ANALYSIS OF COMBINED SEWER OVERFLOW SPILL FREQUENCY/VOLUME IN NORTH OF SPAIN

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ABSTRACT

Combined sewer overflows conducted to receiving waters must be included in the pressure analysis of receiving systems. To estimate these pressures, the number of CSO events or the amount of water released over a time period can be used as a tool to assess the performance of the sewer system. This paper presents a comparison of the hydraulic behaviour of CSO tanks placed downstream from six catchments located in three cities of North of Spain. After modelling the four catchments in Lugo, it was possible to calculate the effect of the specific storage volume of these devices on the amount of water released and the number of CSO events. The results obtained are compared with those reported in Santander (Temprano, 1996) and Santiago de Compostela (Beneyto, 2004). The relationships between the number of CSO events/percentage of spilled runoff and the specific storage capacity of the tanks allowed us to obtain an order of magnitude on which to base the sizing of these structures.

Keywords: Combined sewer overflow, CSO tanks, spill frequency, storm water management model

1 INTRODUCTION

Nowadays, the efficiency of an integral drainage-sanitary plan of a catchment, in which overflow management tools must be included, in terms of reducing the pressure on receiving systems and meeting water quality objectives (physical-chemical, biological and hydromorphological).

All phenomena related to spill pollution from sewer networks must be considered in the pressure analysis of aquatic systems. Three types of phenomena can be distinguished: direct discharge or separate sewer overflow as well as runoff from drainage systems; combined sewer overflows (CSO); pollution spilled from Wastewater Treatment Plants (WWTP) that do not function properly due to non-specific operating plans during wet weather conditions. The main differences between these phenomena are attributed to overflow volumes, average and maximum pollutant concentrations and phases and discharge periods.

Different CSO technologies could be used to minimize the impact exerted on the aquatic receiving system. Design-criteria are usually based on achieving some of the following goals:

- Pollutant mass retention (%) followed by a treatment process (event or annual balance)
- Overflow volume retention (%) followed by a treatment process (event or annual balance)
- Overflow frequency limited to a certain number per year by generating volume capacity in the sewer system and/or WWTP.
- Elimination yield of certain pollutants in CSO. Usually equivalent to a primary treatment level.
- First flush capture for future treatment
- Avoiding peaks of pollution events within the aquatic receiving system
- CSO maximum duration (hours)

It is difficult to develop technologies based on pollution control and to link them to traditional water quality controls in receiving waters due to the intermittent nature of CSO. Nevertheless, it is of utmost importance to carry out an in-depth examination of both the behaviour of combined sewer systems during wet weather as well as the response of aquatic receiving systems.

The pressure exerted by a catchment (with traditional overflow structures or retention tanks) on an receiving system can be controlled by two fundamental parameters: (1) number of overflows per year, and (2) annual overflow volume. The first parameter is related to transitory pollution events which lead to acute levels of contamination, whereas the second parameter deals with chronic environmental problems due to the total mass spilled.

A preliminary approach to the response of a combined sewer catchment with a retention tank can be developed by analysing the relationship between the specific retention volume (m3/net ha) with the number of overflows per year or with the annual spilled runoff volume. These relationships can be generated from an analysis of different catchments located in the same city, region or geographic scope. The principal factors involved are rain regime, catchment morphology, sewer system configuration and the design volume of the storage treatment unit.

This paper presents a study of six urban-combined sewer subcatchments from three cities in the North of Spain with similar rainfall profiles. The main objective was to obtain the final volume of the CSO chamber based on the information provided by the relationships described above.

2 DESCRIPTION OF THE URBAN CATCHMENTS

This paper compares the hydraulic performance of six urban catchments from three cities in the North of Spain: Lugo, Santiago de Compostela and Santander. As can be seen in Fig. 1, in these cities the volume of annual rainfall is around the same order, which illustrates the similar climatic characteristics of the areas analysed.

Temprano (1996) analysed the storage volume needed in a combined sewer system tank in order to preserve the water quality of the receiving media in Santander city. A numerical model was used to analyse the performance of the retention tank located downstream from a synthetic catchment with a 36 ha surface. Results such as the number of overflows per year and the percentage of runoff spilled were obtained on the basis of the rainfall recorded in Santander for 11 years, by analysing several combinations of storage volumes and treatment capacities in the wastewater treatment plant.

A residential urban catchment in Santiago de Compostela was studied by Beneyto (2004). The catchment area totals 80 ha, 56% of which is impervious surface. The combined sewer network and the CSO tank placed downstream from the basin were simulated. The rain recorded during 2002 was used to estimate the number of CSO under different specific storage volumes.

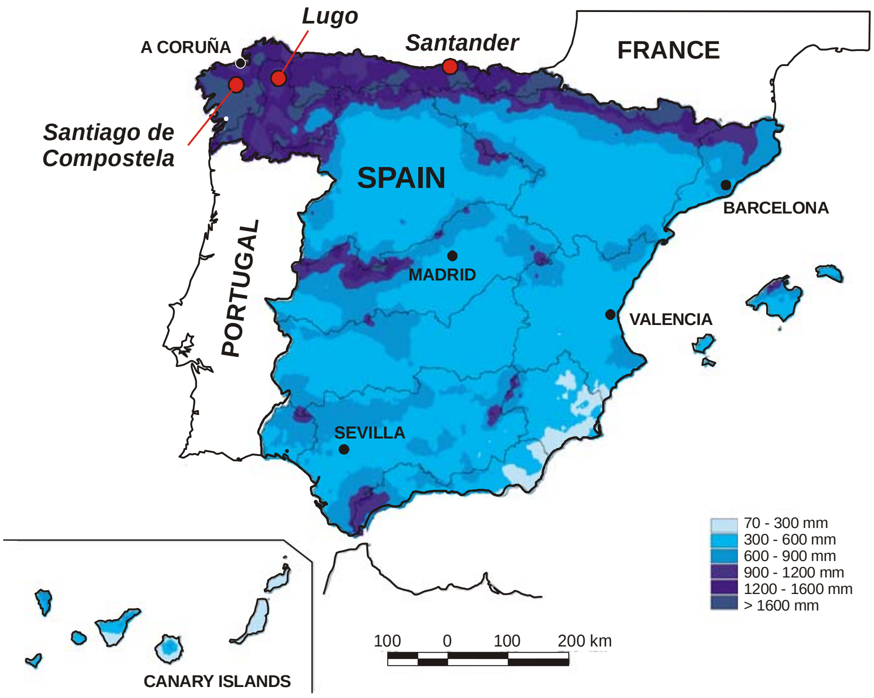

Fig. 1 Layout map of thecities analysed with annual average rainfall in Spain for the period ranging between 1940/41 – 1995/96 (MMA, 2000)

Lastly, the results from the numerical simulation of the four catchments in Lugo are determined. The rain recorded from 1993 was employed to calculate the annual number of overflows from the four storage units located downstream from each subcatchment.

Table 1 gives a brief summary of the hydrological parameters and rainfall characteristics of the six catchments analysed in this article.

Table 1. Summary of the main characteristics of the catchments analysed.

PARAMETER	**SANTANDER Temprano (1996)**	**SANTIAGO Beneyto (2004)**	**LUGO**			
Annual rainfall (mm)	1013	1652	1065			
Mean daily rainfall (mm)	2.77	4.52	2.28			
Rainfall days per year (d)	128	141	131			
Catchment Name	Synthetic	Cancelón	A Cheda	Valiño	Fingoy	A Tolda
Morphology	High-Medium density	Medium density	Medium density	Medium density	Medium density	Medium density
Area (ha)	36	80	96	55	18	92
% Impervious area	90	56	60	58	48	68
Average slope (%)	1	6.7	6.5	6.1	5.3	7.2
Annual runoff volume (m^3)	292584	430740	528920	259945	78468	567444

Version 5.0 of Storm Water Management Model (Rossman, 2005) has been used to develop catchment models. Data from the civil engineering project of the Lugo sewer system was used to determine system network characteristics and catchment zoning. The model has 40 subcatchments, hence the discretization carried out is detailed enough to simulate input flows to CSO tanks (Fig. 2).

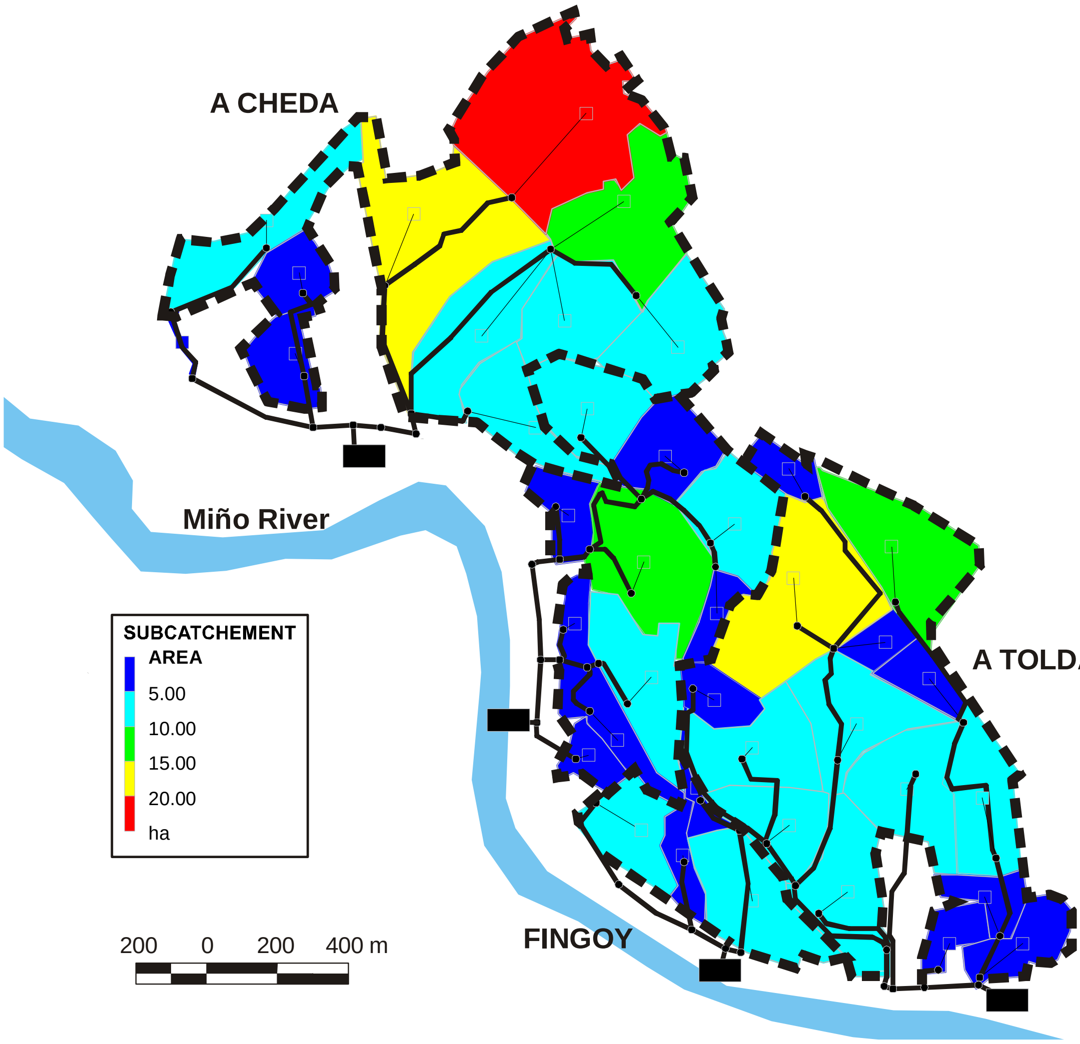

Fig. 2 Layout map of the model developed for Lugo catchments.

Parameters governing runoff generation have been adopted from the shape and average slope of each subcatchment. Manning's roughness coefficient for impervious areas was 0.018 and 0.15 for pervious areas. Depth of depression storage used was 0.15 mm and 2 mm in impervious and pervious areas respectively. To calculate infiltration, the Horton equation was used with an infiltration rate ranging between 75 and 10 $mm \cdot h^{-1}$ (for permeable and impermeable surfaces respectively). The decay constant was 4 h^{-1}.

Storage units are simulated as an in-line chamber with the layout plan of the CSO tanks being built in Lugo. Output flows from the tanks is controlled by a valve which prevents the entrance of flows 6.7 higher than the average flow. Spills are conducted by a lateral side weir.

In Santiago and Santander the catchment modelling was realized with a previous version of SWMM (4.4). The discretization detail of these models was similar to the type developed in the Lugo catchments.

3 RESULTS AND DISCUSSION

Once the catchments were modelled, it was possible to calculate the effect of the size of the devices analysed on the amount of water released and the number of CSO events. Despite the fact that these criteria do not take into account the impact on receiving waters, this method is commonly used to evaluate system performance, owing to its simplicity and the possibility of making comparisons between different locations.

Different tank configurations, consisting of an on-line tank and an off-line tank were tested by Temprano, who concluded that the discharge distribution between the tanks does not modify either the amount of volume released or the number of CSO events (Temprano and Tejero, 2002). Fig. 3 shows the relationship between the number of CSO events and the storage capacity of the tank, as a function of the discharge sent to the WWTP, in a catchment of about 32.4 net-ha. It can be observed that a rate of 20 CSO events per year needs a volume of 45 m^3/net-ha, if a discharge of 5 times the mean daily flow is conducted to the WWTP, or a volume of 150 m3/net-ha if the discharge sent is only two times the dry weather flow.

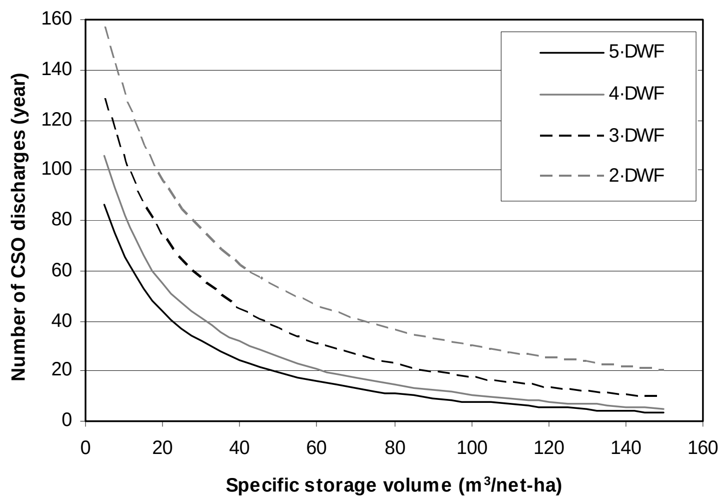

Fig. 3 Relationship between the number of CSO events and the specific storage volume in Santander (Temprano, 1996).

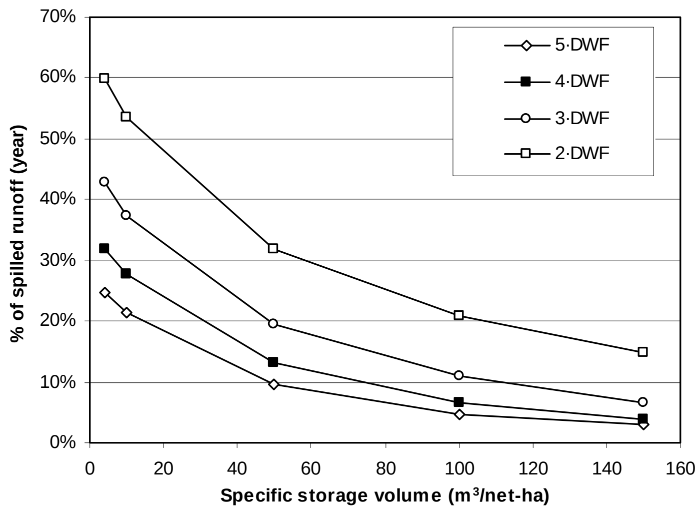

Fig. 4 Relationship between the percentage of spilled runoff volume and the specific storage volume in Santander (Temprano, 1996).

Figure 4 illustrates the percent of volume released during a mean year, taking the above parameters into account. The total runoff volume was 292584 m^3.

The behaviour of a CSO tank in the city of Santiago de Compostela was analyzed by Beneyto (2004). The storage treatment unit simulated by this author has an on-line tank (with 48% of total tank volume) and an off-line tank from which overflows are produced.

Depending on the specific volume of the tank (m^3/net-ha), and on the discharge driven to the WWTP (from 2.5 up to 9.9 times greater than the dry weather flow) either the volume released or the number of CSO events were calculated. Fig. 5 shows the percent of volume released, for a total runoff of 430740 m^3. Fig. 6 shows the number of CSO events.

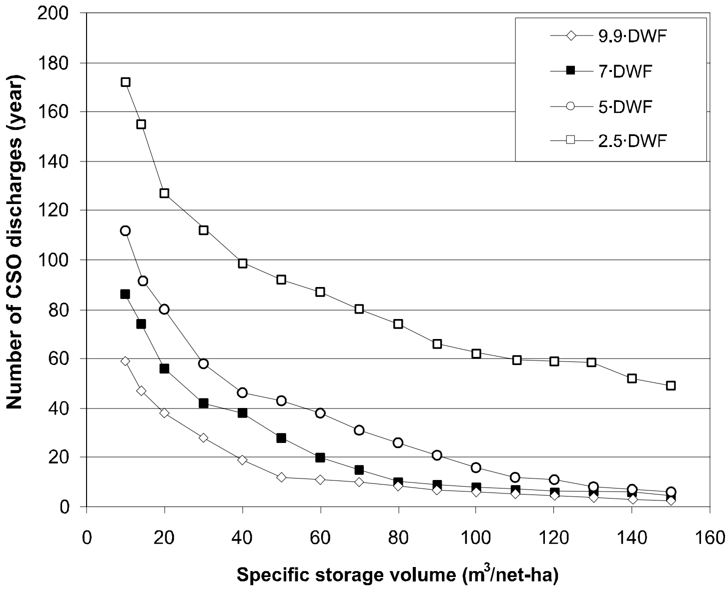

Fig. 5 Relationship between the number of CSO events and the specific storage volume in Santiago de Compostela (Beneyto, 2004).

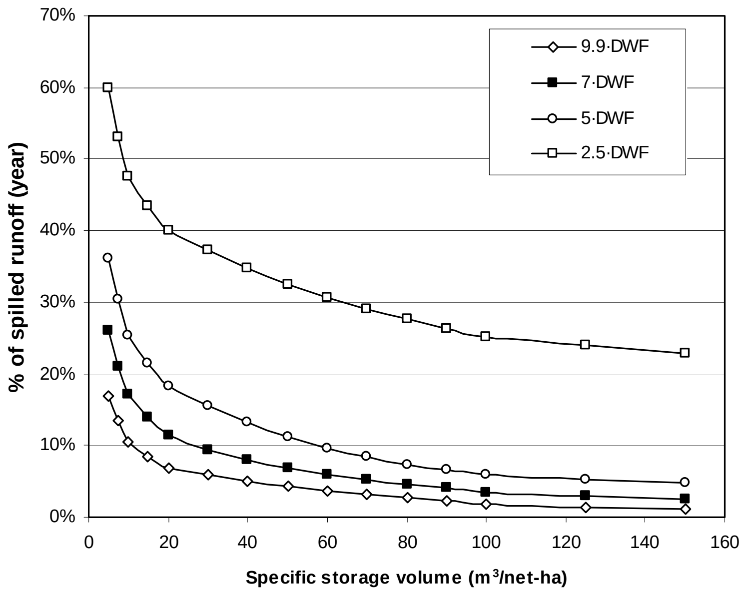

Fig. 6 5 Relationship between the percentage of spilled runoff volume and the specific storage volume in Santiago de Compostela (Beneyto, 2004).

The analysis carried out in Lugo uses the same methodology, and the release volume and number of CSO events have been calculated. The discharge conducted to the WWTP is fixed at 6.7 times the average flow. The results, shown in Fig. 7, are quite similar in the four catchments considered here. However, if the percent of volume released is analysed, the Fingoy catchment exhibits a larger volume (see Fig. 8).

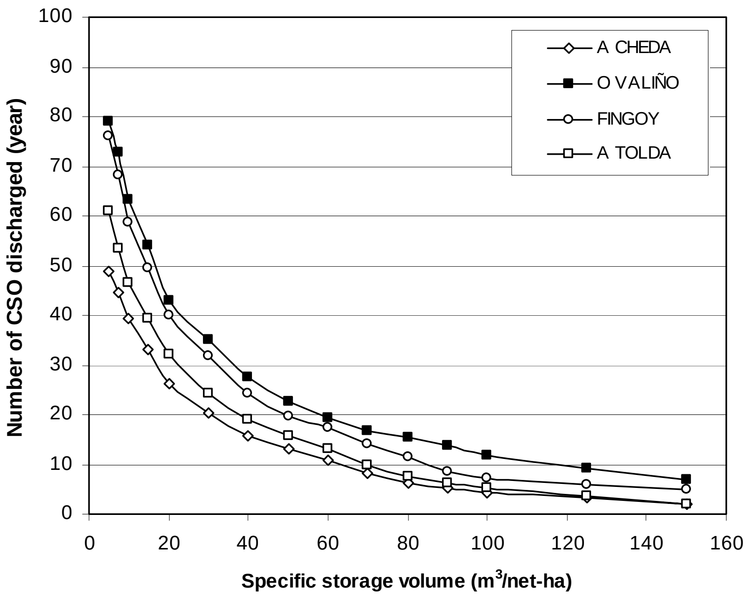

Fig. 7 Relationship between the number of CSO events and the specific storage volume in the catchments analysed in Lugo.

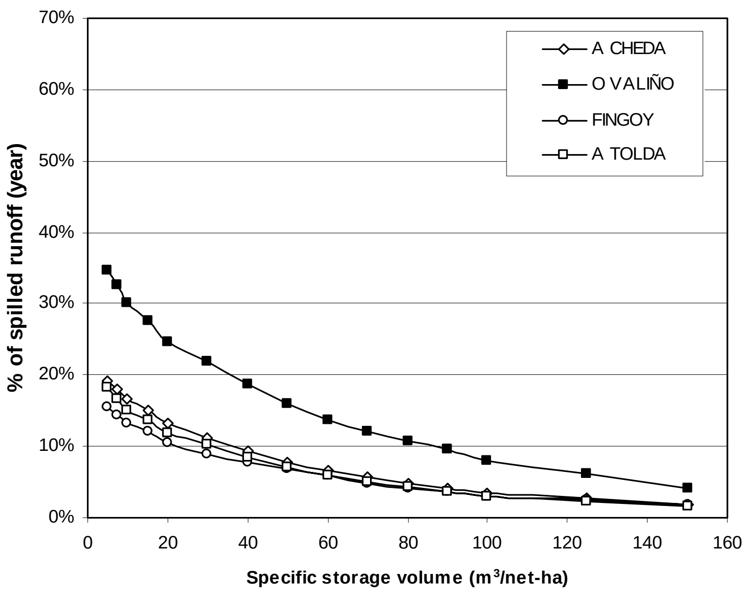

Fig. 8 Relationship between the percentage of spilled runoff volume and the specific storage volume in the catchments analysed in Lugo.

The reason for this behaviour is the shape of the catchment. As can be seen in Fig. 2, the catchments called A Cheda, A Tolda and O Valiño are long and narrow, while Fingoy is short and wide. Concentration times are considerably shorter, and the hydrographs show higher peak discharges.

Fig. 9 shows a comparison between the number of overflows from Santiago de Compostela and Santander. It was found that the relationships in Santiago presented higher values than those obtained in Santander. This is mainly due to the difference in rainfall profiles between the two cities: annual rainfall volume in Santiago de Compostela is 62% higher than the value recorded in Santander (see Table no. 1)

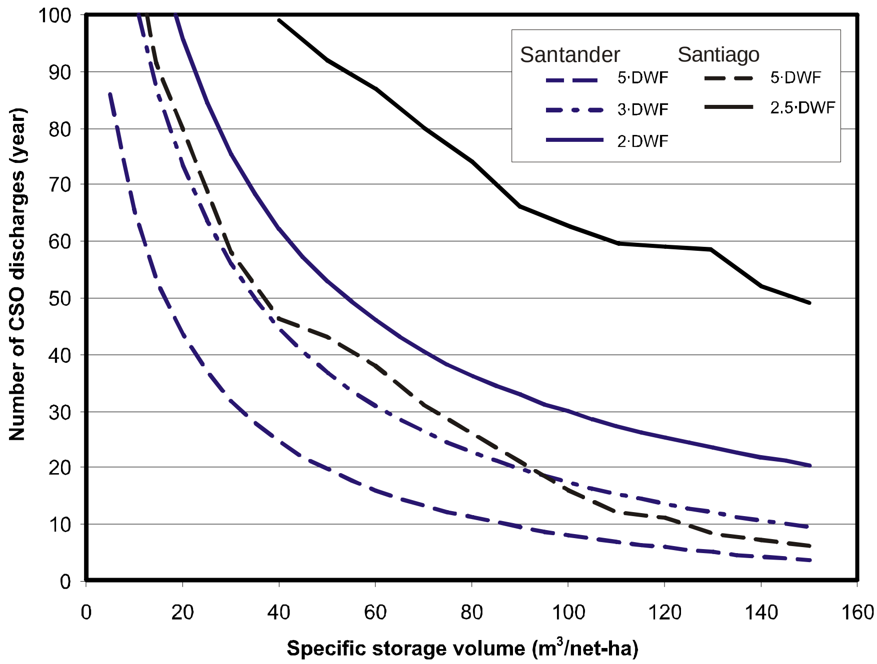

Fig. 9 A comparison between the number of overflows per year in Santiago de Compostela and Santander (average flow ranging between 2 and 5).

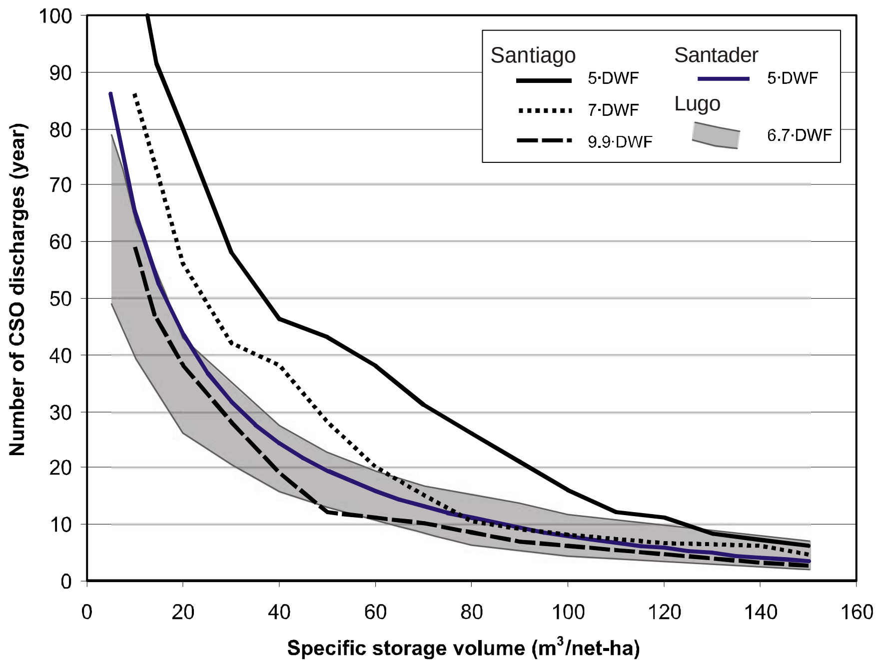

Fig. 10 Number of overflows per year for the three cities analysed (average flow ranging between 5 and 9)

Fig 10 shows the number of overflows that occurred in the cities analysed when the flow conducted to the WWTP is within a range of 5-9 times greater than the dry weather flow.

Lugo's relationship presents the range of variation of the four catchments studied. Santiago was found to have the highest number of CSO for the same flow sent to the WTP and the same specific storage volume. Results form Santander and Lugo are not directly comparable because the flow conducted to the WTP is different. Nevertheless, the trend observed in Santander's curves shows that if the flow sent to the WTP is 7 times higher than the average dry weather flow, the number of overflows per year would be lower than the number of CSO produced in Lugo.

4 CONCLUSIONS

This paper has presented a comparative study of the pressures exerted by combined sewer overflows in the North of Spain on receiving waters. The analysis includes an estimation of both the number of CSO events per year as well as the volume of water released into them.

If our objective is to design a CSO tank that will produce overflows roughly 20 to 30 times per year, the storage volume needed varies substantially depending on the discharge conducted to the WWTP and the city being analyzed. For a discharge sent to the WWTP that is 5-7 times greater than the mean discharge, the storage value fluctuates from 20-50 m^3/net-ha in Santander and Lugo, to 50-90 m^3/net-ha in Santiago. Differences between cities are mainly caused by the higher annual rainfall of Santiago.

If the idea is to retain 90% of the annual runoff, the storage volume in the CSO tanks must be 50 m^3/net-ha in Santander, whereas in Santiago the tanks would have to contain between 60 m^3/net-ha, if a discharge 5 times greater than the average is conducted, and 30 m3/net-ha, in cases where a dry weather discharge 7 times greater than the average is being sent to the WWTP. In the city of Lugo the storage volume would range from 90 m^3/net-ha, in the O Valiño catchment and the 35 m^3/net-ha required in the other catchments.

Despite the differences found among the cities, which may be attributed to different rainfall profiles (mainly intensity and total precipitation) as well as differences in catchment morphology, the curves shown here define a similar design range and they allow us to obtain an order of magnitude of the volume required in the design of these types of infrastructures for "Wet Spain". However, as mentioned earlier, the correct choice of the number of sewer overflows or percentage of spilled runoff for each catchment must be based on the quality criteria of the receiving system to which the discharge is being conducted.

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