation	broad spectrum of components 50–90%	P-removal	available	medium	medium
deep bed filtration	filtration biol. oxidation	SS (90–95%) ammonia	polishing	available optimization	low	high
flocculating filtration	chem. prec. filtration biol. oxidation	SS (90–95%) P (-99%) ammonia	P-removal	available optimization	low	high
microsieves	sieving cake filtration	SS (60–70%)	reduction of SS	available	low	low
(primary) membrane filtration	ultrafiltration microfiltration	SS (100%) bacteria (100%) viruses (100%)	high quality purposes	development	high	high
(advanced) membrane filtration	hyperfiltration reverse osmosis nanofiltration	soluble components (-100%)	high purity water	development	high	medium/high
activated carbon	adsorption	soluble comp. micropollutants	removal of micropoll.	available	high	medium
ion exchange	ion exchange	ammonium heavy metals	demi water	available development	high	low
ozone	chemical oxidation	organic subst. micro-org.	disinfection	available	high	medium
chlorination	chemical oxidation	organic subst. micro-org.	disinfection	available	low	medium
UV	radiation	micro-org.	disinfection	available	medium	high
polishing ponds	biological sedimentation	broad spectrum	polishing	available	high	low
reed bed filters	biological filtration	broad spectrum	polishing	available	high	medium
biofilms	biological filtration	broad spectrum	P-N removal	available	high	low

option to use effluent of WWTP Ede for the preparation of household water. The total scheme includes tertiary treatment, followed by a soil passage, extraction, chlorination and distribution. As tertiary treatment processes, flocculating filtration and membrane ultrafiltration were investigated in a pilot plant during almost one year (December 1997–end of 1998); the capacity of the pilot units was approximately 5–10 m<sup>3</sup>/h.

Investigations with the flocculating filtration unit showed very good results with respect to the removal of suspended solids (< 1 mg SS/l) and substances related to solids (like total P); also a low turbidity (< 0.5 FTU) was reached; the hygienic quality improved with log 1.5. As to the process conditions best results were achieved with aluminium (2 mg Al/l) as a flocculant and a filtration rate of 10 m/h. However, other experiments indicated the possibility to apply higher rates, up to 30 m/h (Van der Graaf and Van Nieuwenhuijzen, 1998).

In the ultrafiltration experiments a complete removal of suspended solids, turbidity, and pathogenic micro-organisms was reached. With tubular membranes a stable flux could be

kept of 35–45 l/m<sup>2</sup>.h at 0.3–0.4 bar. Capillary membranes gave higher fluxes (70 l/m<sup>2</sup>.h). Several experiments showed that better results were reached when the effluent was pre-treated in the filtration unit.

Finally a full-scale unit was designed. The total treatment costs were calculated at € 0.28/m<sup>3</sup> (flocculating filtration) and € 0.45/m<sup>3</sup> (membrane filtration); next to these costs approx. € 0.36/m<sup>3</sup> have to be added for transportation and distribution.

### **Pilot project WWTP Kaffeberg**

In the province of Limburg, in the south of the Netherlands, the wastewater board and the drinking water company have joined forces for the delivery of e-water; e means ecological, economic and efficient. An example of e-water may be the production of process water from the effluent of WWTP Kaffeberg. In order to get more precise information pilot plant investigations were done during 6 months (Oct. '98 /May '99). Flocculating filtration was tested next to two membrane units (one Memcor microfiltration and one ultrafiltration).

With the flocculating filtration unit good results were reached at filtration rates of 7–10 m/h. The dosage of aluminium or iron did not give a great improvement. At dosages higher than 2–3 mg/l an overdosage was reached resulting in a deterioration of the filtrate. A three layer filterbed, consisting of 750 mm of anthracite (2.0–4.0 mm), 500 mm of quartzsand (1.5–2.25 mm) and 300 mm of garnet (0.5–0.8 mm), proved to be very stable.

Special attention was given to the biological nitrification inside the filter; an almost complete removal of ammonium could be performed. In some situations extra oxygen as pure oxygen was needed for full nitrification.

The microfiltration unit proved rather stable at a flux of approximately 95 l/m<sup>2</sup>.h. Problems arose when the suspended solids in the effluent suddenly increased (due to malfunctioning of the final settling tanks). With the ultrafiltration unit a flux of 80 l/m<sup>2</sup>.h could be maintained. Also in this case pretreatment of effluent by flocculating filtration gave an improvement of the results of the membrane units. The final evaluation showed that the required effluent quality was produced at the lowest costs (€ 0.38/m<sup>3</sup>) by the flocculating filtration.

### **Pilot project WWTP Etten**

In a region around the WWTP Etten, situated in the eastern part of the Netherlands, some water problems exist. In a feasibility study it was investigated how effluent could be used for solving these problems; see Table 5.

The most promising solutions were the use as infiltration water, household water and process water. The disadvantages of household and process water were the relatively small scale of the possible supply resulting in capacities of 10 to 200 m<sup>3</sup>/h. From an economic point of view only the second option (200 m<sup>3</sup>/h of process water) may be feasible at a production cost of approx € 0.20/m<sup>3</sup>.

A very interesting option may be the application of effluent as infiltration water, for the replenishment of the groundwater resources which are used for drinking water production. In this case at least ultrafiltration will be necessary. At this stage the costs of approx. € 0.45/m<sup>3</sup> are not yet prohibitive because alternative solutions need a long distance transport system. Further investigations are planned.

### **Costs**

In the past effluent treatment had a bad reputation due to some costs studies resulting in high prices (€ 0.50–€ 5.00/m<sup>3</sup>); this was mainly due to a lack of information and an arbitrary set of boundary conditions (Rienks and Meinema, 1995). But in the last decade it was shown that various reuse options may be also attractive from an economical point of view.

**Table 5** Applications of the effluent of WWTP Etten

	Infiltration	Household	Process	Agricultural	Surface
amount (10 <sup>6</sup> m <sup>3</sup> /y)	1.6–3.6	0.088	0.2–1.5	variable (season)	variable (season)
transport (km)	1–2	4	3–4	2–10	3
treatment	high	high	medium/high	low	medium
time span	direct	5 years	uncertain	direct	direct
alternatives	river water (transport)	rain water	river water (transport)	groundwater	local measures
urgency	medium/high	medium	medium	low	low
willingness for funding	moderate/high	moderate	moderate	low	low

Some disadvantages still have to be overcome in order to improve the applicability of effluent treatment. At first the scale of the project is very important. Generally the costs of treatment decrease with an increase of capacity. This especially counts for capacities between 10 and 1000 m<sup>3</sup>/h. This may plea for large scale projects; nevertheless due to some uncertain factors the risks involved in large projects are high; a difficult paradigm. Also the processes involved in effluent treatment are still in a developing phase; serious optimizations and improvements will finally lead to a reduction of costs. Also the production costs of various equipment, especially membranes, may be reduced further.

This may eventually make more reuse applications to become profitable.

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