Urban Water Journal, 2015
Vol. 12, No. 3, 219–228, http://dx.doi.org/10.1080/1573062X.2013.868499

RESEARCH ARTICLE

Storm tank against combined sewer overflow: Operation strategies to minimise discharges impact to receiving waters

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(*Received 22 March 2013; accepted 18 November 2013*)

The pollution reduction opportunities of a drainage basin, located in Barcelona (Spain), were analysed as a case study in order to assess strategies for optimised management of sewerage networks in the Mediterranean region. The analysis results show that the introduction of a large storm tank against combined sewer overflow significantly reduces the negative impacts associated with discharges during rainy weather. The total annual mass into the receiving waters is reduced by 45%, measured in terms of suspended solid and chemical oxygen demand. The performance of large storm tanks can be optimised taking advantage of the natural sedimentation of the retained rainwater. At optimum stratification conditions, the annual regulation capability can be increased by 15% compared to the traditional operating conditions. Apparently, the environmental impacts associated with the materials used in the construction of the tank will also be reduced per unit volume of regulated water with the increasing annual regulation capacity.

Keywords: combined sewer overflow (CSO); environmental impact; rainfall; sewerage; stormwater quality; urban water management

Introduction

In recent years numerous studies and experiences have demonstrated that rainfall events, regardless of the intensity and volume, can cause overflow of sewerage systems to receiving waters. Consequently, the quality problem of a large fraction of water bodies is caused by these intermittent discharges from urban sewerage systems, occurring during and after the rainfall events (Butler and Davies 2000). These discharges can account for nearly 50% of the total pollution into the receiving waters (Malgrat *et al.* 2004), and are critical for the combined sewer systems.

Cities are increasingly implementing solutions to reduce discharges to receiving waters through the construction of storm tanks against combined sewer overflows (CSO). It is necessary to consider the system as a whole in order to improve the operation of storm tanks (Rauch *et al.* 2002). Most of these tanks are designed to collect the first flush of contaminated water coming from the sewerage network during rainy weather, store a specified volume and then release it to the waste water treatment plant (WWTP) in a controlled and coordinated fashion, thus minimising discharges to the receiving water bodies. However, the WWTPs already tend to have problems in treating the wide avenues of water during rainy weather (Ahnert *et al.* 2009 or Dauphin *et al.* 1998) plus emptying the retention tanks and associated pollution (Maruejouls *et al.* 2010 or Suárez *et al.* 2012).

After rainfall events, especially those associated with high intensity, very common in the Mediterranean climate, the WWTPs take several hours or even a few days to be able to receive the waters from the CSO storm tanks. Therefore, rainwater tends to be retained for a long time, making the tanks completely inoperative during these periods by not being able to process new volumes of subsequent precipitation. This implies that when new rainfall occurs, water from the sewage system will be directly discharged into the receiving waters.

The objective of this study is to analyse the strategies for optimised management of the sewerage networks in general, and of the large storm tanks in the Mediterranean climate in particular, by further minimising the impacts of CSO discharges during rainfall events, taking into account the processes occurring in the urban sewerage system (the hydraulic behaviour and pollution) and in the large storm tank (natural sedimentation process).

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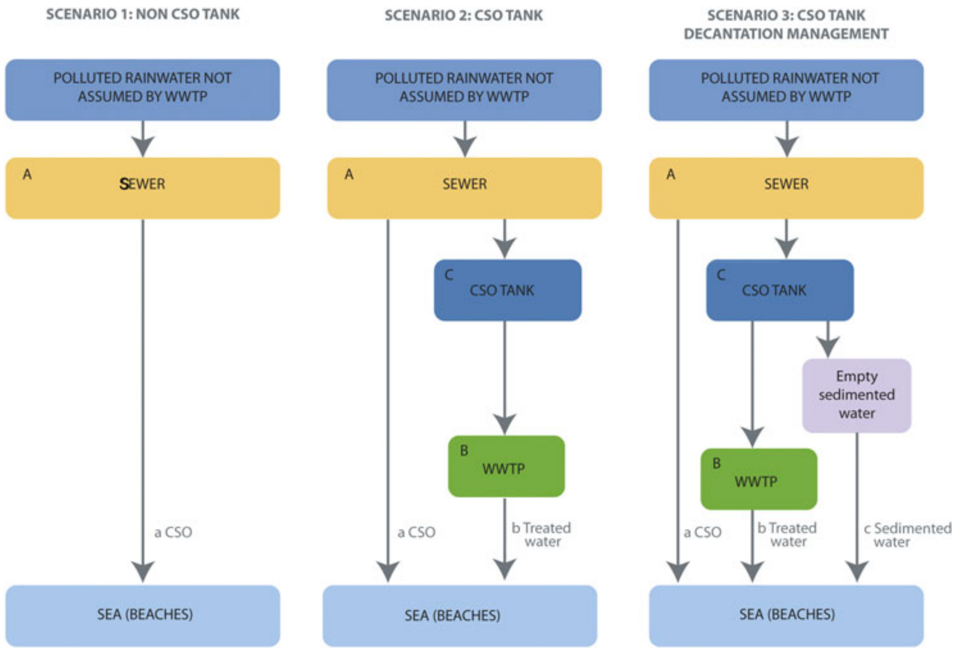

Figure 1. Operational scenarios (1, 2 and 3), subsystems considered in each scenario (A, B and C) and water discharged from each subsystem (a, b and c).

This analysis is based on a pilot urban drainage basin (Riera d'Horta), that has a large rainwater retention tank against CSO, located in the city of Barcelona. The rainfall patterns of this Mediterranean area are characterised by an irregular and moderate average annual volume (600 mm). The convective character of many rainfall events of this region implies high intensity isolated rains in a short period of time. This fact indicates that 2–3 events could contain up to half of the annual rainfall (Montero *et al.* 2009). In addition, the climate change effect may accentuate the intensity of rains in the Mediterranean region (EC 2007).

To evaluate the system, this study quantifies the reduction of pollutant discharge into the receiving waters due to the construction of a storm tank and also determines the possibility of optimising this reduction by operating the tank to take advantage of different qualities of the water column, which is stratified after a settling period. It permits the release of better-quality water to the receiving water bodies and in this way new rainwater flows can again be regulated by the tank, increasing the annual regulation capacity of the tank.

Three scenarios were identified and analysed (Figure 1), where the rainwater is not entirely manageable by the WWTP. Scenario 1 considers the urban drainage basin without a CSO storm tank. Scenario 2 looks at the urban drainage basin with a CSO storm tank under a conventional operational mode. While Scenario 3 contemplates the urban drainage basin with a CSO storm tank taking into account the natural sedimentation process during the operation.

Each of these scenarios considers different subsystems during a period of one real year, 2009, to quantify both the volume and the pollution mass discharged into the receiving water bodies based on the suspended solid (SS) and the chemical oxygen demand (COD). The subsystems taken into account are (Figure 1): the combined sewer network (A), where the overflow of untreated water takes place, the WWTP (B), from where the treated water is discharged, and the storm tank (C), from where the water is sent to the WWTP and/or water is discharged directly to the aquatic environment after settling.

Methodology and materials

Description of the pilot system studied

The Riera d'Horta basin is located in the city of Barcelona, it shares various land uses, including residential, industrial, commercial and green areas. It is 1200 ha and has approximately 200,000 inhabitants, therefore is a densely populated basin. In terms of urban drainage, the basin is characterised by an average ground imperviousness of 75% and a combined sewage system equipped with a large CSO storm tank downstream, the Taulat tank, before the CSO point at the beaches of Barcelona.

The real fill capacity of the Taulat tank, configured in three large filling bodies, is 55,000 m^3 with a storage capacity of 6.11 mm rain. The tank filling process is performed automatically and is remotely controlled in real time using level sensors and gates located in the sewerage network and in the tank. Once the tank is filled, if precipitation has not ceased and pipes operate in surcharged conditions and piezometric level reach the terrain elevation, CSO takes place. This also occurs when the rain intensity produces an increased flow rate in the collectors that exceeds the maximum entry flow rate of the tank (20 m^3/s).

The tank is emptied using pumps. This emptying is coordinated with the WWTP of Besòs, located less than 1 km away from the tank. The WWTP has an entry capacity of 10–12 m^3/s, while the peak urban runoff rate for a 10-year return period in the area served by the treatment plant is approximately 500 m^3/s (Malgrat *et al.* 2008). Due to the irregular rainfall nature of the region and problems generated in the WWTP during rains, the treatment plant takes some time to recover its normal activity after a rainfall event. Therefore, the water is retained in the tank for a minimum of 12 hours up to a few days while waiting for the treatment plant to be able to process this water.

Analysis of the sedimentation process in the storm tank

The natural sedimentation process of the tank water, that occurs due to the gravity on the settleable particles, was analysed. The applied methodology was based on assaying the settling water retained in the tank in a column of sedimentation following the VICAS protocol (Gromaire and Chebbo 2003).

The results from the settling experiments were compared with the ones obtained from laboratory experiments. The samples were collected with automatic sampling equipment in the middle and upper layers of the water column, before and after the sedimentation process. The following components were analysed: SS, Total Solids (TS), COD, Total Organic Carbon (TOC), total nitrogen (N total), total phosphorus (P total), Escherichia coli (E. coli) and intestinal enterococci (IE). These analyses allowed a comparison of the trends and degrees of decontamination established for the SS and the other parameters in the settling experiments.

The settling process was also monitored in real-time with continuous measurement using three remotely-controlled turbidity sensors located at various heights on the same vertical column of water from the tank.

CSO characterisation analysis

Determining the behaviour of the CSO, particularly for the pollutant flows mobilised during rainfall events before the discharge, allows an optimisation of the network management to achieve an operational mode that minimises the impacts on the aquatic environment. A total of nine campaigns were conducted during rainfall events in 2009 to study the mobilisation of the basin flow contamination. For each rainfall event analysed, its hydrograph and pollutograph associated with the following parameters were obtained: SS, TS, COD, TOC, total N, total P, E. coli and IE. The event mean concentration (EMC), which could be defined as the total amount of pollutant mass at a specific point during a rainfall event divided by the total discharge volume in the event (Bertrand-Krajewski *et al.* 1998), and the existence of the first flush were calculated. Campaigns were also conducted in dry weather to determine the pollution associated with wastewater and to study the existence of the dilution factor during rainfall events.

The CSOs vary by up to several orders of magnitude in frequency, volume discharged to the environment, and concentration of pollution discharged (Lee and Bang 2000). The EMC was obtained by calculating the mean concentration, weighted by flow, to work with the large variability in concentrations and forms of pollutograph. The EMC was calculated following the expression presented by Villar *et al.* (2008).

The first flush phenomenon that occurs when a high portion of the total mass of pollution mobilised during a rainfall event is transported by the first waters of the hydrograph that reach a certain point in the basin, was performed via a method proposed by Griffin *et al.* (1980), where the rainwater volume percentage was normalised against the pollution mass percentage. The analysis was performed at a downstream point of the Riera d'Horta sewerage network, immediately before the network flow enters the storm tank and at the point where the CSO enters into the receiving waters. A control station was installed at this site composed of, among other things, an online monitoring sensor for the level/flow and automatic sampler equipment to collect the samples which were subsequently analysed in the laboratory. The sampling began automatically after a threshold level was reached that indicated the flow occurred due to a rainfall event.

Hydrologic-hydraulic analysis

The hydrologic-hydraulic analysis was based on real data from the year 2009. The rainfall of the studied period was analysed from collected data using the rain gauges that CLABSA, a sewer network managing company operating in Barcelona, has distributed throughout the city. This data determines the number of days with significant rainfall ($>$ 1 mm), with maximum intensity exceeding 60 mm/h in 20 minutes, and the total precipitation volume, justifying when and how the CSO are produced.

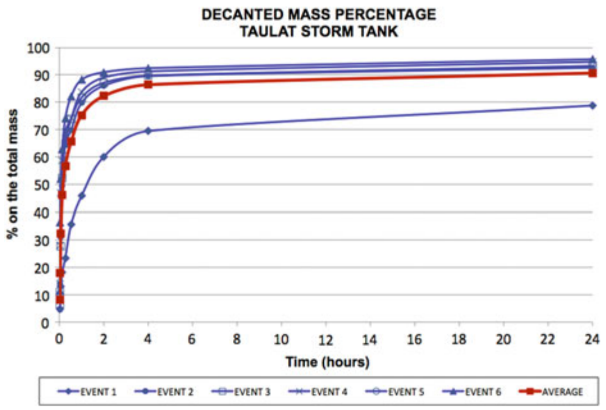

Figure 2. The natural sedimentation process in the Taulat storm tank using the VICAS protocol (SOSTAQUA 2010).

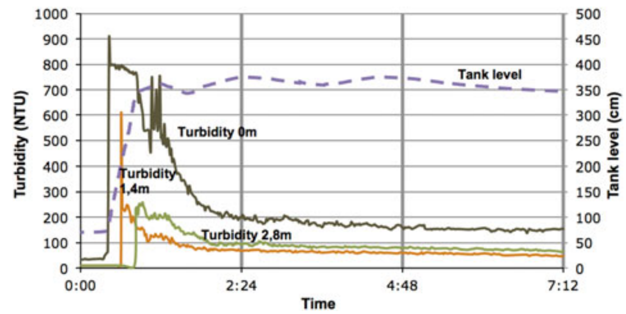

Figure 3. The online and real-time monitoring of the natural sedimentation process by gravity in the Taulat storm tank by measuring the turbidity. SCADA (Supervisory, Control and Data Acquisition System) CLABSA control centre.

During rainfall events with high intensity (mm/h) and high volume accumulation (mm), CSOs are usually detected when the tank reaches its maximum capacity. A level sensor was installed at the overflow point of the sewerage water network to the receiving waters of the Riera d'Horta basin to identify the discharges. A conversion table of the level/flow, made by simulating many rainfall events in the basin using the MOUSE software (version 2009), was used to determine the flow of the discharges. Data processing allowed the identification of each CSO events, the flow discharges at each time, the accumulated volume spilled into each one of these events and the total volume discharged during the 2009 period.

The precipitation data and the CSO data were contrasted with the operational mode of the tank. The level sensors were located in the tank allowing the calculation of the filling speeds, the total volume reached in each rainfall event, the retention time, and the emptying rate. The volume sent to the WWTP was determined by the volume of water regulated in the tank.

Scenarios analysis: volume and mass discharge

The volumes discharged from each of the subsystems to the receiving waters and the regulation volumes from the storm tank were experimentally quantified for all three scenarios. The real data for the year 2009 corresponds to Scenario 2, from which the discharged volume in Scenario 1 was calculated. To calculate the volumes in Scenario 3, all the CSO events and those that could have been avoided a portion of the discharge were considered. The analysis was performed based on the tank filling rates according to the sewer discharge flow in each interval, the settling time, and the flow rate when empting the medium and top layers of the water column to the receiving waters. The drainage to the receiving waters was performed with a system, capable of emptying at a minimum rate of 3 m^3/s per filling body, using both gravity and pumping. For each event where the identified CSO can be reduced, the following variables were quantified: the volume regulated by the tank, the proportion of this volume discharged into the receiving environment after settling, and the proportion sent to the WWTP to be treated. Finally, the annual discharge volumes from each subsystem of Scenario 3 were quantified.

The volumes discharged to the receiving tank from the subsystems referred to each of the scenarios were translated into the total mass discharged, measured in terms of the SS and COD. On the one hand, the calculation of the total mass discharged from the sewage (CSO) and from the tank (sedimented water) uses the average EMC calculated and the average concentrations after the settling process in the tank, respectively, as reference points. On the other hand, the calculation of the total mass discharged from the WWTP uses the actual average output data from the water treated in a plant like the Besòs WWTP. The reference values 16 mg/l SS and 57 mg/l COD were used, provided by competent authorities in the wastewater field ('Catalan Water Agency').

Results

Sedimentation process in the storm tank

The experimental results from the VICAS protocol in the Taulat tank determined a rapid sedimentation of SS during the first hours of water retention. The percentage of sedimented SS was approximately 80% in two hours after starting the natural sedimentation process by gravity (Figure 2), and the most concentrated water settled at the bottom 10–20% of the vertical water column. For this condition, the clearer and better-quality water (the upper 80% of the water column) is discharged into the receiving waters and the most loaded water (the bottom 20% of the water column) is retained in the tank to be sent to the WWTP.

Table 1. Concentrations before and after sedimentation and decontamination performance in the CSO storm tank.

Parameters	Concentration at a height above the 20% of the water column: Before sedimentation	Concentration at a height above the 20% of the water column: At 2 hours after the start of sedimentation	Decontamination efficiency (%)
IE (UFC/100 ml)	1.65E + 06	6.00E + 05	63.5
E. coli (NMP/100 ml)	3.55E + 06	2.28E + 06	35.9
SS (mg/l)	742.7	99.2	86.6
TS (mg/l)	787.0	233.5	70.3
TOC (mg/l)	29.0	10.7	63.1
COD (mg/l)	847.0	109.8	87.0
N total (mg/l)	63.4	13.8	78.3
P total (mg/l)	5.8	2.1	63.0

There was a clear difference between the online and real-time measured turbidity in the intermediate, higher (the clear water), and the lower layers (water loaded with more sedimented solids) (Figure 3). It was confirmed that the trends established through the monitoring of the turbidity in the tank are consistent with the experiments performed following the VICAS protocol.

The laboratory analysis of the water samples, collected before and after the sedimentation process, showed that the settling performance was between 63% and 87%, except in the case of E. coli, where the performance was lower (Table 1). In general, after the natural sedimentation, by gravity, in the tank, not only was the concentration of SS reduced but also a quality improvement was detected in most of the other water pollution indicators analysed.

Characterisation of CSO

The pollutographs associated with the hydrographs show that, in all of the rainfall events analysed, a contamination peak can be detected (Figure 4).

The average EMC value is presented in Table 2, together with the averages from dry weather. A dilution of pollution was not observed. Especially noteworthy is the case of the SS, where its EMC doubled when compared to the dry weather.

The analysis of the first flush phenomenon (Figure 5) indicates the absence of a first flush at the farthest downstream point of the basin. This confirms that first flush phenomenon is more likely to occur in small watersheds (less than 100 ha) than in large ones; in the latter, it is usual for the first flush effects to be minimised (Saul *et al.* 2003).

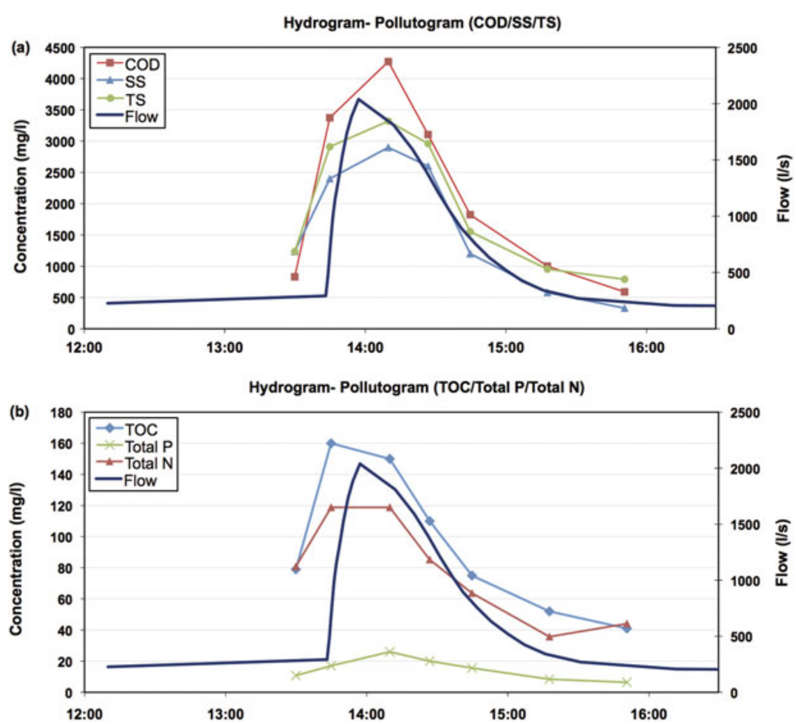

Figure 4. a) Hydrograph and pollutograph of COD, SS and TS for the rainfall event on 05-06-09 (SOSTAQUA 2010), b) hydrograph and pollutograph of TOC, P total and N total for the rainfall event on 05-06-09 (SOSTAQUA 2010).

Table 2. Average concentrations during dry and rainy seasons (EMC).

Parameters	Dry weather mean concentration	Events Mean Concentration (EMC)
IE (UFC/100 ml)	2.20E + 06	4.00E + 06
E. coli (NMP/100 ml)	1.05E + 07	2.61E + 07
SS (mg/l)	517.90	1024.79
TS (mg/l)	1234.88	1232.47
TOC (mg/l)	79.25	39.41
COD (mg/l)	830.54	878.55
N total (mg/l)	80.80	45.22
P total (mg/l)	10.78	9.65

Relationship between precipitation, CSO and storm tank filling

In 2009, a total precipitation of 473 mm and 52 days of significant rainfall (> 1 mm) were recorded. Compared to the average annual precipitation of 600 mm, the year 2009 was rather dry. The precipitation data recorded in 2009 show that 25% of the rainfall was distributed in three-day periods, with very high intensities ($I_{20} > 60$ mm).

During the year of the study, the total CSO into the Riera d'Horta basin was 886,752 m^3 distributed over 32 days. Three events were recorded with a CSO higher than 50,000 m^3, comprising approximately 68% of the volume discharged, and they are correlated with the three days with highest average precipitation recorded (mm) and the highest 20-minute intensity (mm/h) (Table 3).

In 2009, the Taulat storm tank regulated a total of 767,242 m^3 of rainwater from the sewerage network. Each time the level of the sewerage system reached the CSO threshold level, the storm tank started working automatically and filled accordingly.

A total of 23 rainfall events were recorded leading to a total or partial filling of the tank. Out of these, only seven (30%) were not associated with a CSO (Table 4). When a rainfall event is of moderate intensity, a discharge only occurs when the tank is completely full. However, when the rainfall intensity is high, and results in a network flow higher than the tank's intake capacity, discharges are unavoidable during the filling process.

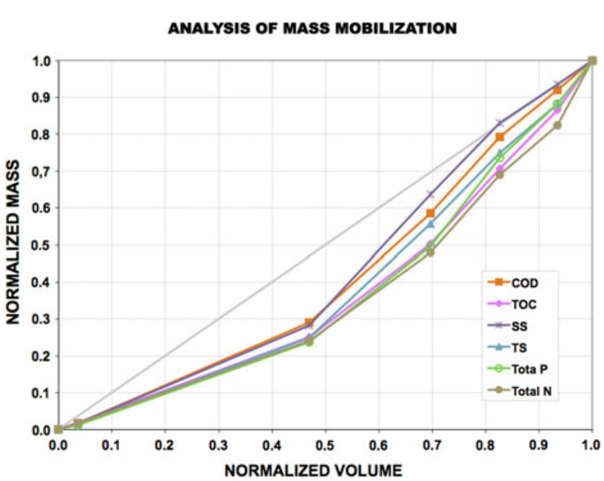

Figure 5. Mass mobilisation analysis (COD, TOC, SS, TS, P total and N total) for the rainfall event on 05-06-09 (SOSTAQUA 2010).

After a detailed analysis of the 32 days where CSOs were detected, it was determined that part of the discharge could have been avoided by using an operational mode that considers the sedimentation process in the tank. For the instances where this was the case, the volume that could have been regulated was quantified as presented in Table 4.

Table 4 shows that there are two types of CSO (Cases 1 and 2) associated with the filling of the tank. Case 1 comprises rainfall events that lead to a partial filling of the tank, caused by a network flow that is higher than the tank's intake; therefore, the discharges could not be minimised. In contrast, Case 2 comprises rainfall events that lead to a complete filling of the tank where a large portion of the discharge takes place after filling, either during the same rainfall event or during events that occurred later on the same day. Part of the discharge could be avoided in this case.

There are two additional types of CSO (Cases 3 and 4) in which the tank is not in operation. It was difficult to avoid the CSO in Case 3 since the tank was not in operation due to small maladjustments in the tank intake flow measurement. Finally, in Case 4, the tank is already full with rainfall from previous days and the discharge could be reduced by a tank operational mode that takes into account the sedimentation process in the tank.

The results obtained from this analysis show that a total of 323,512 m^3 discharged in 2009 could be regulated by the tank using an operational mode taking into account the natural sedimentation process.

Results from the scenario analysis

The results of quantifying the volume regulated by the different subsystems in each of the three scenarios are summarised in Table 5. In Scenario 1, the entire sewage volume was discharged into the receiving waters (CSO). In Scenario 2 (the current scenario), given a traditional operational mode of the storm tank, a fraction of the water

Table 3. Distribution of the CSO as a function of the discharged volume and rainfall characteristics (2009 rainfall estimates).

CSO volume (m^3)	Number of CSO during 2009	Total volume discharged		Range of average rainfall volume (mm)	Range of average intensity (I_{20}) (mm)
		m^3	%		
< 1000	8	4580	0.5	< 1–6.9	< 1–3.8
1000–10,000	10	39,312	4.4	< 1–20.4	2.2–33.6
10,000–50,000	11	240,417	27.1	1.5–22.6	3.4–23.4
> 50,000	3	602,443	67.9	25.8–55.8	29.7–50.7
Total CSO	32	886,752	100	< 1–55.8	< 1–50.7

was regulated by the tank, sent to the WWTP and discharged after treatment, and the other fraction was discharged directly into the receiving waters (CSO). In Scenario 3, the storm tank was operated by taking advantage of the natural settling process that occurs in the tank, where the largest fraction of the water was discharged from the storm tank after sedimentation (80% of the water regulated by the tank), the second fraction was discharged from the WWTP after treatment (20% of the water regulated by the tank), and the unregulated fraction was discharged directly without treatment (CSO). Since the filling and settling events can aggregate in Scenario 3, the emptying point was set at 20% from the bottom of the water column in the tank in order to ensure that the discharge into the receiving waters has the best possible quality. The tank's operational mode in Scenarios 2 and 3 allowed the regulation of 46.4% and 65.9% of the CSO water, respectively.

Table 5 shows that operation of the CSO storm tank in a traditional mode results in a significant reduction of contaminant in the discharges from the Riera d'Horta basin to the Mediterranean Sea, representing a reduction of 45.7% SS and 43.4% COD. The implementation of the Scenario 3 results in an even larger efficiency in the reduction of the total contamination, with a reduction of 60.6% SS and 58.5% COD. Thus, the contamination reduction efficiency of Scenario 3 is 15.0% and 15.1% higher for the SS and COD, respectively, when compared with Scenario 2.

Discussion

The results from the average quality of rainwater in CSO, the EMC, highlight the problems of mobilised pollution management during rainfall events in the sewerage networks. The three pollution sources in the combined basins are: a) the contamination of the wastewater itself; b) the urban surface runoff where the accumulated contamination on the surfaces (streets, roofs, etc.) is flushed and carried into the sewerage network; and c) the re-suspension of sediments settled in sewers during dry weather prior to the rainfall event. The last one, as most authors confirm, is the most significant source (Villar *et al.* 2008 or Chebbo and Gromaire 2004), being the re-suspended mass fraction higher when the dry weather is longer and the rainfall event is more intense. The high EMC detected and the fact that there is no dilution factor in the drainage basin analysed during the rainfall is an indication that the produced discharges can have a large impact on the receiving waters.

The construction of CSO storm tanks is a good solution to reduce these discharges. As shown in the comparison of Scenarios 1 and 2, the availability of a large storm tank against the CSO can greatly reduce the discharge of pollutants to the receiving waters (Table 5). Besides, it is also possible to improve the performance of these storm tanks by increasing the annual regulation capacity. Scenario 3 shows that significant decontamination of the middle and upper layers of the retained water can be achieved within 2 hours of rainfall events due to gravity. Similar results are also found in other studies where sedimentation phenomenon was analysed (e.g. O'Connor *et al.* 2002). Thus changes in a tank's operational mode, that considers the discharge of higher-quality water after the sedimentation process, implies a reduction of the CSO volume.

This operational mode is particularly interesting in the cases where there is no first flush phenomenon detected in the basin. By increasing the regulation volume the impact of the discharges to the environment can be further reduced. On one hand, the goal is to empty the largest possible volume of retained water so that the tank is available quickly to be able to regulate new volumes, thereby increasing the annual regulation capacity of the tank. Consequently, the environmental impacts associated with the materials used in the construction of the tank will also be reduced per unit volume of regulated water. On the other hand, it is important that the discharged water from the tank to the environment has the best possible quality to minimise the impact on the receiving waters.

The SS is one of the widely used indicators in assessing the pollutant content in storm water (Sartor and Boyd 1972), and thus the results obtained in Scenario 3 regarding reduced discharged SS into the receiving waters establish a good representation of pollution reduction strategy from sewerage networks. This is because most of the contaminants are deposited into sediments, particularly the finer particle ones. COD on the other hand is a promising indicator that measures the content of organic

Table 4. Distribution of the CSO as a function of the tank filling and evaluation of the volume that could be regulated (2009 rainfall estimates).

			Number of days	Volume discharged (m^3)	Could it be regulated part of the CSO spilled?	Volume capable of being regulated (m^3)
CSO not detected	Storm tank is in operation	Case 0. Complete/partial filling of the tank	7	0	No	0
		Case 1. Partial filling of the tank	3	6548	No	0
		Case 2. Complete filling of the tank	13	403,622	Yes	157,139
CSO detected	Storm tank is not in operation	Case 3. Empty tank is not in operation	6	7189	No	0
		Case 4. Tank is already full	10	469,393	Yes	166,673
Total			39	886,752	–	323,512

matter in sewerage water indicating the water quality is favourable for the aquatic environment. The results of this study demonstrate that the COD can be reduced significantly using Scenario 3 installation.

The decontamination performance of the storm tank after sedimentation shows that microbiological parameters are the most critical parameters in the operation of the tank allowing release of lowest contaminant water to the environment. In order to improve the microbiological contamination performance, the emptying of the tank after settling can be combined with a bacteriological disinfection system like chlorine dioxide, ozone, UV radiation or bromine disinfection (Takahashi *et al.* 2008).

An operational mode that takes advantages of sedimentation can be monitored online and on a real-time basis using turbidity sensors. Some studies show that there is a good correlation between the turbidity and the SS (Bertrand-Krajewsky *et al.* 2004). This present study has shown that the turbidity measured online follows the same pattern as the settling of the SS in the sedimentation experiments. Although these sensors are not very precise, they provide very useful information on the tendency of the sedimentation process. It is noteworthy that implementing SS modelling is a rewarding tool to know the settling process on storm tanks due to the difficulty of executing on-site campaigns (Dembélé *et al.* 2011 or Maruejouls *et al.* 2012).

The realisation of Scenario 3 affects the operational phase and the infrastructure design. To configure a CSO storm tank such that the emptying depends on the different qualities of the water column stratified in the tank interior, it is necessary to include the placement of emptying gates or pumps at different heights in its design. It is also important to consider the shape and type of the tank in the design so that it favours the sedimentation, such as lamellar sedimentation tanks, silt trap sedimentation tanks or vortex separator tanks. The sedimentation process can also be improved in speed and in the percentage of sedimented matter with the addition of coagulation/flocculation products.

Conclusions

- To achieve the quality objectives set for the receiving waters in an urban environment, it is necessary to equip the sewerage networks with control systems and discharge treatments so that there is an adequate management of the flow and contamination load during rainfall events.
- The introduction of a CSO storm tank in an urban drainage basin with a combined sewerage network system results in achieving significant reduction of discharge impacts during rainy weather. In the Mediterranean basin studied, the reduction was

Table 5. Annual volume regulated by the tank and discharged to the receiving waters in terms of volume, suspended solid (SS) and chemical oxygen demand (COD) from the different subsystems according to the different scenarios (based on data from 2009).

	Scenario 1			Scenario 2			Scenario 3		
Volume regulated by the storm tank (m^3)	0			767.242			1.090.754		
Discharge to receiving water:	Volume (m^3)	SS (t)	COD (t)	Volume (m^3)	SS (t)	COD (t)	Volume (m^3)	SS (t)	COD (t)
A. From combined sewer (CSO)	1,653,994	1695.0	1453.0	886,752	908.7	779.1	563,240	577.2	494.8
B. From WWTP after treatment	0	0	0	767,242[a]	12.3	43.7	218,151[b]	3.5	12.4
C. From storm tank after decantation	0	0	0	0	0	0	872.603[c]	86,6	95,8
Total discharged to receiving water	1,653,994	1695.0	1453.0	1,653,994	921.0	822.8	1,653,994	667.3	603.1
CSO reduction percentage (%)	0	0	0	46.4	45.7	43.4	65.9	60.6	58.5

Notes: a) Corresponds to the entire volume regulated by the tank on scenario 2, b) Corresponds to 20% of the volume regulated by the tank on scenario 3, c) Corresponds to 80% of the volume regulated by the tank on scenario 3.

quantified to be approximately 45% in the discharged SS and COD.

- In order to optimise the storm tank operation, the overall management of the sewer networks, receiving waters and WWTPs it is necessary to understand the physico-chemical processes of the sewerage network during rainfall events (the analysis of the dilution factor or the determination of the existence of a first flush) as well as inside the storm tanks (the sedimentation process inside the water column).
- The performance of the large traditional storm tanks, very common in the Mediterranean region, can be optimised using an operational mode that takes advantage of the natural sedimentation process occurring when rainwater is retained in the tank, requiring some modifications in the design of the tanks. The trends of settling processes could be followed by measuring online turbidity in real time.
- The determination of the optimal stratification condition in the water column allows an improvement to the strategies to discharge better quality water to the receiving waters, which in turn allows the regulation of new polluted flushes not treatable in the WWTP. This results in an increase in the annual regulation capability of the storm tank, which was quantified as 15% higher in the case study system compare to traditional tank operation, and a minimisation of the contamination discharge to the receiving waters (about 60% for SS and COD).
- The environmental impact on the infrastructure associated with the tank materials per m^3 of regulated water can also be reduced with the increase in annual regulation capacity. Additionally, an operational mode that takes advantage of natural sedimentation reduces the consumption and impact of chemicals and energy used in the WWTP due to the reduced volume of water to be treated from the sewerage network. Future research may focus on a Life Cycle Assessment, which can address the global environmental impacts, and thereby the development of strategies to reduce the impacts associated with whole life cycle of the sewerage network including the construction of the storm tanks and the operation and maintenance of these infrastructures.

Funding

This study was based on the results achieved within the framework of "Project CENIT Sostaqua - Technological developments towards self-sustainable urban water cycle (2007–2010)", funded by CDTI (Centre for Industrial Technological Development of the Spain Government) and led by Agbar and, more specifically, within the "Activity 3 - Sustainable Rainwater Management," led by CLABSA.

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