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Biological solution to storm water?

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Abstract Standard practice in Flanders is to limit the hydraulic capacity of sewage treatment works to $6Q_{14}$ (Q_{14} = 1.7 dry weather flow Q_{DWF}). A maximum of $3Q_{14}$ is treated biologically, while the excess flow undergoes only physical treatment in storm tanks. This practice has been challenged by a new high-flow activated sludge operation concept, consisting of the treatment of the full storm sewage flow in the biological train and of the use of the storm tanks as additional secondary clarifiers.

After successful testing in two installations, 56 works of different sizes and types were switched to high-flow activated sludge operation from 1999 to 2002. This paper reports on progress and experiences gained since then. The analysis focuses 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 results indicate that high-flow biological treatment provides a substantial reduction in wet weather discharges while maintaining acceptable process operating conditions.

Keywords High-flow activated sludge treatment; operation; storm water

Background

In the European Union minimisation of storm water pollution is considered a high priority in the short to medium term. As many European urban drainage systems are of the combined type, the management of storm water pollution at sewage treatment works is of particular concern.

It is standard practice for storm water management at treatment works serving combined sewer systems to treat the flow over a certain threshold in storm tanks. Flanders, the northern region of Belgium, where over 90% of the urban drainage systems are of the combined type, is no exception. In Flanders, it is conventional practice to limit the hydraulic capacity to $6Q_{14}$ (1 Q_{14} approximately 1.7 dry weather flow Q_{DWF}): a maximum of $3Q_{14}$ is treated biologically, while the excess flow undergoes physical-chemical treatment only (step screens, sand trap and settling in storm tanks). The storm tanks are generally built in the same manner as secondary clarifiers, to facilitate the plant operability.

Discharge is now regulated for biological treatment but not for the storm water tanks overflow. With the concepts introduced by the EU Water Framework Directive the regulation will likely be set for the total pollution emission to the receiving water (i.e. to both continuous discharge from the biological treatment and discontinuous discharge from the storm tank overflows). 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 regulation for storm tanks.

An alternative solution: high-flow activated sludge operation

Aquafin hoped to significantly reduce the need for extra storage capacity by introducing an innovative wet weather flow management strategy: the treatment of the whole flow ($6Q_{14}$) in the biological lane. The underlying assumption of the concept is that, given the observed dilution of incoming wastewater under wet weather conditions, a higher hydraulic load can be treated biologically if additional secondary clarification is supplied. The latter is supplied by using the storm tank(s) as extra secondary clarifier(s). The design concept applied for the storm tanks made this concept readily applicable.

It is worth mentioning that as a result of the standard design practice of the storm tanks, for certain plant sizes the increase in clarification volume is less than proportional to the increase in hydraulic load. Figures 1 and 2 illustrate this point: while Figure 1 shows a case where one storm tank is added to a secondary clarifier, in Figure 2 one storm tank is added to two secondary clarifiers. The case illustrated in Figure 2 represents the worst-case situation.

Biological solution to storm water ? An environmental point of view

The pollution from storm tank discharges can be a leading cause of water quality impairment. The relative magnitude of storm tank overflow can be more than double the discharges from combined sewer overflows (Kollatsch, 1992; Kruit, 1998; Lust, 1995) and can be a relatively high proportion of the total emission of the treatment works.

Figure 3 shows the relative pollution emission of the storm tank overflow, expressed as a percentage of the total pollutant discharge of the treatment plant, in six Flemish treatment works that comply with nutrient removal standards. The Figure reports on the parameters subject to regulatory discharge (BOD, COD, suspended solids, total nitrogen and total phosphorus).

Figure 3 clearly shows that the relative pollution from the stormtank overflow is far from negligible. The total emission approach adopted in Figure 3 is a good indication of the cumulative effects of the different streams, but does not say anything about the local acute effects during storm events. We can expect that local acute effects like fish mortality due to unionised ammonia and oxygen deficiency will be even larger. Therefore, in pollution

Figure 1 STP Ertvelde – conventional operation with stormwater tank (left) versus high-flow operation with extra clarifier (right): 1 clarifier + 1 storm tank => 2 clarifiers

Figure 2 STP Tielt – conventional operation with stormwater tank (left) versus high-flow operation with extra clarifier (right): 2 clarifiers + 1 storm tank => 3 clarifiers

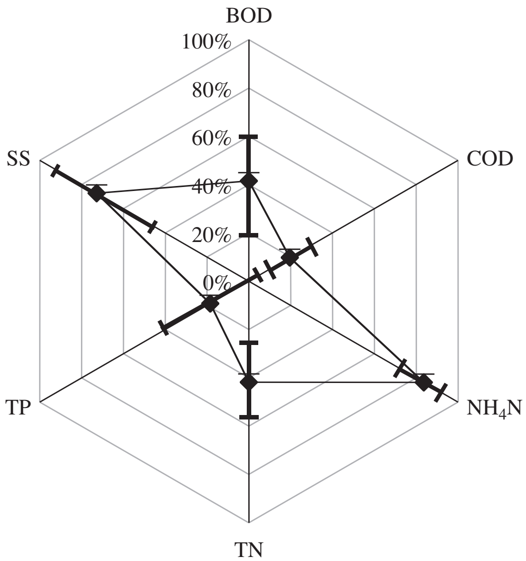

Figure 3 Yearly cumulative contribution of the storm tank overflow to the total pollutant discharge in six treatment works (in 2000)

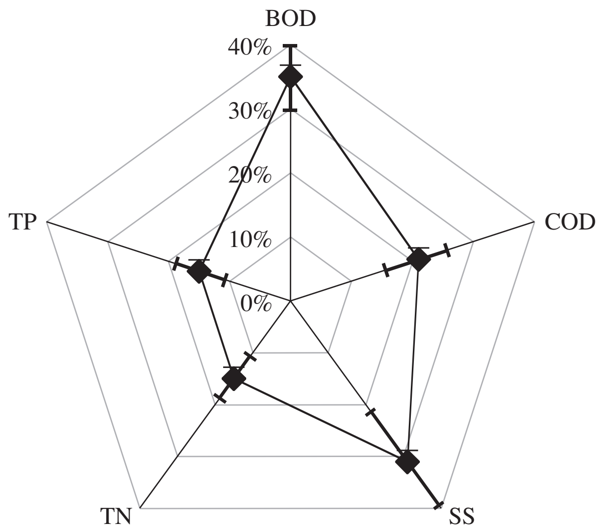

Figure 4 Net overall reduction of the total pollutant discharge during storm events by passing to high-flow AS operation at STP Ertvelde

abatement in Flemish rivers, storm water treatment at treatment works is definitely an important issue.

Full-scale tests were run over several months to evaluate the pollution abatement that can be obtained by passing to high-flow activated sludge operation (Carrette *et al.*, 2000). Figure 4 illustrates the net pollution abatement obtained at Ertvelde sewage treatment works. The reduction percentage of total pollutant discharge of $6Q_{14}$ operation was calculated relative to the $3Q_{14}$ operation mode:

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

Figure 4 shows that a substantial attenuation of the environmental impact of storm water pollution could be achieved. In particular, the unionised ammonia and BOD discharge, which are the main causes of local acute stresses on the river ecology, could be reduced by over 80% and 40%, respectively.

Biological solution to storm water? An operator point of view

Although this is clearly a success story (from an environmental point of view), treatment works managers may have to be encouraged to adopt this approach. In many EU regions, as well as in Flanders, today the permits are limited to the emissions of the biological treatment only (i.e. not on the storm water tanks). From the perspective of the biological treatment only, the treatment works' performance worsens, as it will be shown in the next section. It will also be shown that the worsening of the results is however limited.

An account of the effect of high-flow on the performance of the biological treatment is given in the following section.

Impact on the settling capacity and organic removal

Figure 5 compares the performance of secondary clarification (suspended solids load in the effluent) in the two operational modes during rain events for 11 treatment works that have permits on nutrient removal. In Figure 5, the horizontal axis depicts the level of the average daily load in the effluent, expressed in grams per population equivalent, while the vertical axis shows the cumulative effluent distribution. In order to make a "like for like" comparison, the discharge load for the conventional mode (i.e. 3 Q_{14}-mode) is calculated as total flow pumped to the treatment works (both to biological and storm tanks) times the water quality concentrations of the effluent of the biological lane.

Figure 5, for instance, shows that during storm water conditions the Tielt works (in bold) had a biological effluent load of under 25 g SS/PE/d for 90% of measurements in conventional operation, as well as in the high-flow activated sludge process.

It is worth mentioning that the results shown in Figure 5 can give a good indication to plant managers of those regions, like Flanders, where the permits are set on 24-h composite samples, but does not help managers of those regions, where the permits are set on shorter composite samples (e.g.: 2-h composite samples or, worse, grab samples).

An on-line monitoring program of the SS in the effluent at treatment works of Tielt could provide us with results at shorter intervals (every 10 minutes). The monitoring program started in October 2001, and since then the effluent consent of 35 mg/L has never been exceeded. It is worth reminding that the treatment plant of Tielt represents a worst-case situation concerning the relation between increase in clarification volume and increase of the hydraulic load to the biology (Figure 2).

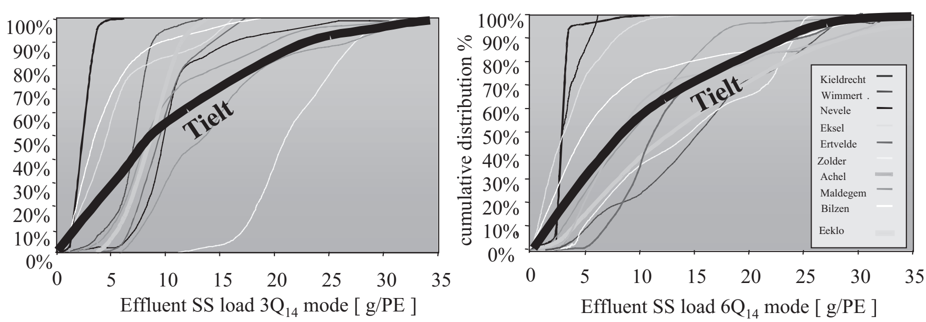

Figure 5 Cumulative distribution of the effluent SS load, expressed in gram per population equivalent, out of the biological train when $Q_{INF} > 3Q_{14}$ for $3Q_{14}$- (left) vs $6Q_{14}$ mode of operation (right)

Inflow and suspended solids concentrations during November 2002 at Tielt treatment works are illustrated in Figure 6. This period represents the worst high-flow conditions the works experienced since the on-line SS measurements are available.

Figure 6 indicates a sharp increase in suspended solids concentrations when the works operated at its maximum pumping capacity (which here is a bit more than $6Q_{14}$), but at all times the effluent consent of 35 mg/L was ensured.

The increased dilution factor in the biological reactors did not show detrimental effects on the settling characteristics. In other words, we could not detect any correlation between change in stormwater regime and settling characteristics of the sludge, expressed as DSVI (data not shown).

Impact on nitrogen removal

Figure 7 compares the nitrification performance (ammonia load in the effluent) in the two operational modes during rain events for 11 treatment works that have permits on nutrient removal. The load for the conventional mode is calculated as for Figure 5 and the data are expressed in daily average.

Figure 7 shows, for instance, that during storm water conditions the Tielt works (in bold) had a biological effluent load of 2.2 g NH_4-N/PE/d for 90% of measurements in

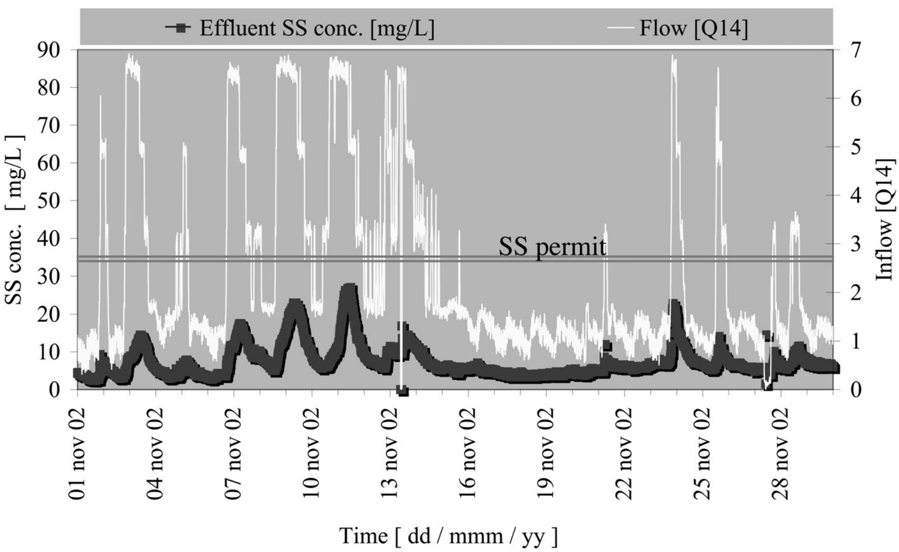

Figure 6 Inflow, expressed as Q_{14}, and measured effluent SS, in mg/L, at the Tielt works: Nov 2002

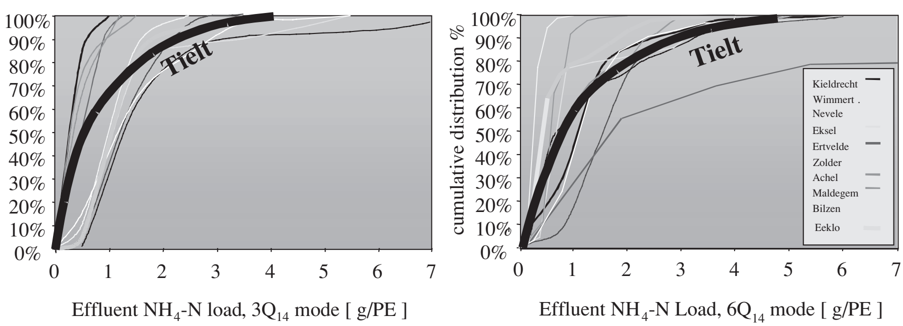

Figure 7 Relative cumulative distribution of the effluent NH_4-N load, expressed in grams per population equivalent, out of the biological train during periods of $Q_{INF} > 3Q_{14}$ for $3Q_{14}$- (left) vs $6Q_{14}$ mode of operation (right)

conventional operation, and of 3.0 g NH_4-N/PE/d with the high-flow activated sludge process.

The main contribution to the reduction in nitrification performance is attributed to the higher sensitivity of the high-flow activated sludge operation to first flush phenomena (data not shown). In Flanders, those phenomena are intense and can lead to insufficient aeration capacity. From the interpretation of our data, the reduction in hydraulic retention time in the biological system seems to play a less relevant role. This is probably because of the already relatively high retention time provided by extended aeration systems.

Impact on phosphorus removal

Three treatment works using enhanced biological phosphorus removal (EBPR) are operated for over three years with the high-flow activated sludge operation. 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 phosphorus removal performance decreases leading to an increase of the discharged mass load from the biological treatment. Such a trend is observed under both conventional and high-flow mode.

On the other hand, the results show that the high-flow mode leads to an accelerated deterioration of the phosphorus removal efficiency (again, the comparison does not take into account the discontinuous discharge of the storm tanks, but only the biological treatment).

Results of the frequency distribution of the effluent phosphorus load (daily average) at Tielt treatment works during periods of $Q > 3Q_{14}$ are illustrated in Figure 8. The treatment works of Tielt (Figure 2) is the first EBPR installation to start operating permanently in high-flow activated sludge mode.

Figure 8 shows a reduction of the process performance during storm water conditions. It is worth noting that during dry weather flow the effluent phosphorus load of the works is generally below 0.5 g TP/PE. This is most likely due to three factors:

- A reduction of the retention time in the anaerobic basin. In Tielt treatment works, for instance, during storm water events (6 Q_{14}) the hydraulic retention decreases to only 30 minutes, while the dry weather flow peak is over 3 hours.
- After prolonged wet weather water conditions, highly dilute wastewater can enter the anaerobic tank at relatively high oxygen concentrations (more than 1 mg O_2/L). The

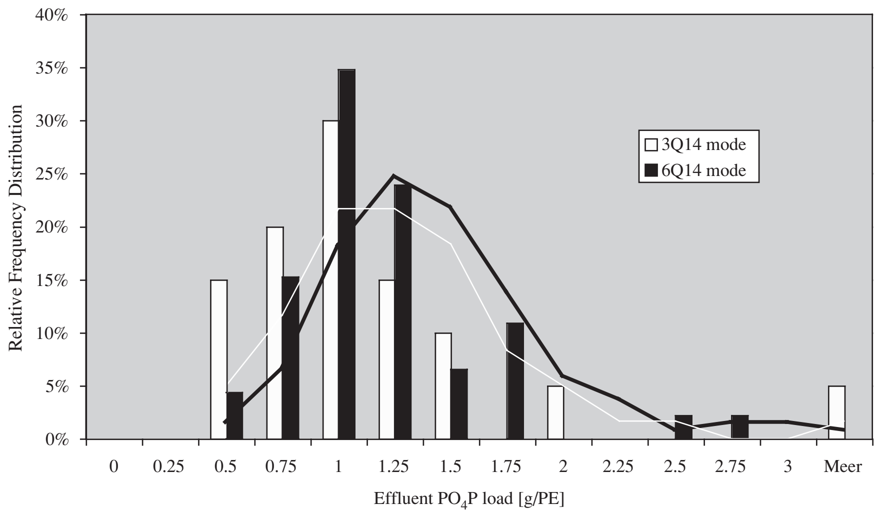

Figure 8 Frequency distribution of the effluent phosphorus results (daily average) during periods of $Q > 3Q_{14}$ at Tielt treatment works

effective anaerobic time is therefore reduced. With high-flow operation the effect of oxygen immission in the anaerobic tank is higher.

- An increase of the effluent SS load. In the EBPR works, a content in phosphorus of 4% DS or higher is generally attained. With a flow that is some cases is double of that in the conventional storm operation (i.e. $6Q_{14}$ instead of $3Q_{14}$) and with similar SS effluent concentration (e.g. 5 g SS/m^3), the effluent phosphorus load, as it is expressed in Figure 8, can increase substantially.

Conclusions

An innovative storm operation has been extensively tested. The operation consists of allowing a two-fold increase of the wet weather flow treatment in the biological train of the treatment works by using the storm tanks as additional clarifiers.

Because of the positive environmental results, from 1999 to 2002 56 works were switched to high-flow operation mode. All comply with the effluent standards, which refer to the EU norms for sensitive areas.

The adoption of the high-flow biological treatment indicates that a substantial overall beneficial impact in attenuating the storm pollution to the receiving water body can be obtained. Taking away the pollution discharge of the stormtanks by using the high-flow activated sludge operation leads to a slight reduction of the biological performance and brings about a significant net overall reduction of the total pollutant discharge to the environment.

The concepts introduced by the EU Water Framework directive will aid the adoption of high-flow activated sludge process operation, as the consents are likely to be set on the total pollution discharge rather than on the biological train only.

In all those areas where the frequency and magnitude of the storm tank overflow can be high (as in Flanders), high-flow secondary treatment seems a pertinent alternative to the conventional strategy of treating part of the storm water in the storm tanks.

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