Two years of full-scale storm operation experience

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Abstract Current practice in Flanders is to limit the hydraulic capacity of the wastewater treatment plant to $6Q_{14}$ (Q_{14} = 1.7 dry weather flow Q_{DWF}). A maximum of $3Q_{14}$ is treated in the biological system, the excess flow undergoing only physical treatment in the stormtank. This practice has been challenged by a new concept, consisting of the treatment of the full storm sewage flow in the biological train and of the use of the stormtank(s) as additional secondary clarifier(s).

This paper reports on the long-term experience gained on a total of 12 full-scale plants. The analysis focused on the parameters subject to regulatory discharge (BOD, COD, suspended solids, total nitrogen and total phosphorus) plus ammonia. Special attention is paid to the performance of the clarification and of the nitrification processes. The significance of the proposed way of operation in attenuating the overall pollution impact on the receiving water body is shown.

Keywords Activated sludge; environmental impact; operational costs; pollutant discharge; storm water management

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Introduction

In Flanders (Belgium), minimisation of storm water pollution is considered a high priority in the short to medium term. With the premise that more than 95% of the urban drainage systems are of the combined type, the management of storm sewage at the wastewater treatment plant (WWTP) is of particular concern and has been subject to intensive research in the last 5 years.

The common practice is to limit the WWTP hydraulic capacity to $6Q_{14}$ ($1Q_{14} \cong 1.7$ dry weather flow Q_{DWF}). A maximum of $3Q_{14}$ is treated biologically, the excess flow undergoing only physical-chemical treatment (step screens, sand trap and settling in stormtanks). The relative pollutant discharge from the stormtank overflow can be substantial and can be one of the major causes of acute pollution into the receiving water body.

In pursuit of attenuating the environmental impact of the WWTP discharges on the receiving water bodies, this conventional storm water operation has been challenged by a new concept: the treatment of the whole $6Q_{14}$ in the biological train using the stormtanks as extra secondary clarifiers.

The underlying assumption of this concept is that, given the observed dilution of incoming wastewater under storm conditions, a higher hydraulic load can be treated biologically if additional secondary clarifier volume is supplied. The increase in the secondary clarifier volume is in this case achieved without building new tanks, but by operating the storm tank as an extra clarifier. Figure 1 highlights this point.

The results of a comprehensive feasibility study led to the adoption of the $6Q_{14}$ mode of operation in a number of WWTPs. The aim of this paper is to report on the full-scale experience with these installations.

Materials and methods

The feasibility of the new storm operation concept was tested in three stages:

- Stage 1: model-based feasibility study
- Stage 2: full-scale validation

- Stage 3: extension of the testing to a number of WWTPs of different size and type

In the first instance, dynamic modelling was used to explore the potential impact of the process alterations to the process schemes. Details of the modelling study are reported elsewhere (Carrette *et al.*, 2000).

Second, the simulations were then validated on full-scale. At WWTP Ertvelde (11,000 PE), a full-scale monitoring period was run over one year. The plant operation was monitored under $3Q_{14}$-mode (classical operation) and under $6Q_{14}$-mode. The basic process determinants (sludge concentration, SVI, temperature, ,…) were similar for both periods. In total, 25 overflow events of the storm tank overflow under $3Q_{14}$ operation and 25 events with an influent flow exceeding the $3Q_{14}$ limit during the $6Q_{14}$ operation period were observed. The sampling points (SP) are illustrated in Figure 1.

Third, tests were extended to a number of WWTPs. At present, 16 WWTPs are regularly operated in the $6Q_{14}$-mode, of which 12 have been since 2000 or earlier (Table 1). The 12 WWTPs, which are the object of this analysis, are widely distributed geographically and their catchments encompass a diverse collection of residential area types. The general features and the actual loading of the WWTPs are listed in Table 1.

It is worth noting that prior to the $6Q_{14}$-mode, all WWTPs respected the effluent consent and at present there is no effluent consent on the spills of the stormtank overflows.

The WWTP performance has been evaluated based on correlation between measured variables (black-box approach). The time span considered in the analysis is as follows: 1) for the $6Q_{14}$ mode, from the start-up of the mode (mentioned in Table 1) to June 30 2001 and, 2) for the conventional operation, the twelve months preceding the start-up of the $6Q_{14}$ mode.

The analysis focused on the parameters subject to regulatory discharge (BOD, COD, suspended solids, total nitrogen and total phosphorus) plus ammonia. Ammonia is included because of the potential acute pollution created by discharge of unionised ammonia into the receiving water body. It is worth mentioning that the consent is expressed in yearly effluent concentrations; COD, BOD and SS are defined as 95 percentile value, the TN and TP as average value.

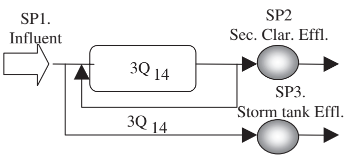

Figure 1a Layout of the $3Q_{14}$ mode of operation

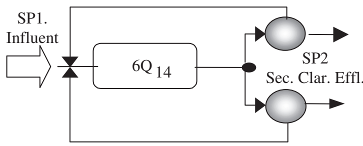

Figure 1b Layout of the $6Q_{14}$ mode of operation

Table 1 Characteristics of the WWTPs under study (← C = chemical P removal; B = EBPR)

Facility No. Town treated	WWTP Type	Design capacity (PE)	Max Hydraulic Capacity (m^3/day)	Start-up $6Q_{14}$ mode	Q_{14}	Loading since the start of the $6Q_{14}$-mode, Average ± St. Dev (% compared to design load) BOD	SS	TN
F1. Kieldrecht	Ox. Ditch, –	8,000	12,269	Jun 00	150	112±57	100±73	147±65
F2 Wimmert.	Ox. Ditch, –	9,000	13,824	Jul 00	185	49±68	82±65	203±62
F3. Nevele	Ox. Ditch, B	10,000	16,934	Jun 00	170	16±6	21±15	72±26
F4. Eksel	Ox. Ditch, C	11,000	16,934	Jul 00	234	24±16	28±34	123±30
F5. Ertvelde	Ox. Ditch, –	11,000	17,280	Feb 99	294	47±41	61±66	112±47
F6. Diest	Ox. Ditch, C	13,500	21,600	Nov 00	160	69±43	61±49	110±22
F7. Zolder	Ox. Ditch, C	13,500	22,291	Sept 00	140	15±90	31±20	54±17
F8. Achel	Ox. Ditch, C	14,000	21,600	Jul 00	188	26±20	37±31	79±24
F9. Maldegem	Biodenitro	14,000	21,600	Jul 00	252	37±26	63±134	88±32
F10. Bilzen	Ox. Ditch, C	20,000	31,104	Apr 00	180	56±32	114±81	87±48
F11. Tielt	Biodenipho	30,000	46,656	Jun 00	171	116±47	108±65	121±44
F12. Eeklo	Biodenipho	47,500	73,440	Feb 00	190	49±58	43±84	84±36

Results

Water quantity

The percentage of time that the average daily flow exceeded the threshold of $3Q_{14}$ varies greatly from WWTP to WWTP. Figure 2 highlights this point. The horizontal axis depicts the level of inflow and the vertical axis shows the cumulative distribution of the average daily flow since the start-up of the $6Q_{14}$ mode of operation. From Figure 2 it can be seen, for example, that while at WWTP Zolder (F7) the average daily flow exceeded $3Q_{14}$ for as low as 7% of the time, at WWTP Maldegem (F9) this condition occurred for about half of the time.

Water quality: continuous discharge

This section will show the effluent quality results of the biological treatment. With the new storm water operation all WWTP's respected the effluent consent (Table 2). Table 2 sets out the effluent results of the water quality parameters subject to regulatory discharge; the BOD, COD, and SS values are expressed on a 95%ile basis, TN and TP on average basis.

During high-flow events the effluent concentrations of all determinants remain generally well below the effluent consent (data not shown). On the other hand, the WWTP performance decreases leading to an increase of the discharged mass load out of the biological treatment. Such a trend is observed under both the $3Q_{14}$ and $6Q_{14}$ mode.

What is of interest here is whether the $6Q_{14}$ mode leads to a substantially accelerated deterioration of the water quality from the continuous discharge of the biological treatment. This can be evaluated in a number of different ways. A useful starting point is to study the relative frequency distribution (RFD) of the water quality load in the effluent of the biological train during high-flow events. A number of such curves are traced out for suspended solids (Figure 3) and ammonia (Figure 4), to indicate the impact of the high-flow operation on the performance of the secondary clarifier and on the nitrification process.

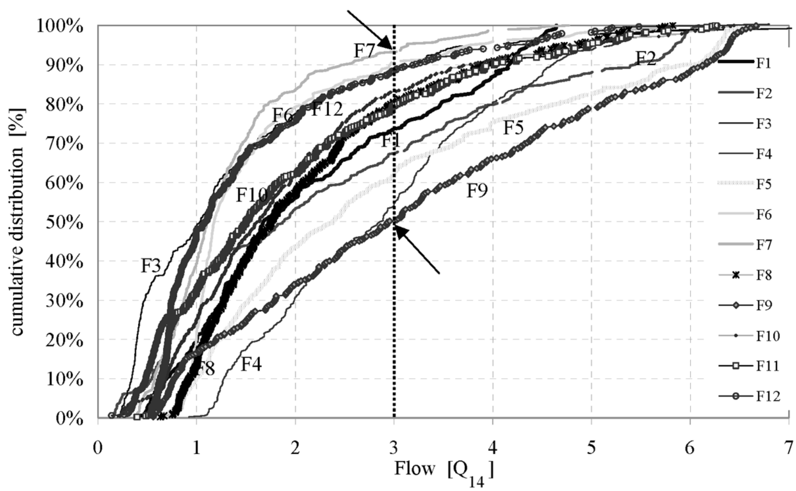

Figure 2 Cumulative distribution of the WWTP's average daily inflow since the $6Q_{14}$ mode

Table 2 Effluent results, in mg/L, since the start-up of the $6Q_{14}$ mode of operation (VMM data)

	Consent		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
BOD	25	95ile	7	5	12	4	6	6	5	4	6	7	6	7
COD	125	95ile	83	53	67	79	64	47	69	76	49	105	94	62
SS	35	95ile	19	21	26	13	19	14	23	21	14	23	15	20
TN	15	AVG	–	–	8.1	10.8	7.1	14.9	9.4	8.5	7.5	6.5	8.9	5.2
TP	2	AVG	–	–	1.0	1.9	1.3	1.2	0.4	0.8	1.2	1.2	1.3	1.1

The performance of these processes is of prime concern when assessing the risk of acute pollution into the receiving water bodies. In Figure 3 and 4 the discharged mass load is expressed in gram per nominal population equivalent. For the sake of comparison, moreover, the values for the $3Q_{14}$ mode are calculated as total flow pumped to the WWTP (instead of total flow conveyed to the biological train) times the water quality concentrations at the effluent of the secondary clarifiers. It is worth noting that the effluent results under $3Q_{14}$ do not include the pollutant load from the storm water overflow.

The observations show that though the pollutant discharge from the biological train under the two modes of operation is comparable for most of the occurrences, under $6Q_{14}$ there is a decrease of the return periods of peak discharges (ie an increase of the peaks). In regulatory terms, the high-flow operation seems to have no significant effect on an average basis, but may exert a significant effect when considering the 95% percentile value.

Further analysis reveals that in the range $3Q_{14} – 5Q_{14}$ the peaks of the discharged mass load are mainly associated with first flush phenomena (data not shown). Observations show that first flush phenomena can produce a substantial increase of the MLSS concentration in the aeration; sometimes leading to a solid overload of the clarifier. Observations also show that first flush phenomena produce a deficiency of the oxygen demand in the aeration basin(s). The resulting anaerobic conditions, which can last several hours, seem the main cause of the deterioration of the nitrification process. As it was to be expected these process disturbances are significantly higher under $6Q_{14}$- than under $3Q_{14}$ mode (data not shown).

Under $6Q_{14}$ mode, the deterioration of the effluent quality is accelerated at flows higher than $5Q_{14}$. This seems to be due to a hydraulic overload problem rather than to first flush events because the same trend is not observed under $3Q_{14}$ (data not shown).

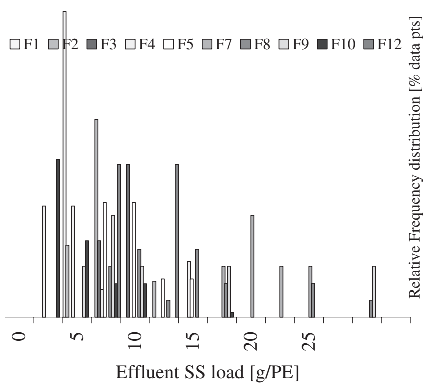

Figure 3a RFD of the effl. SS load: $3Q_{14}$ mode

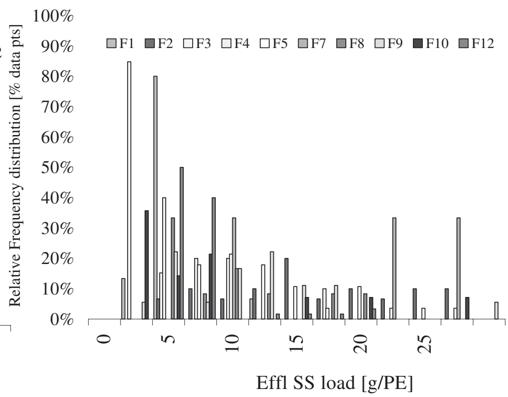

Figure 3b RFD of the effl. SS load: $6Q_{14}$ mode

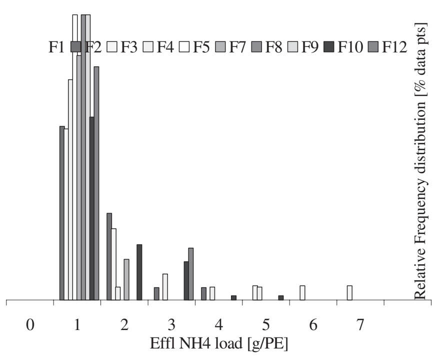

Figure 4a RFD of the NH_4-N_{eff} load: $3Q_{14}$ mode

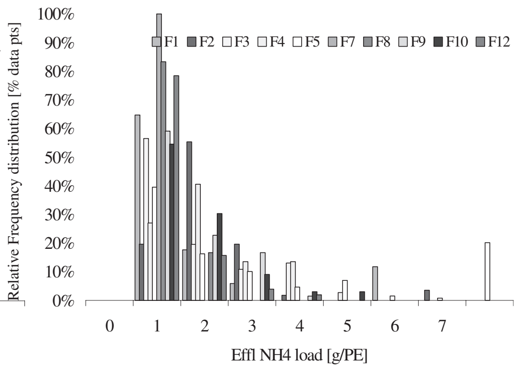

Figure 4b RFD of the NH_4-N_{eff} load: $6Q_{14}$ mode

Ecological impact

Up until now the focus has been on the effluent of the biological train only. But what is the actual overall impact on the WWTP storm sewage discharge when the stormtank overflow is also considered? The following results are limited to the investigation at WWTP Eertvelde. Table 3 shows the classification of the different events under $3Q_{14}$ and $6Q_{14}$ operation into three hydraulic classes during the specific monitoring programme. 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:

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

For BOD, COD, SS and TN a substantial reduction in the 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. For TP no straightforward answer is found. This is most likely due to the fact that at the WWTP there is no chemical nor biological P-removal, apart from the natural P-uptake during biomass synthesis. Figure 5 gives an overview of the average reduction percentages for each of the basic quality parameters subject to regulatory discharge for the different hydraulic classes.

Discussion

The question as to whether treating $6Q_{14}$ biologically is worthwhile depends on the relative magnitude of the different sources of pollutant discharged within the overall waste water system. Three main sources are generally 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 an integrated waste water system. These figures are valid for a classical waste water system in Flanders, where a maximum overflow frequency for the CSOs of 7×/year is applied. Similar figures are also reported for other regions (Kollatsch, 1992; Kruit, 1998).

Table 3 WWTP Eertvelde: classification of events into hydraulic classes for both operation modes

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

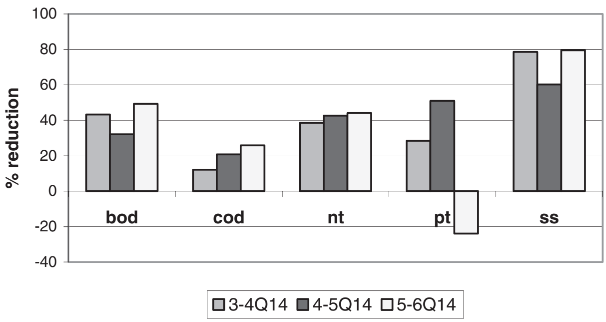

Figure 5 Average reduction percentages in total pollutant discharge by switching to $6Q_{14}$ operation

Table 4 Relative contribution in the total cumulative pollution discharge of a Flemish integrated waste water system (*source*: Lust, 1995)

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

Table 4 clearly shows that the impact of the stormtank overflow is far from negligible. Considering the "total emission approach" adopted in Table 4 is a good indication of the cumulative effects of the different streams, but it does not tell us anything about the local acute effects like fish mortality due to unionised ammonia and oxygen deficiency.

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 generally much higher than 7x/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 and that in the near future the spill frequency concept might be extended to the stormtank overflow.

It has been estimated that for the whole region of Flanders an extra storage capacity of 1,300,000 m^3 would be needed to comply with an extension of the spill frequency concept towards the storm tanks. This represents a total investment of 244 million euro if the classical $3Q_{14}$ operation concept is maintained. By adopting the $6Q_{14}$ storm operation strategy the same objective is reached without any extra investments.

Further investigation is needed on ways to reduce the operational disturbances created by first flush phenomena and by flows higher than $5Q_{14}$.

Conclusions

Due to the frequency and magnitude of the stormtank pollution, high-flow secondary treatment seems pertinent to the Flemish situation. An innovative storm water operation has been extensively tested. The operation consists of allowing a two-fold increase of the storm sewage treatment in the biological train of the WWTP by using the stormtank as an additional clarifier.

The adoption of this practice at 12 WWTPs indicates that it has a substantial overall beneficial impact in attenuating the storm water pollution to the receiving water body, but that further investigation is required on how to reduce the impact of first flush phenomena and of the hydraulic overload at flows higher than $5Q_{14}$.

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