Storm operation strategy: high-flow activated sludge process operation

R. Carrette, D. Bixio, C. Thoeye and P. Ockier

Aquafin nv, Technology Department, Dijkstraat 8, B-2630 Aartselaar, Belgium

Abstract Current practice in Flanders (Belgium) is to limit the hydraulic capacity of the waste water treatment plant to $6Q_{14}$. A maximum of $3Q_{14}$ is treated in the activated sludge system, the excess flow undergoes only physical treatment (stepscreen, sand trap and settling). This paper focuses on an alternative storm management operation strategy aiming at maintaining plant performance and reducing the total pollutant discharge towards the receiving waterbody. Given the observed dilution of incoming waste water under storm conditions, the idea was put forward that higher hydraulic loadings could be treated within the biology if additional secondary clarifier volume was supplied. The new storm operation strategy would consist of treating $6Q_{14}$ biologically using the available storm tanks as additional clarifier volume. Dynamic simulation was used to asses the feasibility of this strategy. In a next step a full scale test was run over several months. The outcome of this case study clearly shows that $6Q_{14}$ can be treated biologically using the storm tank as an extra clarifier.This operation mode eliminates the direct overflow of only physically pre-treated waste water coming from the stormtank towards the receiving waterbody. It was shown that doing so the overall pollutant discharge was significantly reduced.

Keywords Dynamic simulation; environmental impact; pollutant discharge; storm operation

Introduction

River water quality in Flanders (Belgium) has been dramatically bad during the past twenty years, because of the high degree of urbanisation, the industrial and agricultural pollution and insufficient basic treatment infrastructure. Almost no watercourses met even the lowest criteria, which were set out in river master plans. In 1990 the private company AQUAFIN was founded and assigned with the task of the design, construction, operation and financing of the necessary infrastructure for sewage treatment. Nowadays a great deal of collector sewers and treatment plants are being built or scheduled for the near future.

Current practice in Flanders is to limit the hydraulic capacity of the waste water treatment plant (WWTP) to $6Q_{14}$ (Q_{14}=1.7 dry weather flow Q_{DWF}). A maximum of $3Q_{14}$ is treated in the activated sludge system, the excess flow undergoing only physical treatment (stepscreen, sand trap and settling). At present environmental legislation specifies a maximum allowable spill frequency for the combined sewer overflows, but no similar criterion is defined for overflows coming from storm tanks. However in pursuit of minimising the environmental impact towards the receiving waterbodies, the option of treating $6Q_{14}$ into the biology, assuming the WWTP can maintain its performance, deserves further attention.

The underlying assumption in this research was, given the observed dilution of incoming waste water under storm conditions, higher hydraulic loadings could be treated within the biology if additional secondary clarifier volume was supplied. For increasing secondary clarifier volume without actually building new tanks one option is to operate the storm tank as an extra clarifier. This option was evaluated using a dynamic process model and in a second step validated on full-scale. Up to now two full scale plants were studied more closely: the WWTP of Ertvelde and the WWTP of Tielt. The WWTP of Ertvelde (11,000 p.e.) and Tielt (30,000 p.e.) are both existing treatment plants in operation.

This paper ultimately aims at providing an answer to the following two questions: (i) can a WWTP still meet its consents when operating under $6Q_{14}$ mode, (ii) does $6Q_{14}$ operation result in a lower total pollutant discharge towards the receiving waterbody.

Water Science and Technology **Vol 41 No 9 pp 193–201**

Materials and methods

Simulation tools and simulation models

All simulations were run with the WEST simulator package (Hemmis NV, Belgium). To model the complex processes involved in the biological reactors the IAWQ ASM No. 1 (Henze *et al*., 1987) or the IAWQ ASM No. 2d (Henze *et al*., 1998) was selected depending on the plant process. The clarifier model used is a 10-layered Takacs model (Takacs *et al.*, 1991) Model parameters and influent fractionation were taken from previous studies if available, otherwise default parameters were used.

Plant descriptions: test plants

Table 1 summarises the main characteristics of the plants under study and Table 2 gives an overview of the average effluent concentrations versus the consents. The effluent consents for total nitrogen (TN) and total phosphorus (TP) are related to yearly averages, while the effluent consents for COD, BOD and SS are formulated in terms of 95% percentiles.

Model based feasibility evaluation methodology

In order to evaluate the feasibility of certain alterations in the overall process strategy, dynamic simulation was used as a tool to assess potential impacts of these process alterations. For each of the plants under study a rain event was designed and fed to the simulator. Each rain event consists of four phases: (i) a rising phase in which the flow is increasing towards its maximum flow $6Q_{14}$ and the entering load is increasing (ii) a first flush phase characterised by maximum flow and maximum loading (iii) a dilution phase characterised by maximum flow and the entering load drops back to the design load level, (iv) drop phase: return to average flow conditions and design load.

Full scale experiments

In full-scale the plant operation was monitored under $3Q_{14}$ operation mode (classical operation) and during $6Q_{14}$ operation mode. The basic process determinants (sludge concentration, SVI, temperature, aeration control ...) were similar for both periods. Under $3Q_{14}$ operation influent, effluent secondary clarifier and effluent of the storm tank were sampled. Under $6Q_{14}$ operation influent and effluent of secondary clarification were sampled.

Table 1 Main characteristics of test plants

Plant	Type	Design capacity (p.e.)	Actual loading (% compared to design load) BOD	TN	TP	Maximum Hydraulic Capacity (m^3/day)
Ertvelde	Oxidation ditch	11,000	61	119	–	16,971
Tielt	Bio-denipho (Kruger)	30,000	142	121	108	46,656

Table 2 Average effluent concentrations versus consents

	BOD		COD		TN		TP		SS	
Plant	Effluent	Consent	Effluent	Consent	Effluent	Consent	Effluent	Consent	Effluent	Consent
Ertvelde	5	25	70	125	9.1	20	2.2	–	15	35
Tielt	12	25	96	125	8.7	15	1.2	2	13	35

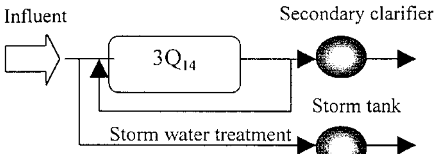

Figure 1 $3Q_{14}$ operation mode process scheme

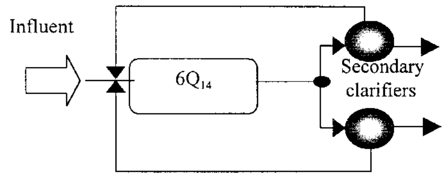

Figure 2 $6Q_{14}$ operation mode process scheme

Flows , DO control, sludge concentration and other basic operation determinants were followed during the campaigns. Figures 1 and 2 give a schematic process lay-out under $3Q_{14}$ and $6Q_{14}$ operation.

The observations with an average daily flow higher than $3Q_{14}$ were classified into three hydraulic classes for both observation periods. This classification was done in order to compare the WWTP's performance for similar types of events.

Results and discussion

Model based feasibility studies

WWTP Ertvelde. The WWTP of Ertvelde is equipped with a stormtank which is interchangeable with the secondary clarifier. The simulation was run using the stormtank as extra clarifier volume and adopting a SVI= 150 ml/g. A design storm of 48 h was fed to the simulator accounting for a maximum influent flow of $6Q_{14}$ (=16971 m^3/day) . A rise time and a flush time of both 2 h were taken during which the flow increased and concentrations were fixed at their dry weather average values. Afterwards a dilution phase of 44 h followed in which the loading dropped back to the average loading level. Figures 3 and 4 show the effluent response for NH_4–N, $N0_3$–N and suspended solids (SS).

The simulation results point out a substantial breakthrough of NH_4–N during the "flush" phase, afterwards as soon as the dilution phase starts NH_4–N levels drop back to lower values. In total the effluent consent is not violated nor for nitrogen, nor for SS (the consents of the other water quality parameters were also met, results not shown). The design storm being fed to the system is probably an overestimation of reality, since during the "first flush" phase the loading is rising up to 10× the design load.

WWTP Tielt. The WWTP of Tielt has two secondary clarifiers and one interchangeable identical stormtank. In $6Q_{14}$ operation mode the stormtank is operated as a third secondary clarifier and the total clarifier volume is increased by 50%. A simulation was run for a $6Q_{14}$

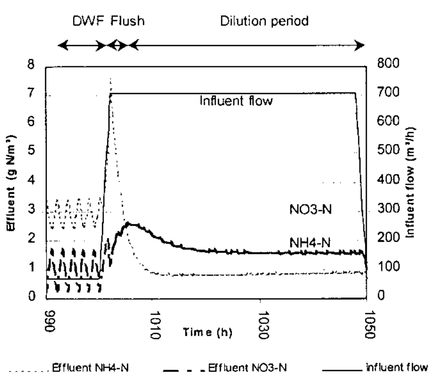

Figure 3 Effluent NH_4–N and NO_3–N for $6Q_{14}$ event

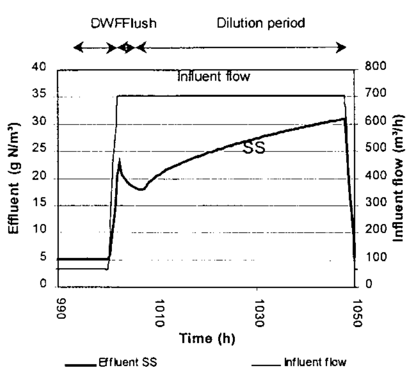

Figure 4 Effluent SS for $6Q_{14}$ event

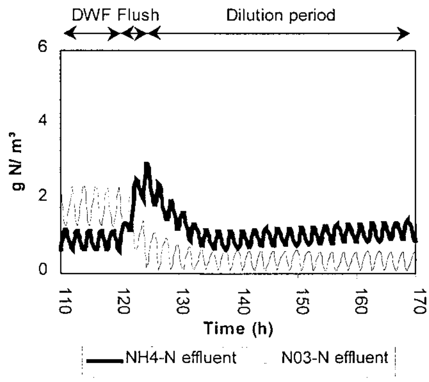

Figure 5 Effluent nitrogen for $6Q_{14}$ event (Tielt)

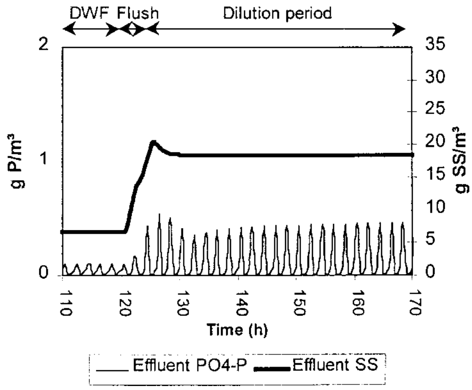

Figure 6 Effluent P and SS for $6Q_{14}$ event (Tielt)

event taking in account a doubling of the load during the first flush period (2 h) for nitrogen, phosphorus, COD and SS. The type of design storm was altered in this way since as observed in practice under storm weather conditions the loading never exceeded the level of 2× the design load. The simulation was run using the stormtank as extra clarifier volume and adopting an SVI=40 ml/g as observed on regular basis at the treatment plant. Further details on the simulation model used can be found in Carrette *et al.* (1998). Figures 5 and 6 show the effluent response for NH_4–N, $N0_3$–N, PO_4–P and SS. Once more a breakthrough of NH_4–N is observed during the "first flush", however the peak height is rather limited (2 mg NH_4–N/l). This limited breakthrough compared to the previous case is related to the less severe storm event imposed on the system.

Full scale experimental tests

At the WWTP of Ertvelde a full-scale monitoring period was run over several months. In total 25 overflow events of the storm tank were observed under $3Q_{14}$ operation. During the $6Q_{14}$ operation period in total 25 events were observed with an influent flow exceeding the $3Q_{14}$ limit.

Effluent performance under $6Q_{14}$ operation. Figures 7 and 8 show the effluent performance for the $6Q_{14}$ operation period for the basic water quality parameters.

Figures 7 and 8 clearly show that at all times the effluent consents are met (consent total nitrogen= 20 g/m^3; BOD=25 g/m^3; SS=35 g/m^3) . These results would indicate that the

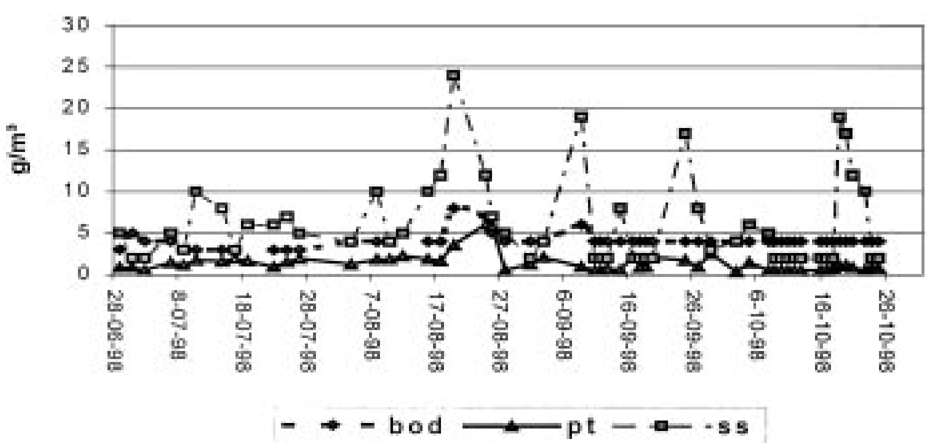

Figure 7 Effluent variations for BOD, total phosphorus (pt) and suspended solids (SS) over time

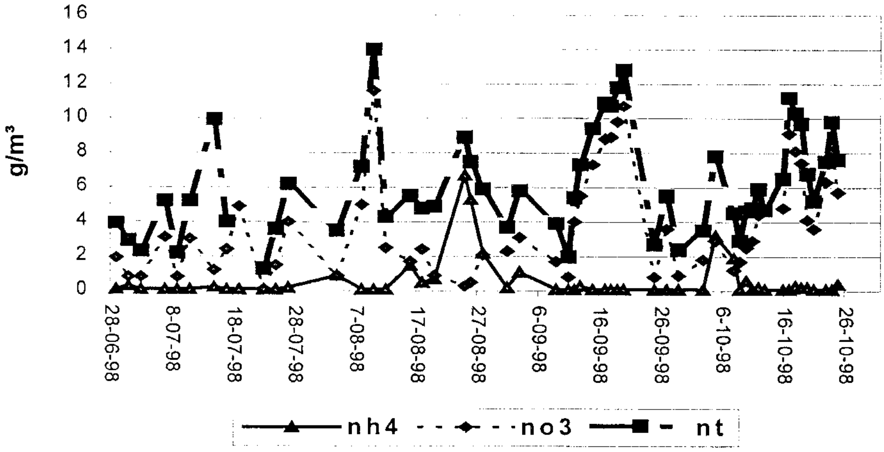

Figure 8 Effluent variations for NH_4–N, NO_3–N and total nitrogen (nt) over time

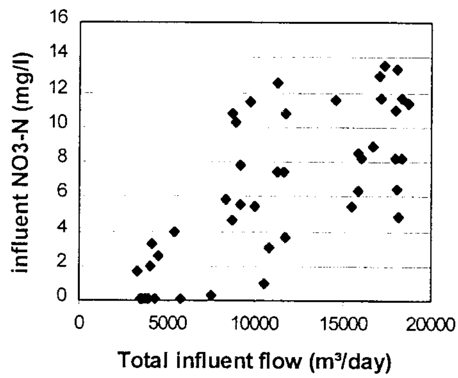

Figure 9 Scatter graph influent flow-influent nitrate concentration

biological system does not suffer from the high flow variations imposed (observed flow range: $1Q_{14}$–$6Q_{14}$). The relative high NH_4–N peak observed on 25 August is due to a failure of the aeration control.

Some NO_3-peaks in the effluent are observed, these occur in general under high flow conditions. These peaks are not due to a deterioration of denitrification but to the input of nitrates with the influent. This can clearly be seen in the scatter diagram represented in Figure 9. This nitrate influx is most likely originating from fertilizer run-off in rural areas.

Comparison of total pollutant discharge $3Q_{14}$ versus $6Q_{14}$ operation. Table 3 shows the classification of the different events under $3Q_{14}$ and $6Q_{14}$ operation into three hydraulic classes. An event is defined as an observation day with an average daily influent flow higher than $3Q_{14}$.

To quantify the impact of $6Q_{14}$ operation in terms of total pollutant discharge the reduction percentage of total pollutant discharge of $6Q_{14}$ operation was calculated relative to the $3Q_{14}$ operation mode:

$$\text{Reduction percentage}(\%) = \frac{[\text{pollutant discharge } 3Q_{14} \text{ operation}] - [\text{pollutant discharge } 6Q_{14} \text{operation}]}{[\text{pollutant discharge } 3Q_{14} \text{operation}]} \times 100$$

Table 3 Classification of events into hydraulic classes for both operation modes

	Number of observations	
Hydraulic class	$3Q_{14}$ operation mode	$6Q_{14}$ operation mode
3–4 Q_{14}	9	8
4–5 Q_{14}	4	9
5–6 Q_{14}	12	8

Table 4 Relative contribution in pollutant discharge of the integrated waste water system (Lust, 1995)

Pollutant discharge source	Relative pollutant discharge (%)
Combined sewer overflows	6
Stormtank overflow	13
Effluent biological treatment	81

Figure 10 gives an overview of the average reduction percentages for each of the basic quality parameters for the different hydraulic classes. Summarising one can state that for BOD, COD, suspended solids and total nitrogen a substantial reduction in total pollutant discharge is obtained by switching to $6Q_{14}$ operation mode. These reduction percentages range between 10 and 80% depending on the water quality parameter considered. The highest reduction percentages are obtained for suspended solids (80%), nitrogen and BOD reduction percentages mount up to 40%, COD reduction is in the range between 10 and 25%.

For total phosphorus (pt) no straightforward answer is found. This is most likely due to the fact that at the WWTP there is no chemical or biological P-removal, apart from the natural P-uptake during biomass synthesis.

To assess the true potential benefits in terms of environmental quality it is necessary to view the overall waste water system discharge. The question whether or not treating $6Q_{14}$ into the biology is worthwhile, depends on the contribution of each of the sources of pollutant discharge within the waste water system. Three main sources can be identified: discharges from combined sewer overflows (CSOs), from storm tank overflow and the continuous discharge from the biological treatment. Table 4 gives an overview of the relative contribution of each source expressed as a percentage of the total pollutant discharge of

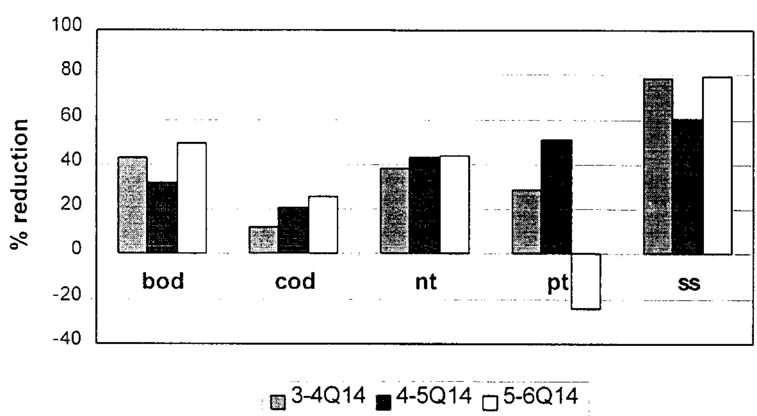

Figure 10 Average reduction percentages in total pollutant discharge by switching to $6Q_{14}$ operation

an integrated waste water system (Lust, 1995). This relative distribution is valid for a classical waste water system in Flanders accounting for a maximum overflow frequency for the CSOs of 7×/year. Similar figures relating to the relative distribution between total pollutant discharge coming from CSOs and total pollutant discharge originating from the treatment works are mentioned by Kollatsch (1992) and Kruit (1998).

These figures show that the stormtank overflow is far from negligible. The total pollutant discharge by CSOs is in relative terms the smallest. However, this does not imply that CSO discharges are of little impact on the ecosystem quality. Adopting this "total emission approach" (Kollatsch, 1992) does not cover the local acute effects like fish mortality due to unionised ammonia and oxygen deficiency. Total nutrient input into the receiving waterbodies and associated eutrophication can be evaluated by this total emission approach. Nevertheless the fact remains that pollutant discharge originating from stormtank overflow is higher than pollutant discharge coming from CSOs. Taking into account that a stormtank can be considered as an improved combined sewer overflow construction, that the yearly overflow frequency of the storm tank is in general much higher than 7×/year and that the discharge of the stormtank overflow is concentrated on one discharge point, it is clear that its environmental impact should not be underestimated. Hence, eliminating the storm tank overflow by using it as an extra clarifier within a $6Q_{14}$ operation mode will result in a significant reduction of the overall pollutant discharge towards the receiving waterbody.

Although the storm operation strategy has been validated on a relative small WWTP, the concept is not restricted to small WWTPs. On the contrary, the reduction in total pollutants discharged towards the receiving waterbody will become even more important when dealing with large WWTPs, as the total amount of water treated in such cases is much larger and hence the total pollutant discharge potential is larger.

Conclusions

Full scale tests confirmed that effluent consents could still be met when adopting the specified $6Q_{14}$ operation mode. Dynamic simulation served hereby as a valuable tool in assessing the impact on process performance when treating higher flows into the biological part of the WWTP.

Furthermore it was demonstrated that by applying this $6Q_{14}$ operation strategy the overall pollutant discharge at the level of the WWTP was significantly reduced compared to the classical $3Q_{14}$ operation mode. This extra pollutant discharge reduction ranged from 10 to 80% depending on the water quality parameter under consideration. Viewing the relative importance of the stormtank overflow discharge into the total pollutant discharge balance of the integrated waste water system, a significant reduction can be obtained in pollutant discharge on the overall waste water system by selecting the 6Q14 operation mode.

Acknowledgements

The authors wish to thank the staff of Aquafin lab and the staff of the Department of Operations for their valuable collaboration in this research. In specific the authors wish to thank Jeroen Van de Voorde for his help in the full scale measuring campaign.

References

Carrette R., Bixio D., Boonen I. and Bogaert H. (1998). Modelling the Performance of a WWTP using the ASM 2d Model: a full-scale Case Study. Presented at Integrated Modelling User Group (IMUG) 98. Brussels, Belgium, October 21–23, 1998.

Henze, M., Grady, C., Gujer, W., Marais, G.v.R. and Matsuo, T. (1987). Activated Sludge Model No. 1, IAWPRC Scientific and Technical Report No. 1.

Henze, M., Gujer, W., Mino, T., Matsuo, T., Wentzel, M.C., Marais, G.v.R. and Van Loosdrecht, M.C.M. (1998). Activated Sludge Model No. 2d – Outline. Proceedings of the fourth IAWQ Kollekolle Seminar on Activated Sludge Modelling. Copenhagen, Denmark, March 16–18 1998. *Wat. Sci. Tech.*, **39**(1), 165–182.

Kollatsch, D-Th. (1992). Total discharges taken into account for comprehensive planning of urban drainage and wastewater treatment. *Wat. Sci. Tech.*, **26**(9–11), 2609–2612.

Kruit, J. (1998). Optimalisatie afvalwatersysteem Nijmegen, Haskoning. Proceedings NVA Symposium 6 November.

Lust, A. (1995). Een bekkenmatige aanpak van de waterzuiveringsinfracstructuur. MSc. thesis, Centre for Environmental Sanitation, University of Ghent.

Takacs, I., Patry, G.G. and Nolasco, D. (1991). A Dynamic Model of the Thickening/Clarification Process. *Wat. Res.* **25**, 1263–1271.