Integrated control of sewer system and WWTP with SmaRTControl

Gestion intégrée du réseau d'assainissement et de la station d'épuration avec SmarRTControl

Kees de Korte

Waternet, PO Box 94370, 1090 GJ Amsterdam, The Netherlands,
e-mail kees.de.korte@waternet.nl

RÉSUMÉ

Les Pays-Bas disposent d'un grand nombre de réseaux d'assainissement étendus et ramifiés. La gestion en temps réel - GTR - peut améliorer la performance de ces réseaux. L'objectif de SmaRTControl est d'améliorer la performance du réseau d'assainissement et de la station d'épuration en réduisant les rejets des déversoirs d'orage. Cet article argumente les possibilités d'amélioration des performances des stations d'épuration par le système SmaRTControl. La question principale reste la prévention du pic de charge d'ammonium par la réduction contrôlée du débit maximal envoyé à la station d'épuration pendant les périodes pluvieuses. L'effet des conduites sous pression est un facteur important. On en conclue que leur influence n'est pas négligeable vis-à-vis du pic de charge en ammonium. Il est en effet possible de minimiser efficacement ces pics avec le SmaRTControl en réduisant les débits maximaux sans pour autant créer d'effets négatifs sur les déversoirs d'orage.

ABSTRACT

In the Netherlands many large branched sewer systems exist. RTC can improve the performance of these systems. The objective of SmaRTControl is to improve the performance of the sewer system by reduction of combined sewer overflow (CSO) and the WWTP. This paper discusses the opportunities for improving the performance of the WWTP by SmaRTControl. The main issue is the prevention of ammonium peak loads by controlled reduction of the maximum flow to the WWTP under rain weather flow conditions. The effect of pressure pipes is an important factor. It is concluded that pressure pipes have a large influence on the ammonium peak loads. Ammonium peak loads to WWTP's can be effectively reduced by SmaRTControl by reduction of the maximum flow without adverse effect on CSO's.

KEYWORDS

Ammonium, integrated control, RTC, sewer system, simulation, stormwater, wastewater, WWTP

1 INTRODUCTION DUTCH SEWER SYSTEMS

In the first part of the last century, mainly combined sewer systems were used in the Netherlands. Separated systems were introduced later, nowadays this is the usual type in new town expansions. Sometimes the improved separated system is used, this is a separated system where a small part of the stormwater is pumped to the wastewater treatment plant (WWTP) with a small capacity. The Dutch ‘basic design’ characteristics for drainage districts are summarised in Table 1.

system	storage capacity mm rainfall	pumping capacity to treatment plant mm rainfall / h
combined	7 + 2 *	0.7
separated	0	0
improved separated	4	0.3

* 7 mm in sewer + 2 mm in storage basin with sedimentation function

Table 1. Dutch basic sewer system design characteristics

Especially in the western part of the Netherlands, the groundwater level is about 0.5 – 1.5 m below the surface. This means that big and deep sewers are quite expensive. For that reason the drainage districts are typically small and connected in series by intermediate pumping stations, resulting in a large branched system. In Amsterdam the total number of wastewater pumping stations exceeds 450. Typically, a limited number of drainage districts is connected to the WWTP by a pressure pipe(system). The total capacity of the pumping stations directly pumping to the WWTP equals the capacity of the WWTP.

2 OBJECTIVES SEWER SYSTEM CONTROL

The objectives of Waternet, the water cycle company for Amsterdam and surrounding areas, for the control of sewer systems are partly strategic and partly operational. The strategic objective is: use your assets. This means that all stormwater storage capacity, previously constructed at high costs, should be fully used before a combined sewer overflow (CSO) occurs. The operational objective is: everything under control. This means that the total system is performing as designed and that flexibility is present to enable to control the performance in detail. The objectives result in different control modes for rain weather flow (RWF) conditions and dry weather flow (DWF) conditions. For RWF conditions the objective is CSO reduction (use the available storage capacity before a CSO occurs) and to avoiding unnecessary high flows and peak loads to the WWTP. For DWF conditions the possibility of storage of wastewater in the sewer system can be used to improve the performance of the wastewater treatment by equalizing the diurnal flow pattern. These objectives fit within the scope of objectives as presented in the current state of the art of RTC (Schütze et al. 2004).

3 CONTROL SYSTEM

The RTC system SmaRTControl is the result of a cooperation of Waternet and Humiq. SmaRTControl is based on a generic algorithm. This means that the software of the controller itself contains no characteristics of the drainage districts and pumping stations (e.g. in decision rules) and can easily be used for simulation and real time application for different sewer systems, see Figure 1. The generic algorithm is a two stage constrained optimization procedure. The first stage is without and the second stage with taking the specific pumping capacities of each pumping station into account.The characteristics of the sewer system and pumping stations are supplied to the control system as configuration input files. The inputs to the controller are the storage capacities in use (in real time derived from measured levels) and the outputs are setpoints for flow of the pumping stations, both at 15 minute intervals.

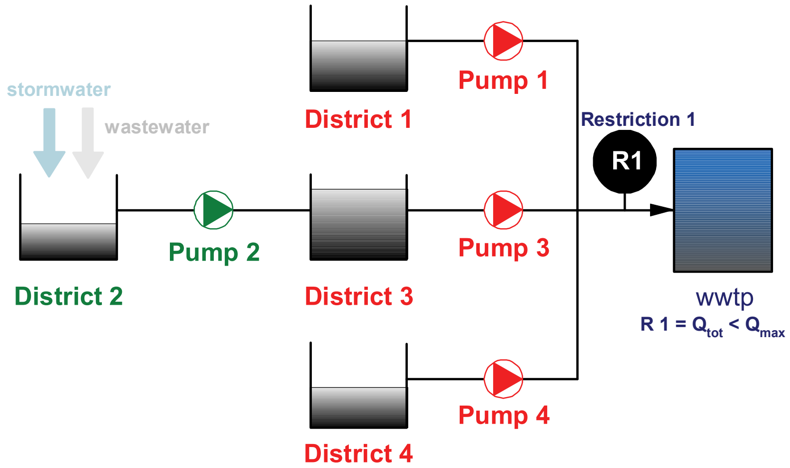

Figure 1. Hydrological model

For RWF conditions and only CSO prevention, mainly feed back control is used; no meteorological data are used for forecasting the rainfall in the drainage districts in future. In fact the drainage districts itself are used as rain gauges by measuring the level and calculating the used storage capacity. The strategy of the control system is enabling maximum flow to the WWTP (restricted by the capacity of the WWTP) and equal filling of the storage in the drainage districts. For flexibility and fine tuning options exist for:

1. priority for individual drainage districts; each individual drainage districs can get a higher or lower priority in comparison to the average district. With a higer priority the use of storage capacity will be lower. This enables a fine tuned long term distribution of the quantities of CSO over the districts, e.g. related to surface water quality or pollution load;
2. control of improved separated systems as a group; the control stops pumping of stormwater from these systems to the WWTP when the average use of storage capacity in the combined systems exceeds a specified value. This results in a better performance of the combined systems ;
3. local control of individual drainage districts; in the simulation environment local control of (a number of) pumping stations of individual drainage districts can be introduced to assess the effect on the performance of the entire system ;
4. SmaRTControl can deal with a time-varying maximum flow to the treatment plant Qmax e.g. when only moderate rain is forecasted and/or for different activated sludge settling properties. Hydraulic peak flows usually result in a decreased treatment performance. For control of Qmax, rain forecasts are required.

The effect of SmaRTControl on large branched sewer systems under both RWF and DWF conditions in a simulation environment is described by de Korte et al. (2009). For a system of 19 drainage districts (Figure 2) it was concluded that the performance of large branched sewer systems for RWF conditions can be improved using SmaRTControl in combination with an increased pumping capacity in the drainage districts without increasing the existing maximum flow to the WWTP.

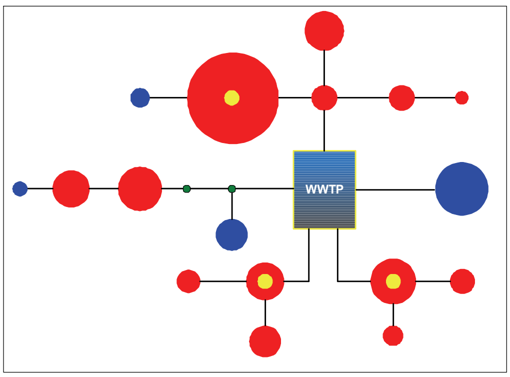

Figure 2. Structure of sewer system with 19 drainage districts

4 OPPORTUNITIES FOR IMPROVING THE PERFORMANCE OF THE WWTP

Control of the time-varying maximum flow to the treatment plant Qmax of SmaRTControl offers great opportunities for improving the performance of the entire system of sewers and WWTP.

Under DWF conditions the diurnal flow pattern to the WWTP can be improved considerably by controlled storage in the sewer system (Figure 3, de Korte et al., 2009). In this case Qmax is limited to approximately the average daily flow. Selected drainage districts are used for storage of wastewater. Small flow variations are necessary to compensate for extra or less wastewater flow to the system compared to the long term average flow pattern.

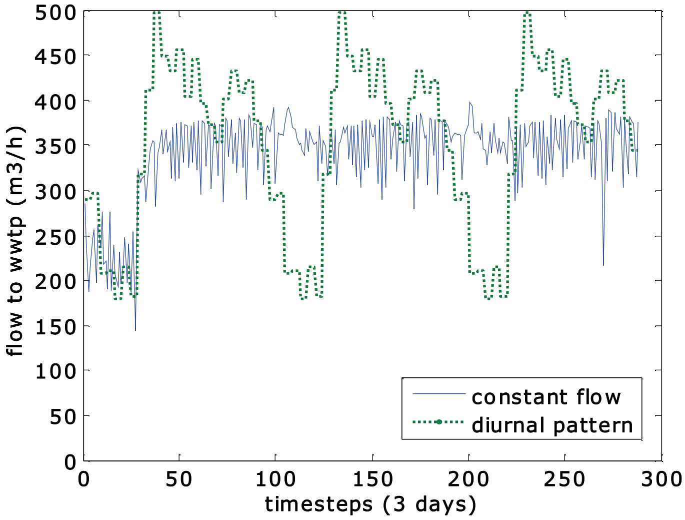

Figure 3. Diurnal pattern and constant flow to the WWTP

Qmax (the time-varying maximum flow to the WWTP) can be adjusted manually by the operator or automatically by SmaRTControl.

4.1 Manual adjustment of Qmax for maintenance reasons

The manual adjustment of Qmax can be useful for maintenance reasons. When treatment units are out of operation the hydraulic capacity of the WWTP is decreased. Without SmaRTControl, the capacity of the flow to the WWTP is usually decreased by reducing the capacity of one or more final pumping stations, simply by switching off individual pumps. This can very well cause unbalance in the system because all other upstream (and eventually not reduced final) pumping stations will operate at the original capacity. With SmaRTControl, Qmax is reduced and the control system operates in the usual way. In fact, the reduced Qmax is implemented automatically for all (final and upstream) pumping stations within the strategy for CSO prevention.

4.2 Manual adjustment of Qmax for process reasons

The manual adjustment of Qmax can also be made for proces reasons. An unusally high SVI (Sludge Volume Index, indicating the settleability of the activated sludge and thus the performance of the secondary settling tanks) can be responsible for discharging large quantities of activated sluge into the receiving water. The effect can be much more serious than a CSO. In this case the whole system performs better in terms of effect on the receiving water quality when Qmax is reduced to the maximum capacity of the secondary settling tanks (preventing sludge discharge) while accepting extra CSO's. Of course the location of effluent discharge and CSO's has to be taken into account. On the other hand, an unusually low SVI allows for pushing Qmax to the hydraulic limit of the WWTP, which is usually significant higher than the design Qmax. This can reduce CSO's without further consequences for the WWTP.

4.3 Automatic adjustment of Qmax for peak load prevention and reduction

An automatic adjustment of Qmax by SmaRTControl is possible to prevent or reduce peak loads to the WWTP. The ciritical component is ammonium, which can not be temporarily stored by the micro organisms of the activated sludge. An ammonium overload will consequently lead to ammonium peaks in the effluent. Sometimes phosphorous can be critical as well. Especially in treatment systems with biological phosphorus removal, influent hydraulic and phosphorus peak loads can cause phosphorus peaks in the effluent. This paper will focus on ammonium.

Figure 4 shows ammonium peaks in the effluent as a result of previous rain events for the WWTP West in Amsterdam (22-28 May and 4-7 Sept 2009).

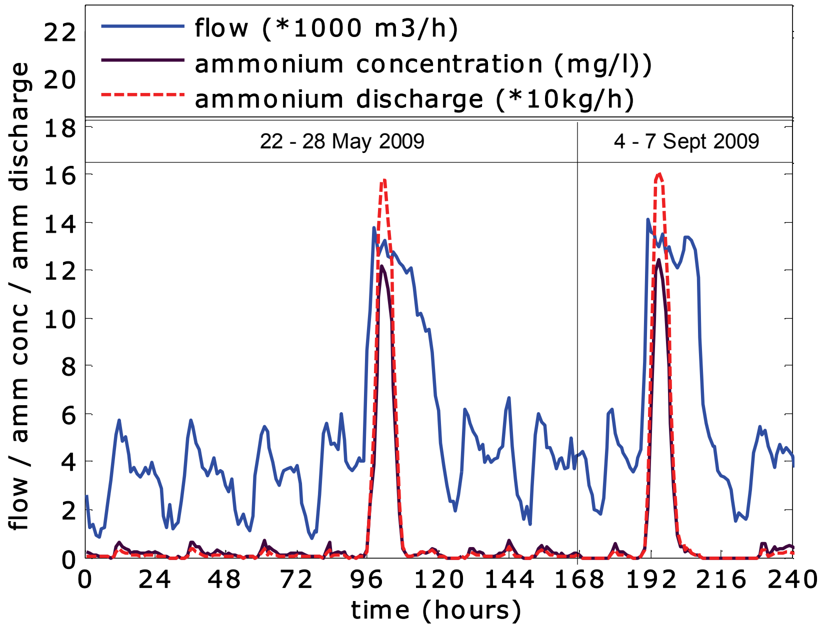

Figure 4. Ammonium peaks in effluent of WWTP West in Amsterdam

During DWF periods, the flow shows the usual diurnal pattern. During the rain events in May and September the flow suddenly increases and stays at a high level for about one day. Shortly after the beginning of the rain events, the concentration and discharge of ammonium in the effluent show a marked peak. Obviously, the WWTP is not capable of handling the ammonia load. Both in May and in September, the ammonium concentration and ammonium discharge decrease long before the flow decreases: high flow rates are not the only reason for ammonium peaks.

The presence of pressure pipes between the drainage districts and the WWTP are identified as an important factor for peak loads before (Langeveld, 2004).

To assess what can be expected theoretically, simulations were made of a sewer system with a pressure pipe connecting to the WWTP. The simulations were based on:

1. a wastewater flow with a diurnal variation ;
2. a constant ammonium concentration of the wastewater of 60 mg/l ;
3. water flows modeled in 19 drainage districts (Figure 2);
4. ammonium modeled in one drainage district (the total of the 19), considered to be completely mixed for wastewater and stormwater;
5. a pressure pipe with plug flow characteristics connecting the drainage district to the WWTP with a hydraulic retention time (HRT) of 0 (no pressure pipe), 1 and 2 hours at Qmax. For reference: WWTP Amsterdam West is connected by pressure pipes with a total content of 2 h at Qmax ;
6. three different rain events: Rain 1 is a block rain for demonstration, Rain 2 is a real heavy rain event, Rain 3 is a light rain event with the same pattern as Rain 2 (Figure 5). Rain 1 and 2

both result in a CSO, Rain 3 shows a maximum use of storage capacity of 20% for the combined systems.

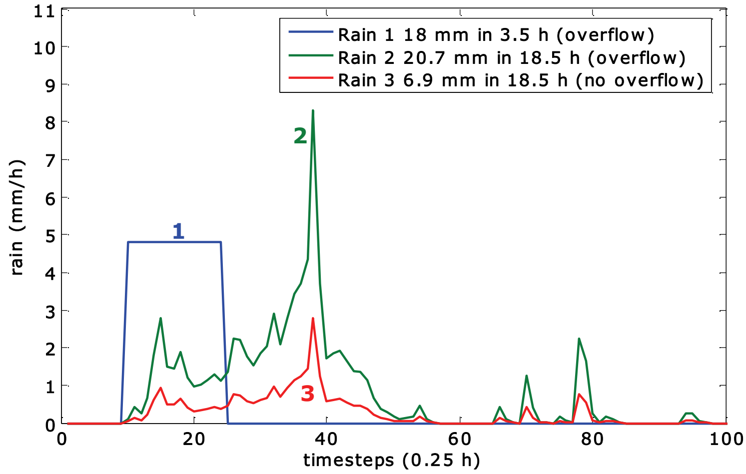

Figure 5 Rain events

The first simulation results are the ammonium concentrations and peak loads for Rain 1 at the inlet of the WWTP for 3 cases: no pressure pipe (HRT = 0), a pressure pipe with HRT = 1 h and a pressure pipe with HRT = 2 h (Figure 6).

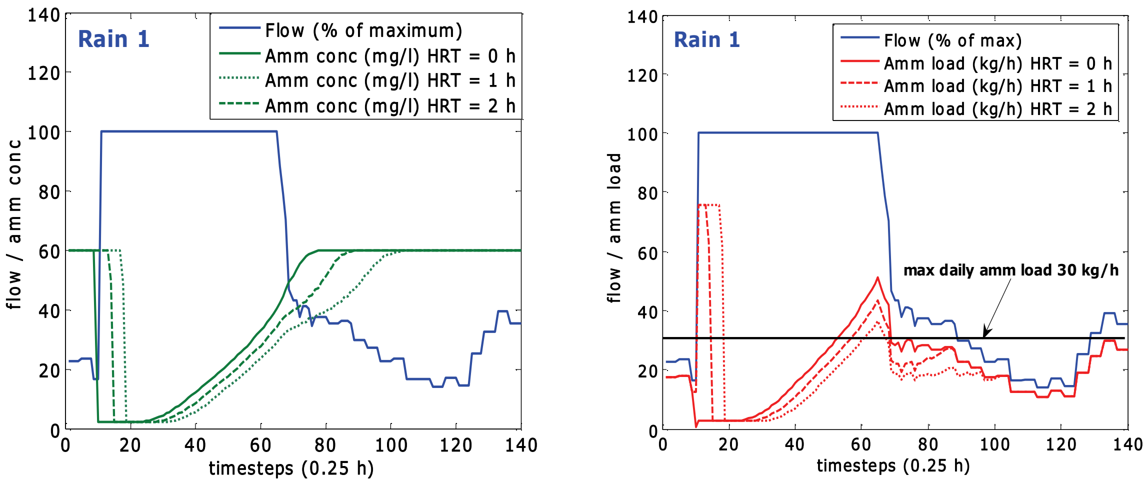

Figure 6 Simulated concentrations (left) and peak loads (right) of ammonium to the WWTP

Figure 6 (left) shows that the ammonium concentrations drop suddenly to low values when the rain event starts. This is caused by the dilution by stormwater in an empty sewer system and by storage of ammonium in the sewer. As soon as the rain stops, the sewer system is emptied and the ammonium concentrations slowly increase to the original value of 60 mg/l. The presence of pressure pipes causes a delay in both the initial decrease and the final increase of the ammonium concentration. The effect is stronger for the pressure pipes with a larger HRT as can be expected with these starting points.

Figure 6 (right) presents the resulting ammonium loads to the WWTP. Without pressure pipe, the ammonium load initially decreases strongly as a result of dilution and storage in the drainage district. With pressure pipe however, the concentrations remain at the original value as long as the diluted wastewater does not arrive at the WWTP. Combined with the increased flow rate, the ammonium load shows a strong peak, the length of which is proportional to the HRT of the pressure pipe. The initial peak is approximately 2,5 times the maximum daily load of 30 kg/h under DWF conditions.

Remarkable is the final peak, long after the rain stopped. This peak is caused by the increasing ammonium concentration combined with emptying the drainage districts at full capacity. This peak is not as high as the initial peak, but high enough to present opportunities for improvement. The final peak load is smoothed by the presence of a pressure pipe, because by the time the high ammonium concentrations arrive at the WWTP, the flow already decreases to about DWF. After the initial peak a period with low ammonium loads exists, however the flow rate is at maximum.

Compared to the response of the ammonium concentration in the effluent as presented in Figure 4, the effect of the first peak and the next period with the low ammonium load are clearly visible. There is no trace of the final ammonium peak. Because the final peak is small for a pressure pipe with HRT = 2 h, this is as expected.

In SmaRTControl a strategy is developed for peak shaving of both the initial and final ammonium peaks. This strategy determines the required flow (restricted Qmax) to obtain a specified ammonium load within the restrictive conditions:

- no effect on CSO's;
- no use of storage capacity of the drainage districts above a certain level.

and requires:

- ammonium concentration measurement at the WWTP;
- rain forecasts some days ahead.

The effect of the ammonium peak shaving depends on the intensity and pattern of the rain events. Figure 7 shows the results of the peak shaving for the heavy Rain 2 and the moderate Rain 3 (pressure pipe with HRT = 1 h).

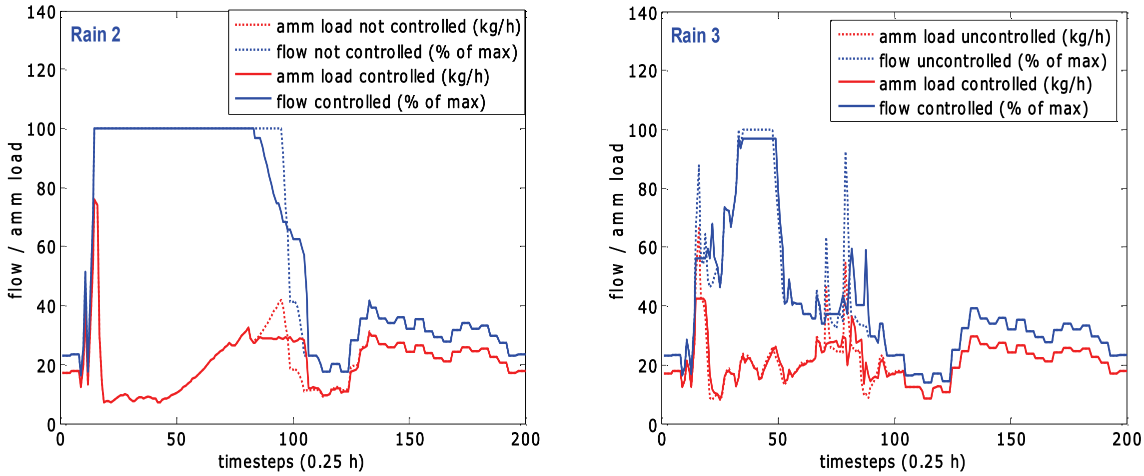

Figure 7 Simulated loads for heavy (left) and moderate rain (right) of ammonium to the WWTP

Analysing the graphs, it can be concluded that during heavy rainfall (left graph) the initial peak will not be shaved as a consequence of the restrictive conditions, but that the final peak close to emptying the sewer system is reduced very well by reducing Qmax. During moderate rainfall the first increase in flow can be reduced within the restrictive conditions, but not enough to shave the peak completely. During the rest of this rain event, the flow is reduced several times, again with clear peak shaving as a result.

It can be concluded that peak shaving is possible, but that the effects depend on the rain intensity and pattern. To asses the expected benefits, a long rain series (the whole year 1963) is simulated. Figure 8 shows the percentile values of the ammonium load to the WWTP during rain events for different HRT of the pressure pipes, both controlled and uncontrolled (with and without reduced Qmax).

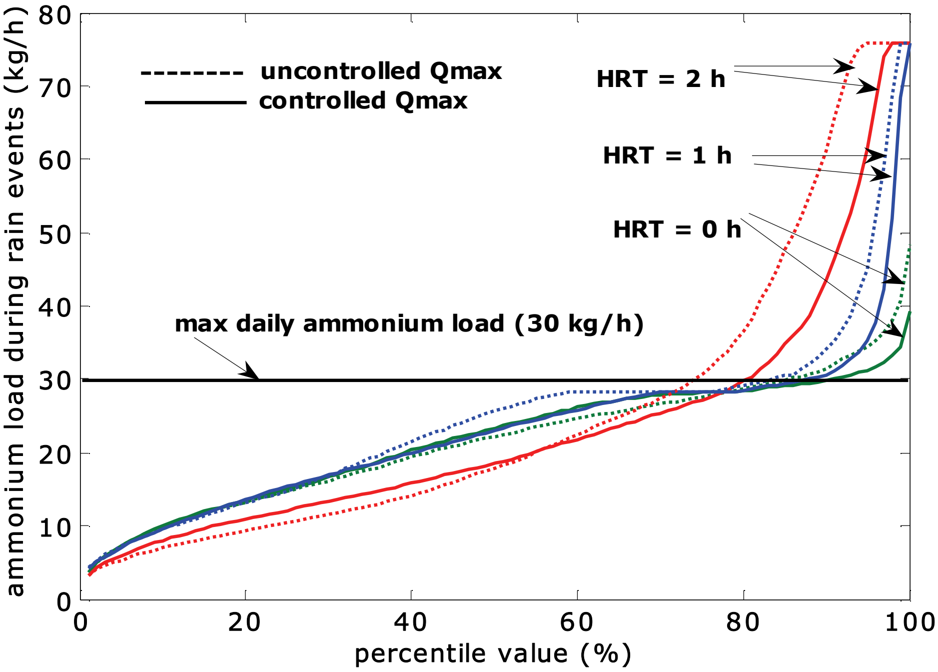

Figure 8 Percentile values of the ammonium load to the WWTP during rain events for different HRT of the pressure pipes.

This figure shows that:

- the presence of pressure pipes have a negative influence on ammonium peak loads; peak loads are higher and more frequent;
- peak shaving offers benefits, especially the frequency of peak loads is reduced considerably.

5 DISCUSSION

All the results presented so far are based on simulations. The reason for that was to get a clear view on the consequences for the ammonium load at the WWTP. In practice the completely mixed character of the sewer system will not be the same as in the model. The same is true for the plugflow character of the pressure pipe; it is usual that more drainage districts discharge to the pressure pipe, but at different distances from the WWTP, which introduces some degree of mixing.

Another important aspect is that the reduction of Qmax relies on rain forecasts for some days ahead. These rain forecasts are translated into future use of storage capacity based on:

1. the present maximum use of storage capacity in the combined drainage districts;
2. the calculation of the decrease of the use of storage capacity by pumping;
3. the increase of the use of storage capacity as a result of forecasted rainfall.

A certain risk exists that inaccurate rain forecasts result in extra CSO's; this risk can be reduced by specifying a low maximum use of storage capacity of the drainage districts. In the simulations a maximum of 40% was specified. This means that, regardless of the rain forecasts, no flow reduction will take place if one of the combined systems uses (or is expected to use) over 40% of the storage capacity.

Finally, the effects of controlling Qmax for ammonium peak shaving should not be overestimated. Figure 8 shows the results during rain events. RWF conditions constitute approximately 13 % of the time. The rest of the time is under DWF conditions with diurnal variations only. Nevertheless, peak shaving of ammonium loads is an interesting opportunity to increase the performance of a WWTP.

6 IMPLEMENTATION IN AMSTERDAM

Waternet and Humiq will continue their cooperation in implementing a prototype of SmaRTControl in Amsterdam Noord. The sewer system of Amsterdam Noord has 97 drainage districts serving 88.000 inhabitants. 27 drainage districts are influenced by rain and are modelled. Finally 14 districts will be included in the prototype for central control, the remaining 13 small districts will continue to operate under local control, but may be included later when necessary. SmaRTControl will be commissioned in 2010.

7 CONCLUSIONS

Based on the results of the simulations the following conclusions can be made:

1. ammonium peak loads to WWTP's can decrease the performance of the WWTP due to overloading ;
2. the presence of connecting pressure pipes has a large influence on the WWTP's ammonium peak loads ;
3. the ammonium peak loads to WWTP's can be effectively reduced by SmaRTControl by reduction of the maximum flow to the WWTP under RWF conditions ;
4. ammonium peak shaving has no adverse effect on CSO's as long as the relevant restrictive conditions are met.

8 ACKNOWLEDGEMENTS

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