Key tools to accelerate fulfilment of the EU Urban Waste Water Treatment Directive in the Flemish region of Belgium

P. Ockier, C. Thoeye and G. De Gueldre

Aquafin nv, Technology Department, Dijkstraat 8, B-2630 Aartselaar, Belgium (E-mail: *paul.ockier@aquafin.be*)

Water Science and Technology: **Vol 44 No1 pp 7–14** © IWA Publishing 2001

Abstract The EU Urban Waste Water Treatment Directive (UWWTD) has been transposed in 1992. The whole area of the Flemish region was designated as a sensitive area. This implies nutrient removal for all works in agglomerations of more than 10,000 population equivalent (PE). Thanks to an accelerated investment programme, which is in a final phase now, the wastewater treatment plants (WWTPs) will fulfil treatment in 2005. Key tools for a quick and economic execution of the programme are standardisation for new WWTP's and increasing computerisation for retrofitting existing WWTPs. The UWWTD also stipulates the reuse of treated wastewater and sludge. Strategies are explained.

Keywords UWWTD; dynamic modelling; membrane bioreactors; co-incineration

Transposition of the Directive

Belgium is divided into three regions: Flanders, Wallonia and Brussels. The environmental policy is a regional responsibility so that environmental legislation, policy and execution are different from one region to another. This document will be limited to the approach in the Flemish region (5,927,000 inhabitants).

The UWWTD has been transposed in 1992 (regional executive order "Vlarem II") and has been reviewed in 1995. The whole area of the Flemish region was designated as a sensitive area. This implies collection and nutrient removal for agglomerations of more than 10,000 PE before 31/12/1998, collection and secondary treatment for agglomerations between 2,000 and 10,000 PE before 31/12/2005. For agglomerations less than 2,000 PE appropriate treatment is imposed.

Until now, the Flemish government has defined 118 agglomerations of more than 10,000 PE and 115 agglomerations of less than 10,000 PE. According to Vlarem II, limit concentrations have to be fulfilled for N **or** P for agglomerations of more than 10,000 PE. Also the minimum percentage reduction of overall load of N **and** P for all WWTPs must be at least 75%. The consents of the plants above 10,000 PE all impose N **and** P removal.

Actual situation with the Directive

Figure 1 and Figure 2 summarise the development between 1995 and > 2007 of respectively nitrogen and phosphorus loads and the corresponding percentage reduction of all WWTP's. The minimum percentage reduction of 75% will be fulfilled in 2005. The remaining additional cost for the treatment and collection system is estimated at 5.2 billion Euro.

Standardisation for new WWTPs

Since 1990 the Flemish Government started an intensive programme to increase the purification percentage, that amounted at that time to only 33%. Aquafin Ltd. was established and appointed to renovate, build and operate the necessary main infrastructure.

In order to realise an increased number of WWTPs Aquafin has extensively standardised the applied process technology, based on several comparative economical and

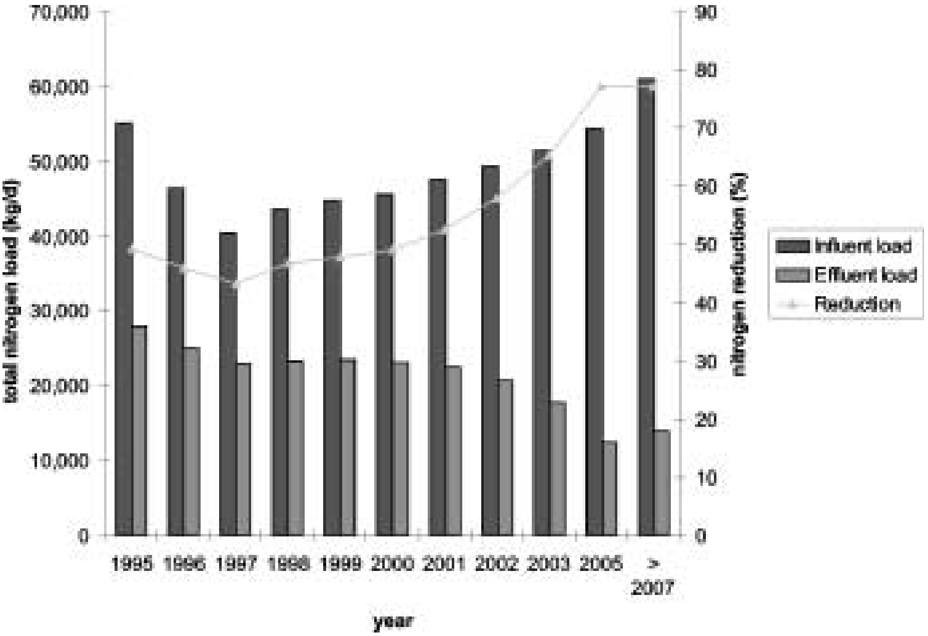

Figure 1 Planned development of the total nitrogen load and corresponding percentage reduction for the Flemish Region

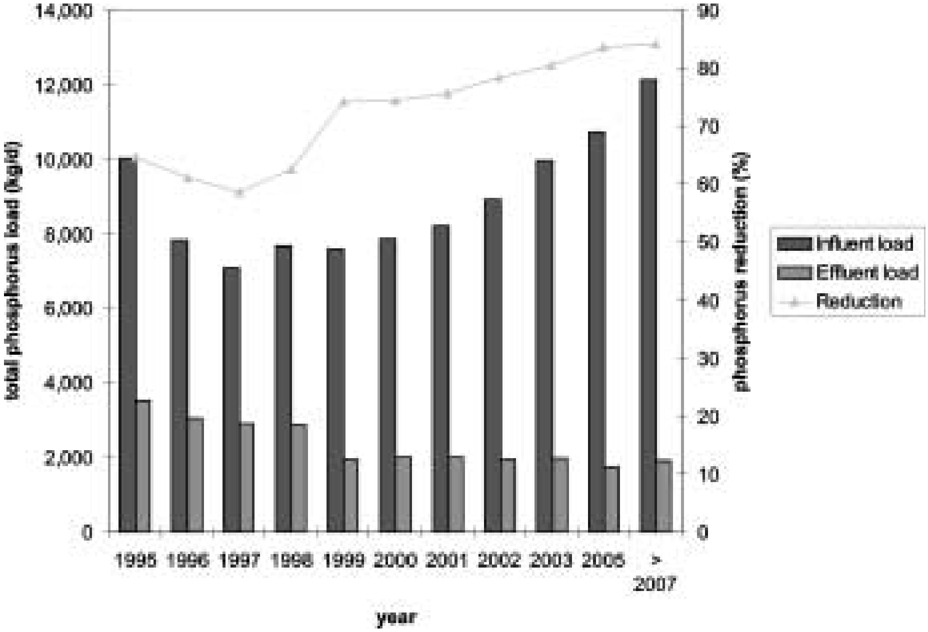

Figure 2 Planned development of the total phosphorus load and corresponding percentage reduction for the Flemish Region

environmental studies. Standardisation is applied for the overall process technology for treatment of wastewater and sludge, as well as for the different process units of a WWTP. The standardisation also results in standard process schemes, standard calculation methods and standard process control. All of this is summarised in a technology manual. As an example, the overall standard approach as a function of the WWTP size and different effluent consents is given in Table 1 for large scale WWTPs (> 2,000 PE) and in Table 2 for small scale WWTPs (< 2,000 PE). The standardisation allows accelerated design and construction of many WWTPs and efficient operation.

Increasing computerisation for retrofitting of existing WWTPs

The increasing processing capacity in computers offers enormous potential for using information and modelling technology in sewage treatment.

Dynamic modelling

Until recently sewage works were designed on the basis of limited data and rules of thumb. They took little account of plant specific conditions.

Advanced characterisation of the influent and of specific activated sludge parameters can lead to an appropriate design with the help of deterministic models describing the activated sludge processes. Dynamic models take account of the impact of events such as storms, the failure of equipment and control strategies. The combination of both approaches of models leads to a tailor-made design.

From 1994 up until 1998, the combined results of pilot-scale testing, lab-scale and dynamic modelling were used for the upscaling of 5 large WWTPs (Merksem: 50,000 PE, Deurne: 215,000 PE, Sint-Niklaas: 56,000 PE, Antwerpen-Noord: 105,000 PE, Brugge: 300,000 PE) towards nutrient removal (Lodewijckx *et al*. 1997). During these projects, practical know-how and insight in the feasibility of available techniques was gained.

This experience and expertise resulted in the development of a standard procedure. The standard procedure consists of two distinctive phases.

Phase 1 At the start, a detailed statistical analysis of the historical data is made and interpreted by an expert. Historical data are available for at least five years. The decision

Table 1 Standardisation overall process technology for large-scale WWTPs

Design capacity	BOD/COD/SS/N/P	BOD/N ratio	Process
2,000–5,000 PE	25/125/60/-/-	–	1 oxidation ditch with central clarifier with possibility of batch operation – chemical P-removal
5,000–10,000 PE	25/125/60/-/-	–	1 oxidation ditch with anoxic zones – surface aerators – chemical P-removal
10,000–30,000 PE	25/125/35/15/2	< 4	1 oxidation ditch with intermittent aeration – surface aerators – chemical P-removal
		> 4	1 oxidation ditch with anoxic zones – surface aerators – chemical P-removal
30,000–100,000 PE	25/125/35/15/2	–	2 oxidation ditches with alternating aeration – fine bubble aeration – biological P-removal
> 100,000 PE	25/125/35/10/1	–	Depending on local circumstances

Table 2 Standardisation overall process technology for small scale WWTPs

Consents	BOD/COD/SS	BOD/COD/SS	BOD/COD/SS/N/P
Design capacity	50/250/60 mg/l	25/125/60 mg/l	25/125/35/15/2
20–500 PE	Primary sedimentation tank and two stage reed bed	–	–
500–1,000 PE		Rotating biological contactor (RBC) with sub-surface flow reed bed	Oxidation ditch Chemical P-removal
1,000–2,000 PE		Oxidation ditch	

whether to go to phase two or not is based on analysis of the uncertainties followed by a cost-benefit assessment of the experimental research required to fulfil the defined target. At this stage, adequate tools for the experimental research in phase 2 are selected.

If the uncertainties are acceptable, dimensioning is done with a static model based on a standard fractionation of the influent.

Phase 2 From this point onwards, the study shifts from desk-research to "field-work" such as sampling, installing on-line analysers and performing lab-tests. In a few cases, pilot-scale testing can be cost-effective.

During the measurement campaigns, on-line respirometry and other measurements are regularly interpreted by an expert through modem connection. In this way, an accurate sample selection can be obtained, as only those samples are selected for further (expensive) lab analyses that contain the most information.

From 1999 on, this standard procedure is implemented for the upscaling of another 16 wastewater treatment plants with a capacity in the range of about 20,000 to 200,000 PE. In 8 of the 16 cases, it was necessary to proceed to phase 2.

Thanks to the use of pilot testing, characterisation of wastewater and dynamic modelling, several millions of euro could be saved. Some of the projects have been described in detail elsewhere (Bixio *et al*. 2000). The reduction of the number of clarifiers and of the aeration volume for the WWTP of Bruges e.g. (as a result of pilot scale testing + lab tests + dynamic modelling) resulted in savings of about 2,000,000 euro (Boonen *et al*. 2000, Carette *et al*. 1998).

Decision supporting models/risk analysis in treatment plants

One of the remaining issues when dealing with modelling of complex systems is the degree of uncertainty linked to the model predictions. In other words to what extent can the model predictions be taken for reality? Two levels of uncertainty can be distinguished. One level of uncertainty is related to the inherent variability of certain system inputs, a second level is linked to the uncertainty related to the estimate of model parameters. Characterising and quantifying this uncertainty is of utmost importance in order to allow the decision maker to select the best possible scenario.

The combination of stochastic modelling techniques with the currently available deterministic models could provide the answer needed. By building a stochastic shell around the deterministic models one can quantify the uncertainty contained within the model prediction. At present a research project is set-up to couple a stochastic Monte Carlo engine with the well known ASM No. 1 model describing the WWTP performance (Rousseau *et al*. 2001).

The stochastic simulation takes into account both input and parameter uncertainty, in this way dealing with the difficulties to estimate model parameters and taking into account the inherent uncertainty in specific processes. For each model input that is considered, a probability distribution is specified. One sample from each input distribution is selected, and the set of samples ("shot") is entered into the deterministic model. The model is then solved as it would be for any deterministic analysis. The model results are stored and the process is repeated until the specified number of model iterations is completed. Using Monte Carlo techniques, it is therefore possible to represent uncertainty in the output of a model by generating sample sets for the model inputs, and running the model repetitively. Instead of obtaining a discrete number for model outputs as in a deterministic simulation, a set of output samples is obtained.

In this case, the resulting model outputs are concentration-duration-frequency curves. After a large number of "shots", one obtains a large number of cdf curves, which can be used to construct an "uncertainty band" on the cdf curves (see Figure 3). Based on this risk analysis one can estimate the probability of exceeding the effluent limits of a WWTP. This methodology will ultimately result in optimised designs with known risk factors.

Reuse of treated wastewater

Art. 12 of the UWWTD stipulates that "treated waste water shall be reused whenever appropriate. Disposal routes shall minimise the adverse effects on the environment".

In Belgium the amount of renewable water is not much higher than 1,000 m^3/inhabitant/year. Countries with less than 1,000 m^3/inhabitant/year are classified as countries with limited availability of water. Belgium already uses more than 40% of this theoretical supply (EEA 1999). There is an international consensus that sustainable water management is indispensable for national economies when water consumption is more than 30% of the theoretical renewable amount. Above this value water becomes a limiting factor for the national economy (Renaud *et al*. 1998).

This high figure for Belgium is the direct consequence of the high population density, in particular in Flanders (434 inhabitants per km^2). As a result of this shortage, pressure on the ground water reserves is considerable and sustainable management of the water cycle is becoming necessary. Examples of Aquafin projects involving reuse and integrated water management are as follows.

New technologies in reuse. In this project, new technologies are being developed for the advanced treatment of effluent to specified degrees of purity. In particular, new combinations of chemical and physical methods of disinfection are being evaluated. Particularly the feasibility of using evaporation for wastewater reclamation has been studied in detail. A new compact reuse concept incorporating membranes is under development.

In addition, on-line measuring methods are being developed to ensure a fail-safe quality control of reclaimed water from WWTPs. The goal is to come to rapid detection of microorganisms and micropollutants (Dewettinck *et al*. 2000). Particular attention is being paid to intelligent monitors that use simple measurement principles such as pH, oxygen concentration, conductivity and redox potential. A strategy based on molecular techniques is being developed to monitor the bacterial quality of reclaimed water.

Membrane bioreactors. Due to the decreasing cost and the increasing quality of membrane technology, it is now possible to consider new concepts, such as membrane bioreactors, in sewage treatment. The compactness of this system offers hitherto unknown possibilities in

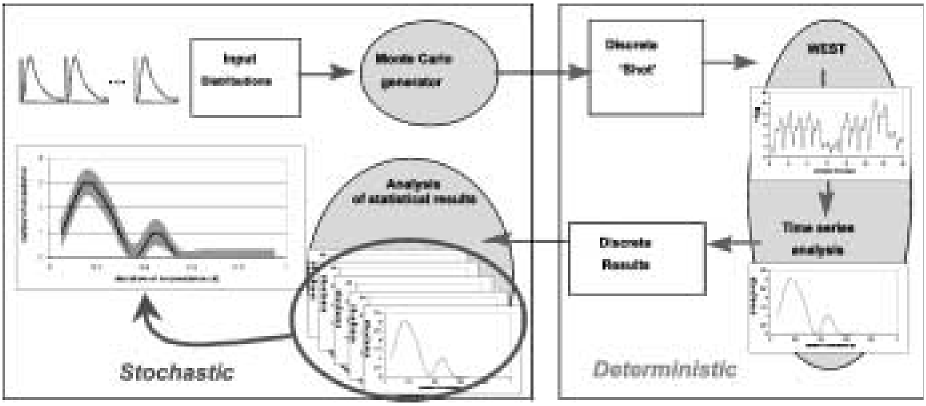

Figure 3 Monte Carlo methodology

the renovation of sewage treatment works, as it eliminates the need for clarifiers and allows for low loaded nitrifying systems in (existing) smaller volumes.

An additional advantage in the use of membrane reactor technology is the production of filtered, low-bacteria effluent with the possibility of reuse. A removal of > log 5 of faecal coliforms with MBR technology is reported (Churchouse *et al*. 1999, Gander *et al*. 2000). At the same time several researchers are emphasising the low production of sludge from membrane bioreactors (–25%). This is not so surprising in itself considering the very high sludge ages reported (up to 160 days) with this type of treatment.

The WWTP of Schilde (28,000 PE) has to be adapted to nutrient removal and has to expand. Due to the limited available surface and the impossibility to expand to the neighbouring land (nature reserve) and because the available volumes at the current WWTP are very low, the option of compact membrane bioreactor technology (MBR) was chosen.

The renovation (see Figure 4) involves a separation of the installation into two parallel purification lines: an MBR-line and an activated sludge-line. The MBR-line will take care of the nutrient removal. This adaptation to nutrient removal means that the current sludge oxidation tank will be converted into a bioreactor with an anoxic and an aerobic tank. Next to these tanks a membrane extraction unit is installed. This MBR line will purify an almost constant flow. For the benefit of the nutrient removal, extra C-source will be dosed.

The hydraulic capacity of the current biological purification (AS-line) will be expanded by providing for extra settling capacity. This treatment line will take care of the flow variations.

The sludge treatment will consist of a thickening table for the secondary sludge from the MBR and AS-line. The primary sludge from the AS-line will be fed in the current thickener, which will then work as fermentor, to provide for extra C-source for the nutrient removal in the MBR-line. At the end, all the sludge is stored in a new sludge buffer tank, before liquid transportation.

The phosphorus removal in both treatment lines will be obtained by adding $FeCl_3$.

Closing the water cycle. The production of drinking water on the Flemish coast by the local drinking water companies is based on the extraction of fresh groundwater from the aquifers under the dunes. Current water extraction has reached its maximum capacity and might lead to the intrusion of salt water. Therefore the integration of WWTP effluent into the existing drinking water production process is being developed and is under construction in partnership with Aquafin. The goal is to come to sustainable ground water extraction by artificial supplementation of the aquifer.

The effluent from the sewage treatment plant at Wulpen is going to be further purified by microfiltration (0.1 μm pore diameter) and then by reverse osmosis (1Å). A variety of

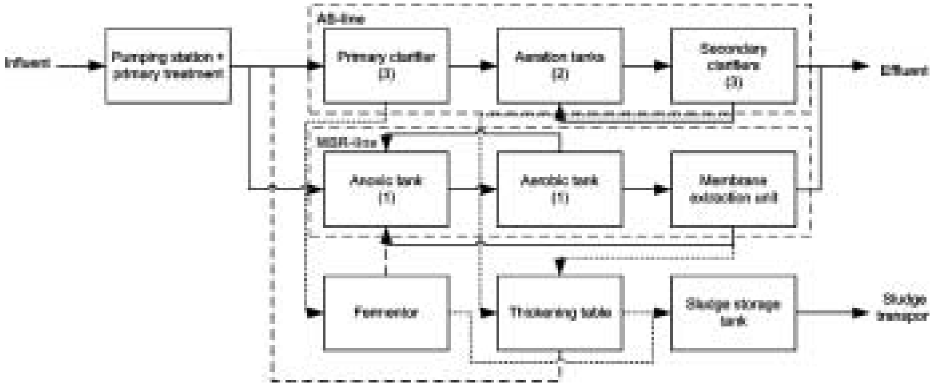

Figure 4 Renovation of the WWTP of Schilde

membranes have been investigated for this purpose in a preliminary pilot phase.

The drinking water company IWVA has obtained a license to infiltrate 2,500,000 m^3 reclaimed water per year in one of their water extraction sites in the dunes. This will reduce the extraction of "natural" ground water by 1,000,000 m^3 per year. The project will become operational in 2001. This is the first Flemish and European project in which effluent from a sewage treatment plant will be further treated on a large scale to obtain infiltration water and finally drinking water quality (Van Houtte *et al*. 1999).

Aquafin plans a similar project in cooperation with the Water Company GWKH. The WWTP of Heist has to be upgraded to 60,000 PE including nutrient removal.

Presently two systems are evaluated on pilot scale:

- WWTP effluent polishing with microfiltration followed by reverse osmosis – 4 m^3/h pilot plant
- MBR-effluent treatment with reverse osmosis – 2 m^3/h pilot plant

The selected system must be operational in 2003, including infiltration in the dunes, extraction and potable water production.

Use of sludge

Art. 14 of the UWWTD stipulates that "sludge arising from waste water treatment shall be reused whenever appropriate".

The expected quantity of sludge from treatment works in Flanders will amount to approximately 105,000 tons of dry solids by the year 2005 (at the moment it is 75,000 tons ds /year). The new Flemish legislation (VLAREA) has severely restricted the use of sewage sludge in agriculture and it is Aquafin's strategy to avoid dumping sludge at all if possible. One of the alternatives is drying the sludge followed by co-incineration in coal fired power plants (Luts *et al*. 1999). On a European level there has been little experience with co-incineration of the dry granules in coal fired power plants. Incineration was mainly applied in industrial and municipal incinerators.

A first campaign was organised in 1995–1996, with two separate short-duration tests at the coal-fired power plant in Mol where undigested sludge was co-incinerated over a wide range of co-incineration rates by weight of dry solids. The aim of this project was to investigate whether adding dried sludge to the combustion process is technically possible, whether the emissions remain below the permitted levels and whether the quality of residual products (bottom ash, fly ash) remains acceptable.

In view of the promising results of the initial tests, a second campaign was commissioned in 1998 to examine the long-term effects of adding about 3% by weight of dry solids of partly digested sludge to the combustion process. The objective now was to examine in more detail the effect of co-combustion on corrosion and fouling and to verify the conclusions of the initial campaigns.

Only small negative effects were noted on the emission levels during these tests and all measurements remained within the emission consents (Vlarem II) for power plants. Also positive effects were noticed on the dust emission and the NO_x.

The residual substance of a coal fired power plant, bottom ashes and fly ashes, are desired products in the building sector. At the moment they are entirely reused as respectively lightweight supplementary substances in concrete applications or in cement production. Both products occur on the list of secondary raw materials of VLAREA (1998), which also implies that standards are set for the total content (target-values) and the leachability (limit-values) of heavy metals.

The co-incineration of sludge increases the total concentration of heavy metals in the bottom and fly ashes, but the leachability of the heavy metals in bottom and fly ashes remains far below the limit values for application as aggregates and is not influenced by the co-firing of sludge (Devoldere *et al.* 1998). Because of the high flame temperature (>1,400–1,600°C) fly ashes as well as bottom ashes are vitrified structures in which the heavy metals are immobilised and are not released on contact with water.

Co-incineration is advantageous from an ecological point of view, because sludge with a calorific value of about 43% of that of coal can be used for the production of electricity. With a co-incineration capacity of 40,000 tons ds/year in prospect for 2005, a reduction of 44,000 tons of CO_2 emissions a year can be achieved.

The tests resulted in a contract with a local electricity company: 10,600 Tds was incinerated in a coal-fired power plant in 1999. Also the co-incineration of mechanically dewatered sludge is now being tested.

Conclusions

The 2005 deadline of the UWWTD will be met for wastewater treatment. In order to realise an increased number of new WWTPs, Aquafin has extensively standardised the applied process technology. For retrofitting the existing WWTPs a tailor-made design is worked out, based on the use of computer models. A model of risk analysis of the model uncertainties is under development.

Reuse of treated wastewater is a high priority in the region of Flanders. A project with microfiltration and reversed osmosis is under construction. Projects and research based on membrane bioreactor technology are ongoing.

The use of sludge is another priority. Emphasis is laid on the thermal use of dried sludge in coal-fired power plants. Positive tests resulted in a contract with a local electricity company.

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