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Control of CSO retention tank emptying: interaction with the wastewater treatment plant

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ABSTRACT

Retention tanks are commonly used in many North American and European cities to prevent pollution caused by combined sewer overflows, which are discharged to the receiving waters without treatment. Retention tanks enable the control of hydraulic loads entering wastewater treatment plants during wet weather. However, theoretical studies have shown that discharges from these tanks could have a negative impact on the WWTP's (Waste Water Treatment Plant) effluent. Characterization of such discharges is necessary to better understand these impacts. This study aims at: (1) characterizing water quality during emptying of a tank; and (2) characterizing the temporal variation of settling velocities of the waters released to the WWTP. Two sampling campaigns have been realized in Quebec City and laboratory analyses have shown a wide variability of total suspended solids (TSS) and Chemical Oxygen Demand (COD) concentrations in the water released from the tank. Suspended solids seem to settle quickly because they are found in large amounts during the first 15 minutes of pumping to the WWTP. A second concentration peak occurs at the end of the emptying period due to the cleaning of the tank. Finally, settling velocity studies allowed characterizing combined sewer wastewaters by separating three main fractions of pollutants which correspond to the beginning, middle and end of emptying. In most of cases, it is noticed that as pollutant load increases, so do particle settling velocities.

INTRODUCTION

In the context of operational water management (Beck, 1981) retention tanks, commonly used to minimize the impact of combined sewer overflows (CSO) on receiving water bodies, can no longer be considered only as a treatment alternative, but should be viewed as a proactive tool for water management of urban systems. To maximize the environmental benefits of retention tank implementation, one must make sure that the tanks are well managed individually, but mostly as a system together with the collection system and the WWTP. This is a challenge, because the management of retention tanks is dichotomous, as already shown 25 years ago by Lindholm (1985).

During and after rainfall events, urban catchments can generate excessive runoff leading to hydraulic overloads to the WWTP and additional pollution to be dealt with. Lindholm (1985) wondered whether retention was really an overall positive solution for an urban system: the emptying of the retention tanks, depending on the hydraulic and environmental conditions at that moment, could degrade the WWTP's effluent significantly enough to create an overall negative impact on the system. This study, although theoretical, asked the question abruptly, and has yet to be answered clearly. Several other theoretical studies have been conducted to try and provide an answer (e.g. Lessard and Beck, 1990; Bauwens et al., 1996). In all cases, the authors show the potential impacts of retention tanks emptying to the WWTP and the importance of analyzing the urban system as a whole to properly quantify the benefits of the implementation of retention tanks. Calabro and Viviani (2006) identified that one of the challenges for the future will be to take into account the effects of retention tanks on the WWTP, in order to optimize the size of the tanks and to minimize overall overflows to the receiving water bodies, i.e. to minimize the total loads from both the sewer overflows and the treatment plant's effluent.

While there are studies on retention tanks (e.g. Aires et al. 2003), no field study has been identified on the specific subject of emptying, which is a shortcoming. This research project was thus developed to analyze the interactions between the retention tank and WWTP on a real case study. In an initial step, emptying waters from a retention tank were characterized.

The purpose of this paper is thus to characterize the emptying waters and compare them with the WWTP's influent, especially in terms of settleability, a key parameter for the treatment of such waters.

METHODOLOGY

Analyses were mainly done to characterize suspended solids (SS), since pollution loads are linked to SS (Michelbach, 1995; Ashley et al., 2004; Rossi, 2004). This characterization has been done in two main steps:

1) Monitoring the pollutant concentrations during the emptying of the tank in terms of suspended solids (SS) and organic matter (COD);
2) Characterizing the evolution of the settling velocities of particles during emptying.

Watershed characteristics

The off-line retention tank in this study is located downstream of a Quebec City urban catchment. The total area is 1.54 km^2 with an average imperviousness of 51%. The land use includes 28% institutions, 41% residential, 12% commercial, 12% industrial and 7% green areas. The catchment is separated in two parts: the upstream is composed essentially of residencies and institutions and is located about 70 m higher than the second, which mainly contains commercial areas and industries. The concentration time is about 26 minutes and the total population is estimated to be around 5200 habitants. The retention tank has a capacity of 7580 m^3 and was designed for 4 overflows per year.

Tank operation

The retention tank is rectangular shaped and comprises two parts. The first one is the control chamber located online the interceptor. Its role is to derive flows to the tank when certain conditions are met (e.g. high water levels in the interceptor, high flow rates at the inlet of the WWTP). The other part is the tank itself, which is located 200 m downstream the control chamber. Wastewater can follow four paths (Figure 1):

1) During dry weather, the flow pass through the control chamber and goes into the interceptor to be sent to the WWTP;
2) During wet weather, the rising level in the control chamber leads to an overflow over a weir to a 200 m long pipe which ends in the tank;
3) When the tank is full, the inlet is closed. Then, the water level rises in the control chamber until it reaches the overflow pipe. All the exceeding flow is then routed to the St Charles river;
4) Once the spilling has stopped and the conditions in the interceptor allow for it, the pumps located downstream of the tank are activated and the tank emptying begins. Water is returned to the control chamber in order to be sent to the WWTP via the interceptor.

The whole system is equipped with several sensors for its real-time operation. These sensors include nine level meters (lit 00X, Figure 1) allowing estimations of flows and volumes. At the end of emptying, the cleaning system is switched on. The principle is to release water, from storage cells located upstream of the tank providing a high enough flow velocity to remove settled particles. The cells are first filled up with the stormwater entering the tank at the beginning of the event.

Sampling campaigns

The data were collected during two sampling campaigns in the summers of 2009 and 2010. Sampling consisted in collecting water at the outlet of the tank. Several samples were taken with a variable time interval (2 minutes to 2 hours) during each event. These time intervals were set in order to observe all pollutant concentration dynamics during emptying. These data were compared with wastewater sampled at the East WWTP of Quebec City after the grit chambers and at the outlet of the primary settler. Some twenty grab samples were collected during night and day, at different times throughout the year. Those samples were then analysed at the Laval University's environmental laboratory, mainly for SS, COD and settling velocity (Vs).

At the retention tank, grab samples were collected with an automatic sampler (*SIGMA 900max)* connected to a float switch (FLYGT ENM-10). The sampler is located at the outlet of the tank, just after the pumps (Figure 1). Those samples were then mixed to have composite samples for Vs measurements.

Laboratory analyses

Once the samples were collected, they were either analyzed immediately or stored in a cold chamber at 4°C to be analyzed within 24 hours. Conservation tests were conducted in order to assess the phenomena of flocculation that may have an impact on the Sv measurements. Those tests showed that it is acceptable to carry out the measurements within the following 24 hours.

The TSS analyses were done according to Standard Methods (AWWA et al., 2005). Total COD was analyzed with the Hach closed-reflux method (method Hach 8000) after grinding and homogenization of the samples. Measurements of the Vs distributions were carried out using the ViCAs protocol (Chebbo and Gromaire, 2009) both on composite and grab samples. It gives the mass percentage of particles that have a Vs lower than the velocity noted on axis X.

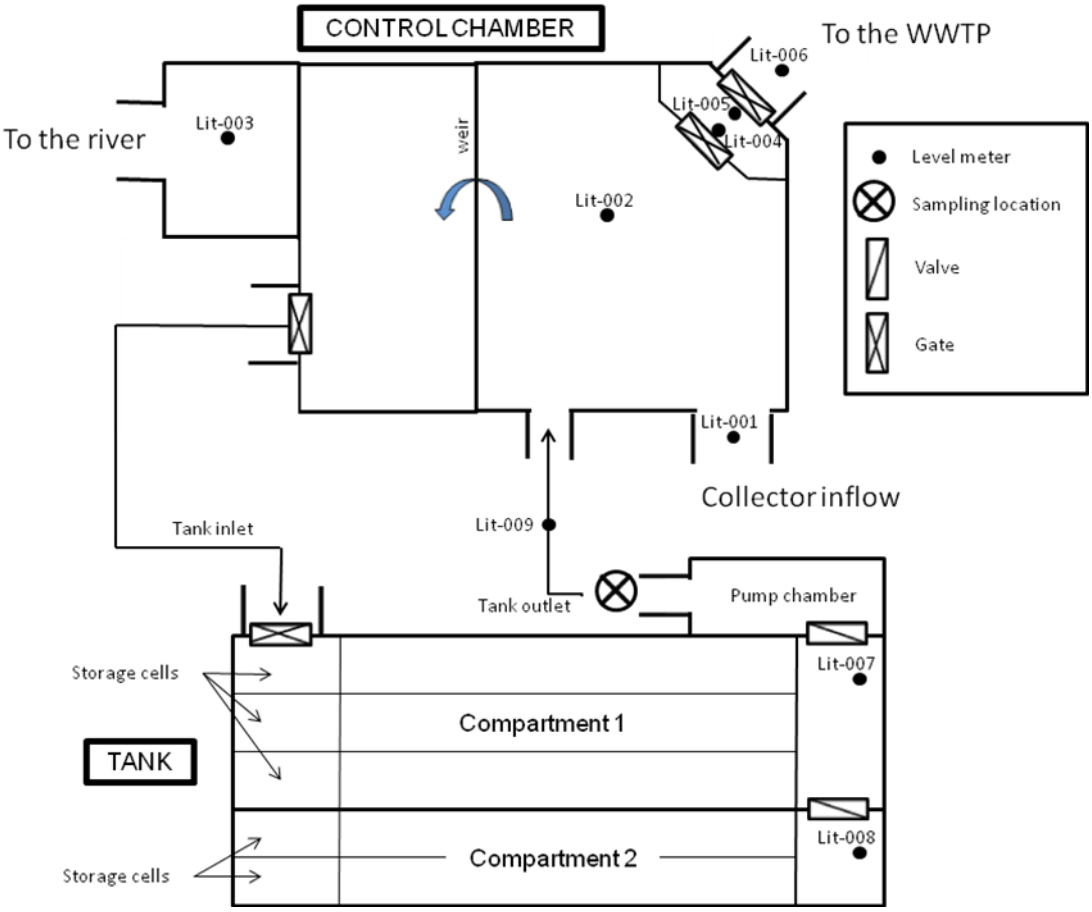

Figure 1 : Schematic of the retention tank (lit-00X means level meter N°X)

Flux calculation

Flux calculations were carried out for some events, i.e. when the pollutograph was complete and showing all the concentrations variability. The fluxes were calculated using the linear interpolation method of concentration points (Kronvang and Bruhn, 1996). Masses were calculated by integrating the fluxes (eq. 1):

$$\hat{L} = \sum_{i=0}^{n+1} \sum_{t_i < t \leq t_{i+1}}^{i} q_t . \frac{c_{tj}\left(t_{j+1} - t\right) + c_{tj+1}\left(t - t_j\right)}{t_{j+1} - t_j} \qquad (1)$$

The flux ($\hat{L}$) depends on the flow (q_t) and the concentration (C_t) at the time (t). That equation must be chosen when the time interval of flows is shorter than concentrations time interval. The level meter system provides volumes in the tank with a quite good accuracy and high frequency (1 minute interval). Those data were used to determine the flow at the outlet. Indeed, the sensors are located near enough the pumps to adequately represent the variation of the volume.

RESULTS AND DISCUSSION

Rain events characteristics

More than 18 rainfall events were sampled during the summers of 2009 and 2010. The characteristics of those events are summarized in Table 1. Many different types of storms were sampled. For example, the maximum intensity for 5 min covers a range from 1.2 to 45.6 mm/h, total precipitations are between 0.8 and 45.7 mm and volumes retained in the tank between 460 and 7580 m^3 (full tank). One can note that the quiescent times (i.e. when there is no inflow nor outflow) in 2009 are shorter than one hour except for the event of September 27th, which is due to the long duration of the rain (25h30). The quiescent times are longer in 2010, which is probably due to mechanical problems with the pumps, caused by roadworks on the watershed, which led to a huge quantity of sand drained into the combined sewers.

Water quality: dry weather

Characterization of the Vs distribution during dry weather conditions was carried out on samples from the East WWTP of Quebec City. The results are shown on Figure 2. A colored zone represents the range of settling velocities observed in the samples from a certain site, i.e. the upper and lower lines are the maximum and minimum of values collected. The dark range consists of 3 samples (3 curves) collected at different times at the outlet of primary treatment. The grab sample concentrations are between 36 and 98 mg/l. The pale range is the average of 13 samples collected before the grit chamber and the primary settler. The TSS grab sample concentrations vary from 77 to 623 mg/l.

Table 1 : Rainfall characteristics

Date (dd/mm)	Duration (h)	Cumulated height (mm)	Max. intensity for 5min (mm/h)	Previous dry weather period (h)	Quiescent time in the tank (min)	Volume in the tank (m^3)
18-07-09	2h25	13,1	44,4	18,75	5	3100
27-07-09	0h55	6	25,2	6	5	4064
17-08-09	0h10	2,2	25	189	10	480
18-08-09	01h00	7,5	21,6	19	55	2700
21-08-09	0h50	3	3,6	18	25	1950
23-09-09	1h40	1,8	9,6	25	15	460
27-09-09	25h30	45,7	16,8	90	240 and 50 *	7400
02-10-09	10h40	0,8	1,2	8	30	4600
07-10-09	18h00	23,7	10,8	34	30	6780
01-06-10	13h25	29,6	18	24	1360 and 15 *	7406
06-06-10	27h20	11,3	6	60	20 and 17 *	2548
24-06-10	08h40	22,7	42	103	1560	7398
28-06-10	00h30	4,7	45,6	61	7	969
09-07-10	09h45	14,2	36	213	93	4189
13-07-10	03h40	6,6	7,2	89	15 and 516 *	1869
16-07-10	01h15	6,1	15,6	53	10	2785
21-07-10	01h30	2,9	4,8	133	2	653
03-08-10	04h50	29	19,2	230	30	4036

* *Both values are respectively for a first and second emptying phases*

A ViCAs curve must be interpreted as follows: the lower the curve the larger the fraction of rapidly settling particles. Considering a sedimentation velocity of 1.6 m/h (40 m^3/m^2*d) to be the typical design overflow rate for primary sedimentation units, Figure 2 shows that between 83% and 91% of the particle masses at the outlet of primary settler have a Vs lower than their design velocity (1.6 m/h). Furthermore, one can note that between 44% and 78% of the influent particle masses have settling velocities lower than 1.6 m/h, resulting in 56% to 22% of particle masses that can be intercepted by a primary settler.

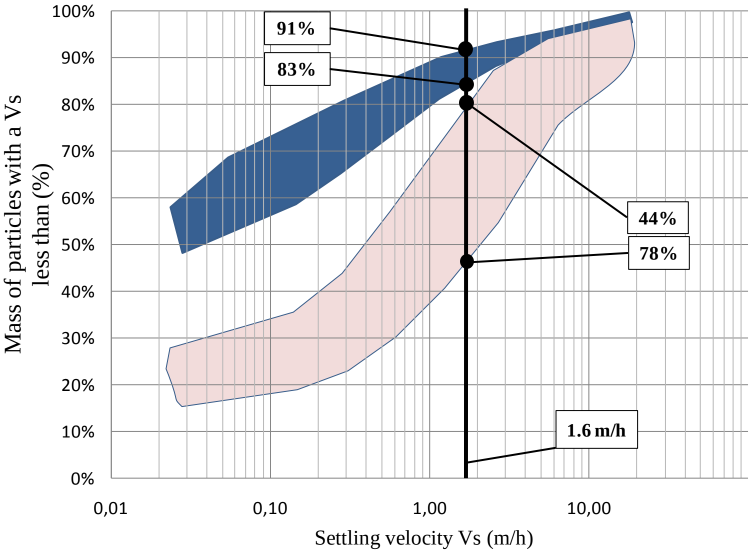

Figure 2 : Vs curves for dry weather wastewater. “Dark” is the Vs distribution range of wastewaters from the effluent of primary settling. “Pale” is the Vs distribution range of wastewaters from the influent of primary settling.

Water quality: tank emptying

Sampling during tank emptying was carried out for more than 18 events during the summers of 2009 and 2010. A huge variability of pollutant concentrations during emptying is observed. TSS concentrations measured vary between 27 to more than 20000 mg/l. In terms of COD, the observations are similar with concentrations varying between 32 and 4 000 mgO_2/l. For most of the events, concentrations remain within the ranges reported in literature for combined sewers: around 176 to 2500 mg/l for TSS and 42 to 900 mgO_2/l for COD (Metcalf and Eddy, 2003; Bertrand-Krajewski, 2006). However, for a few events the concentrations are largely exceeding these values. These extreme values can be linked to the roadworks on the watershed that brought a large quantity of sand in the pipes. Generally, the maximum value is reached at the beginning of the emptying as the pumps start to draw water from the well where sediments have accumulated. Some of the variability can also be linked to characteristics of the rainfall event (e.g. intensity, duration, antecedent dry weather period...) and the retention time in the tank.

Two typical pollutographs for emptying waters are shown in Figure 3. In fact, TSS present in the first peak arises from the cleaning of the previous event, i.e. solids trapped in the pump well. Consequently, the value of the concentration at this first peak cannot be linked to the current event characteristics, but should be linked to the characteristics of the previous one. For the July 27th 2009 event (Figure 3a), the last peak is not well represented because of the lack of data points collected. If it would have been collected at shorter intervals, it might have had a shape similar to the one shown in Figure 3b. The increase of the TSS and COD concentrations at the end of emptying happened during the last 15 minutes only, which correspond to the cleaning (as in Figure 3b shows it). Three distinct phases can be observed for most of the events during emptying: the beginning, the middle and the end. During the middle phase, TSS concentrations are quite constant around 80 mg/l, while during the two other phases, TSS concentrations are high and variable.

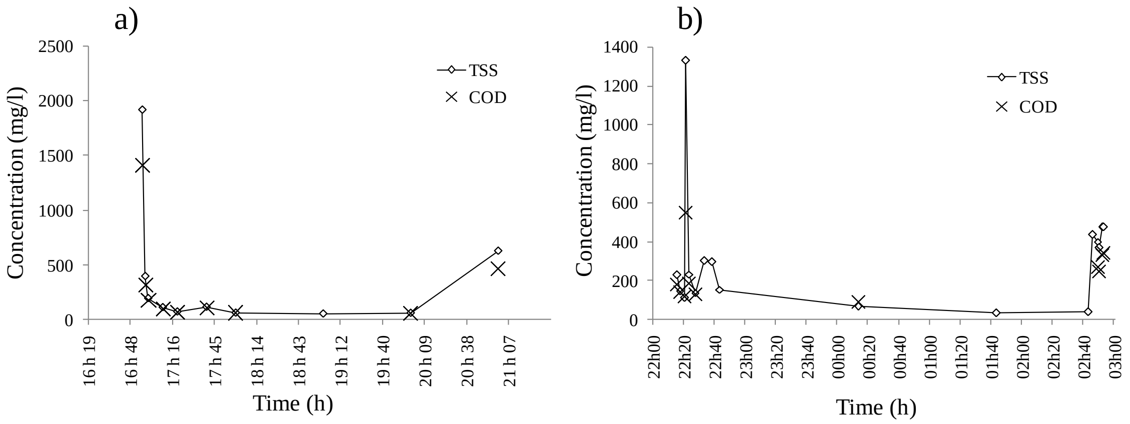

Figure 3 : TSS and COD concentrations at the outlet of the retention tank for different events: a) July 27th 2009; b) June 6th 2010.

Mass fluxes were calculated with equation 1 for those both events, showing that about 10% of the SS load is returned within the first 15 minutes, 70% in the middle phase and 20% in the last 15 minutes of emptying.

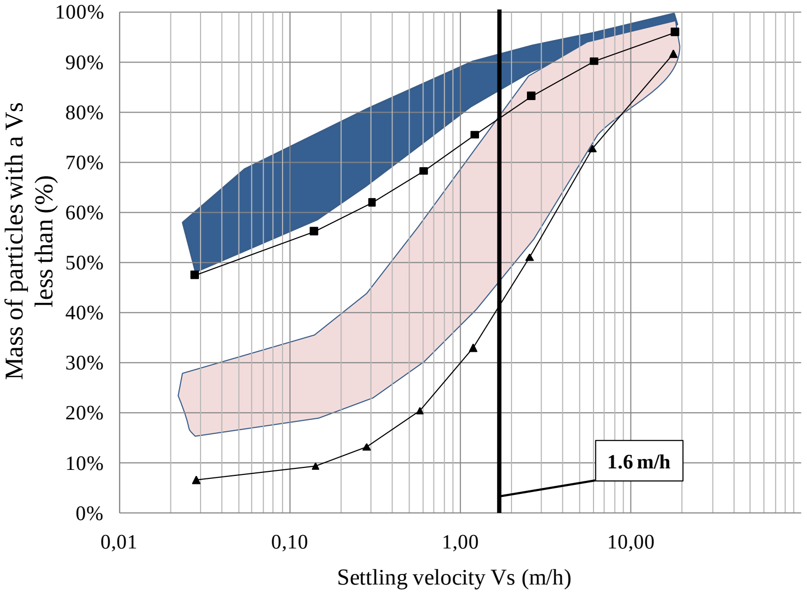

Figure 4 : Vs average curves for emptying waters versus Vs curves for dry weather. Square symbols represent the average of the Vs distributions of particles from water released during the middle of emptying. Triangle symbols represent the average of the Vs distributions of particles from water released at the end and at the beginning of emptying. Dark and pale ranges are the same as in Figure 2.

For each of the three emptying phases, Vs analyses were carried out (Figure 4). The curves represent the averages of 1) Vs distributions of particles contained in wastewaters from the middle phase (upper curve average of three samples) and 2) Vs distributions of particles contained in wastewaters from the beginning and the end of emptying (lower curve average of six samples). The second curve combines Vs distributions from the beginning and the end phases as they are similar. Figure 4 also shows that the particles from the middle portion of emptying have a Vs distribution similar to that of the effluent of primary settling (dark range). Moreover, particles contained in the waters from the beginning and the end of emptying tend to settle faster than those collected before the grit chamber (pale range), which means that they will be removed by primary settler.

Table 2 presents the characteristics of the ViCAs results used to plot Figure 4. One can observe that the concentration average at the outlet of the tank (beginning and end) is the highest (1765 mg/l) and correspond to the wastewaters containing a fraction of particle mass which settles the fastest. Indeed, 80% of the particle mass contained in those waters has a Vs lower than 7.46 m/h and 20% lower than 0.23 m/h. Furthermore, the average TSS concentration at the outlet of the tank (middle) is 68 mg/l with 80% of the particle mass having a Vs lower than 2.5 m/h and 20% lower than 0.015 m/h. Those data reveal that as the concentration increases, so does the particle settling velocity. The difference observed between the Vs corresponding to the 80 percentile fraction at the outlet of the tank (middle) and the primary settler effluent can be explained by the important range of values (36 to 99 mg/l) which results in a high Vs.

Table 2 : TSS concentrations of samples and Vs (m/h) values for the 20 and 80 percentile in particle fractionation.

Sample location	***TSS concentration (mg/l)*** ***Average*** *Min-Max*	***Vs (m/h)*** ***Fraction*** ***20%***	***Vs (m/h)*** ***Fraction*** ***80%***
Primary settler influent	**392** *74-623*	0.037	4.3
Primary settler effluent	**76** *74-81*	0*	0.56
Outlet of the tank (middle)	**68** *36-99*	0.015	2.5
Outlet of the tank (beginning and end)	**1765** *392-8390*	0.23	7.46

** Corresponds to non settleable matter (Vs < 0.01 m/h)*

CONCLUSION

The settleability of particles contained in waters released to the WWTP was analysed and compared with the influent and effluent of a WWTP's primary sedimentation unit. From this study it can be observed that:

1. For waters at the beginning and end of the emptying period, the mass of solids with a Vs below 1.6 m/h (40 m^3/m^2*d) is low, around 40%, which underlies the fact that most particles released to the WWTP will be removed by primary sedimentation.
2. However, only about 20% of the mass of SS from the middle phase period has a Vs higher than 1.6 m/h. Therefore, 80% of these solids cannot be removed by the primary sedimentation unit. Their settleability curve is actually similar to that of a primary effluent.
3. Overall, within the wastewaters returned to the WWTP, about 30% of the TSS mass will settle in the primary clarifier but the 70% left will have a particle Vs distribution similar to that of a primary settler effluent.

4. ViCAs analyses show that there is a link between the TSS concentrations and the Vs distribution obtained from combined sewer samples. As the concentration increases, so does the settling velocity.

This study provides interesting information regarding the management of emptying waters and their potential impacts. It stresses the fact that retention tank should be emptied in a context of operational management. For example, emptying must be done after the rain event, when the receiving water flow rate is at its highest, the river watershed reacting more slowly than the urban catchment. Considering that the quality of emptying waters is mostly similar to that of a primary effluent, it might be more interesting, depending on environmental constraints, to return these waters to the watercourse than to the WWTP, as the latter might be hydraulically overloaded, and thus, less efficient. However, it would be equally logical to return waters at the beginning and end of the emptying period to the WWTP, since they are highly loaded.

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