Effect of on/off pumping strategy on sewer sediment behaviour elucidated by high frequency monitoring at the treatment plant inlet

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Abstract
Recent developments in on-line sensor technology supplying high temporal resolution data and advanced data quality control (DQC) tools ease the task of understanding in-sewer processes, allowing for better integrated management of sewer systems and wastewater treatment plants (WWTP). The present study illustrates how data with high temporal resolution and advanced DQC tools can be used to: (i) detect unexpected shock loads during dry weather due to an on/off pumping strategy, (ii) understand the processes in upstream sewer systems under wet weather, and (iii) take the necessary actions to reduce the shock loads at the WWTP. The results for a selected week show that the on/off pumping strategy creates unnecessary peaks with 50-200% increased flows. This affects the water quality arriving at the WWTP, particularly with respect to the total suspended solids concentrations, which increased by 150-200%, making up a TSS-load increase by up to 400%. The dissolved concentrations increased only by 10-20%. The data from on-line sensors, upgraded by DQC procedures, are currently forming an information-dense basis for calibration of a sewer water quality model, which will be used to better understand the processes taking place upstream the plant and to reduce their impact on the performance of the WWTP.

Keywords data quality assurance; dry weather; on-line sensors; operations; sewer processes; wastewater composition; wet weather

INTRODUCTION

Integrated management of sewer systems and wastewater treatment plants (WWTP) has a great potential in terms of overflow reduction, protection of receiving waters, and optimized control of sewer and WWTP operations. However, this potential depends on data availability to understand the on-going processes and to react accordingly. For example, sedimentation, erosion and transportation of sediments in the sewer network can significantly affect the performance of WWTPs and the quality of the overflows from combined sewer systems.

Several studies have investigated these processes in laboratory and full-scale (e.g. Arthur and Ashley 1998, Carbone et al. 2012, Chebbo et al. 2001, Kim et al. 2010, Schlütter and Schaarup-Jensen 1998, Skipworth et al. 1999) and several models exist to predict these in-sewer processes (e.g. Ashley et al. 1999, Banasaik et al. 2003, Gamertih et al. 2009, Mannina and Viviani 2010, Mannina et al. 2012, Tait et al. 2003). Willems (2008) however tried to identify the most important uncertainty sources in sewer quality modelling and concluded that uncertainty from the water quality submodels is an order of magnitude higher than that for flow submodels. One of the main reasons for this uncertainty is lack of sufficient water quality data (e.g. Mannina et al. 2006, Willems 2008), and another reason is knowledge gaps on the very complex in-sewer processes (e.g. Willems 2008).

While data collection and monitoring of water quality in sewer systems has been challenging in the past due to the practical difficulties in sampling and expensive lab analysis, recent developments in on-line sensor technology have eased this task (Gruber et al. 2005). In contrast to sampling with subsequent lab analysis, the on-line sensors further allow collecting large amounts of high-frequency data and provide these values immediately. Hence, they can be used in real time control (RTC). In recent years various research groups have installed on-line sensors in sewer systems to study in-sewer processes (e.g. Gamerith et al. 2009, Metadier & Bertrand-Krajewski 2012). However, on-line sensors can be affected by the harsh conditions in the sewer and WWTPs, resulting in poor-quality observations. Therefore, good statistical tools for data quality control (DQC) are necessary to properly use the results from on-line sensors (Alferes et al. 2013). The combination of on-line sensors and DQC tools gives new dimensions on process understanding both during dry and wet weather situations.

The present study illustrates how data with high temporal resolution and advanced DQC tools can be used to: (i) detect unexpected shock loads at the inlet to a WWTP during dry weather due to an on/off pumping strategy, (ii) understand the processes in upstream sewer systems under wet weather, and (iii) take the necessary actions to reduce shock loads to the WWTP.

MATERIALS AND METHODS

System description

This study was performed in the catchment area of the Lynette WWTP, Denmark, which has a design capacity of 750,000 PE and treats 66 million m^3 combined wastewater per year. The contributing catchment is divided into three major subcatchments: Tuborg Nord (2546 ha), Strandvænget (2257 ha) and Kløvermarksvej (5093 ha). These subcatchments are connected to the WWTP by pumping stations. Water is pumped to the WWTP using 3 sewer pipes (see Figure 1), North, South 1 and South 2. The control strategy at subcatchments Tuborg Nord and Strandvænget is to pump as little as possible and activation of the pumps is controlled by level gauges, resulting in an on-off pumping strategy for the North pipe. The control strategy at Kløvermarksvej is to avoid flooding, and the pumps of South 1 and South 2 are therefore frequency controlled.

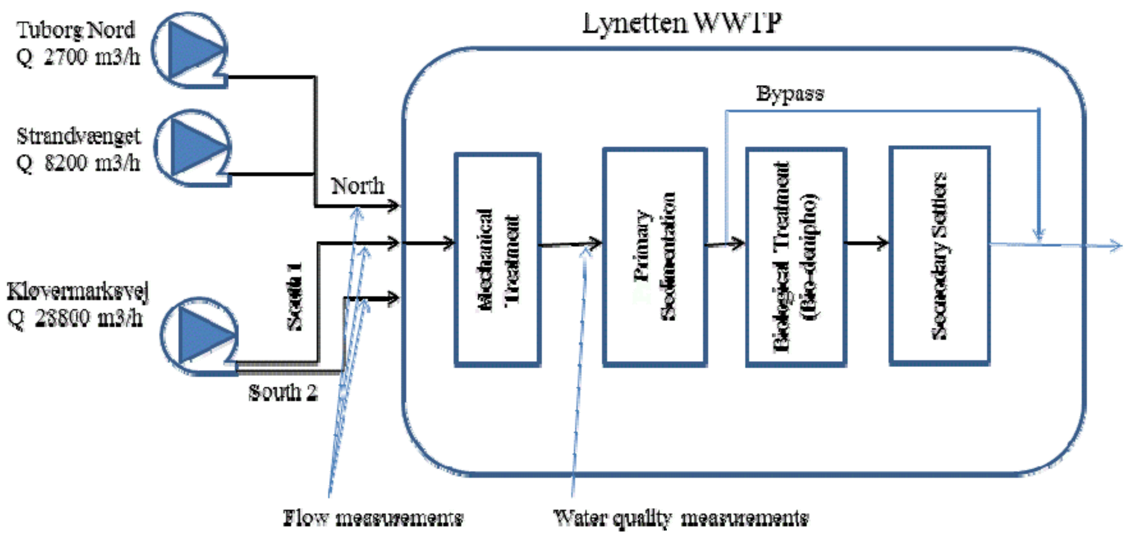

Figure 1. Schematic overview of pumping stations, sewer pipes, and location of the flow and water quality measurements studied in this paper.

Flow, water quality measurements and data quality control

From each sewer pipe (North, South 1 and South 2) flow was measured using flow meters and stored with 120 seconds resolution. Water quality measurements were carried out at the inlet to the primary clarifier using Primodal Systems Inc.'s RSM30 monitoring stations (Rieger and Vanrolleghem 2008), which consists of on-line sensors, a data collection and analysis system and a data transmission system.

Table 1. Water quality parameters, on-line sensors and temporal resolution of the data.

Parameter	On-line sensor	Temporal resolution (s)
pH	pHD-S sc pH (Hach-Lange)	5
Turbidity and TSS	Solitax (Hach-Lange);	5
	Spectrolyser (S::CAN)	60
COD (total and dissolved)	Spectrolyser (S::CAN)	60
Ammonia	Anise (Hach-Lange)	5
Chloride	Anise (Hach-Lange)	5
Potassium	Anise (Hach-Lange)	5
Temperature	pHD-S sc pH (Hach-Lange);	5
	Anise (Hach-Lange);	5
	Spectrolyser (S::CAN)	60
Conductivity	3700sc (Hach-Lange)	5

Monitoring started on 19/12/2012 and has been going on till 21/5/2013. Table 1 shows the monitored water quality parameters, on-line sensors, and temporal resolution of the data. This paper focuses on the period from 15/2-2013 – 22/2-2013, since both dry weather patterns, the effect of different weekdays and a wet weather period is included. To study the effect of these factors on inlet water quality at the WWTP, total suspended solids (TSS), dissolved chemical oxygen demand (COD) and ammonia (NH_4-N) are selected, since particulate concentrations are well represented by TSS and COD and NH_4-N are two of the most important dissolved wastewater quality parameters.

For proper data analysis and to extract useful information the collected data was validated using advanced DQC procedures. The applied method encompasses two consecutive steps: outlier detection and filtering. Outliers are detected by comparing measured values with calculated forecast values using autoregressive models. The detected outliers are replaced with their forecast value and a proper *accepted data* series is generated. To reduce the corruption of the signal noise, in the second step the *accepted data* is smoothed by using a kernel smoother. Details of this procedure can be found in Alferes at al. (2013).

RESULTS AND DISCUSSION

Advanced DQC to improve the data quality

Figure 2 shows the application of the advanced DQC routines to improve the data quality and thereby improve the basis for interpretation of the on-line data. The dark blue curve illustrates the smoothed signal created from applying DQC to the original signal (light blue).

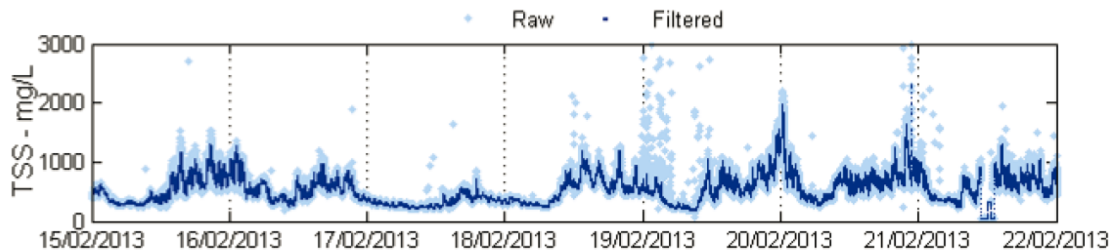

Figure 2. TSS time series treated with advanced DQC to improve data quality.

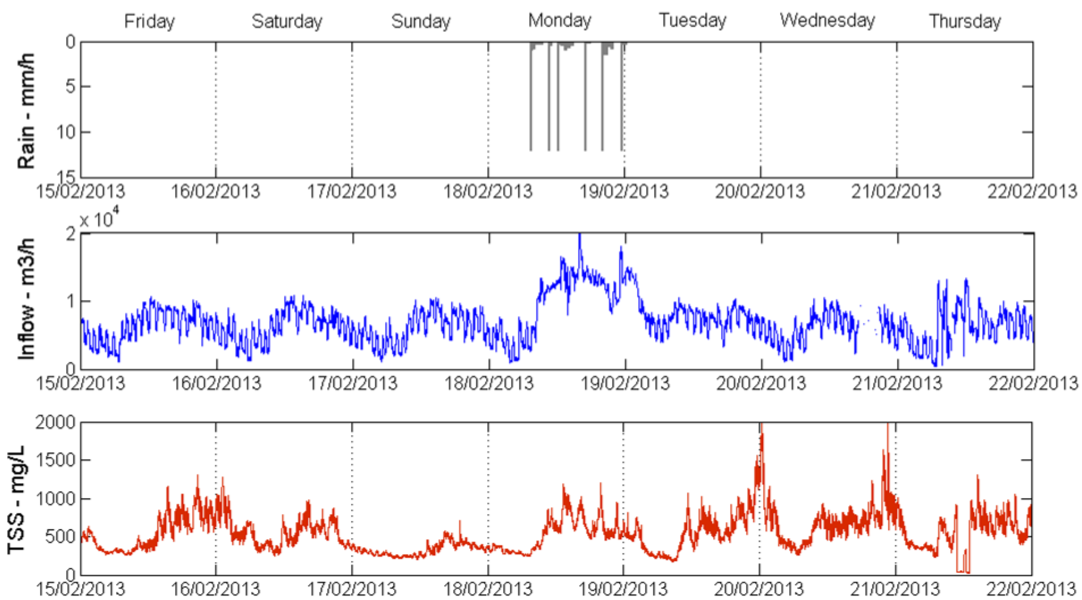

Figure 3. Rain, inlet flow, and TSS variations during the selected week.

Understanding variations in the water quality parameters

Figure 3 shows the variation in measured rainfall, inlet flow, and TSS during the selected period representing dry weather (15/2-17/2 and 19/2-22/2), wet weather (18/2-19/2) and the effect of weekdays (Friday – Thursday). The flow pattern is typical of a sewer system with an on/off pumping operation. While the overall observed TSS-pattern is typical for WWTP inlets, the high frequency data from the TSS on-line sensors show frequent sub-hourly concentration peaks during dry or wet weather corresponding to the flow peaks from the on/off pumping operation. Sudden flow increases by 50 – 200% occur within a short time and corresponding peaks in the TSS concentration can be deduced.

Total suspended solids and dissolved concentrations during dry weather

Figure 4 shows diurnal flow variations in the three sewer pipes to the Lynetten WWTP and the effect of these variations on TSS and dissolved concentrations during a selected dry weather period (15th February 0:00 – 16th February 12:00, i.e. Friday - Saturday). Due to the on-off pumping operation 32 distinct flow peaks are seen in the North sewer pipe, resulting in increases in total flow by 50-200% when the North pump is switched on. Comparing the flow peaks with TSS peaks, the TSS peaks only appear from 13:00-03:00, i.e. the TSS concentration increased by 150-200% shortly after the flow increase, making up a TSS-load increase by up to 400%. This behaviour is also seen during weekdays (see Figure 5) and compared to week-ends the distinct TSS peaks occur a couple of hours earlier during weekdays (figure 4 and 5) This correspondence supports the hypothesis that the TSS-peaks during 13:00-03:00 are caused by the on/off pumping operation of the North pumping stations, where TSS settles when the pump is switched off and resuspension happens when the pump starts again. The absence of TSS peaks during 02:00-13:00 is probably due to the absence of sources contributing to high TSS. To support this hypothesis, it would be interesting to measure the water quality parameters individually for each sewer line at the point of flow measurements and this work will be carried out in the future.

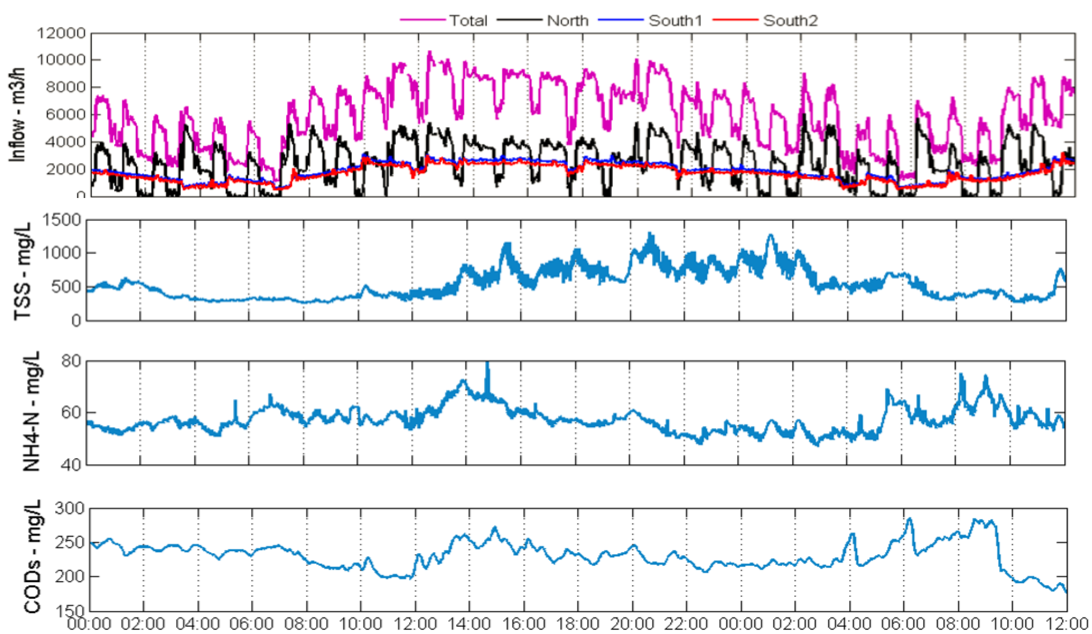

Figure 4. Diurnal variations in flow and water quality at the inlet of the Lynetten WWTP during dry weather (15/2 00:00 – 16/2 12:00).

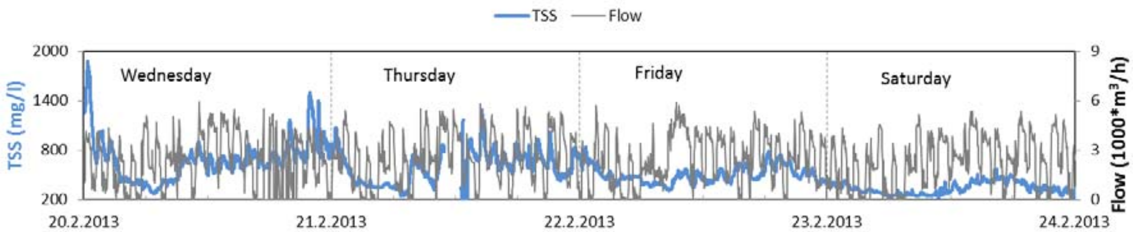

Figure 5. Diurnal variation in TSS concentrations and flow for different weekdays.

Peaks for dissolved concentrations are also seen. However, these peaks are only 10-20% increases and usually occur when the flow from the North pumping station is off.

Depending on the available treatment capacity at the WWTP, it is expected that sudden load shocks as shown here will be propagated across the entire WWTP, affecting the treatment efficiency. To investigate whether this is the case at Lynetten further monitoring of water quality is required at various unit processes of the WWTP.

Total suspended solids and dissolved concentrations during wet weather

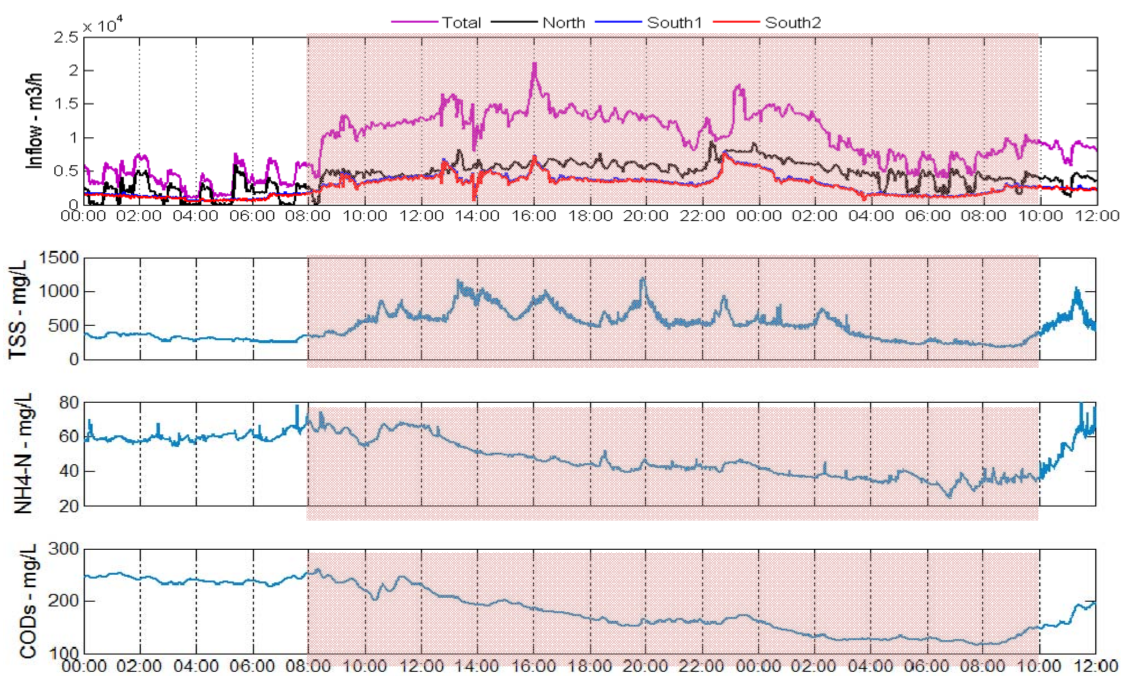

Figure 6. Variations in flow and water quality at the inlet of the Lynetten WWTP during wet weather (18/2 00:00 – 19/2 00:00). The marked area represents a rainfall event.

Figure 6 shows the effect of the on/off pumping strategy on TSS and dissolved pollutant concentrations during the wet weather period from February 18th – 19th, where it rained from 7.30 on February 18th till 10.00 on February 19th. This resulted in increased water levels and thereby the pumping operation of the North pumping station changed from on/off pumping to more or less continuous pumping. Therefore, very few distinct flow peaks due to pumping operation were observed. Rather, a few flow peaks were observed in the two South sewer pipes. This time TSS concentration peaks were seen corresponding to these flow peaks, and a few TSS peaks were observed even in the absence of flow peaks. Since it is a very big catchment area and it doesn't rain at the same time and uniformly over the entire catchment area, the observed TSS peaks in the absence of flow peaks could be due to first flush effects arriving from different catchment areas. The peaks for dissolved pollutant concentrations also occur. However, these peaks were only 10-20% higher and usually occurred at the same time as the peaks for TSS.

Observations from these on-line sensors, upgraded by DQC procedures, are currently forming an information-dense basis for calibration of a sewer water quality model, which will be used to better understand the processes taking place upstream the plant and to reduce their impact on the performance of the WWTP.

CONCLUSIONS

This paper has demonstrated that high temporal resolution data from on-line sensors provide valuable information that helps understanding processes in the sewer network. In the present study high-frequency data from on-line sensors were used to understand the effect of pump operation on the water quality at the inlet to the Lynetten WWTP during dry and wet weather periods. The results showed that the on/off pumping operation created distinct flow peaks, with the flow increasing by up to 50-200%, which in turn resulted in distinct concentration peaks of TSS of the same order of magnitude making up a TSS-load increase by up to 400%. The load thus increased fourfold during such on/off pump switches. The dissolved pollutant concentrations on the other hand only increased by 10-20%. The data from on-line sensors, upgraded by DQC procedures, are currently forming an information-dense basis for calibration of a sewer water quality model, which will be used to better understand the processes taking place upstream the plant and to reduce their impact on the performance of the WWTP. Monitoring of the water quality closer to the flow measurement points is being carried out to document the erosion effects. Furthermore, monitoring of the outlet from the primary clarifier is being carried out to investigate whether the shock loads created by on/off pumping operation are propagated across the entire WWTP, affecting the treatment efficiency.

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