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Influence of SUDS Allocated Area on Runoff Reduction in Developing Urban Catchments: a Case Study in San Sebastian (Spain)

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Abstract

Despite the increasing use of Sustainable Urban Drainage System (SUDS) techniques, it is still difficult for urban planners to identify how many shall they implement, especially when planning new developments. In addition, most agencies or public authorities limit runoff outflows to the greenfield or undeveloped conditions, but planners do not have the capacity to link this objective to the level of SUDS implementation. Thus, the objective of the present study is to analyse the relation between the implementation level of SUDS and the reduction of urban catchment ouflows (peak flow and volume), compared to greenfield condition. For that purpose, a hydrological model was created with the Storm Water Management Model (SWMM), based on a case study of 3.2 ha in Donostia/San Sebastián (Spain). The greenfield scenario was characterised with a CN equal to 78. Pervious and impervious areas were identified into the urbanised plot, as well as the existing drainage network. Finally, certain area of SUDS was assigned to each subcatchment randomly, and hydraulic variables were compared at the outlet with the ones in the greenfield situation. As the area is a dense urban area, the considered SUDS for this study were green roofs, permeable pavements and bio-retention cells. Four storm scenarios were used, with a 30 minutes duration but different return periods: 2, 5, 10 and 20. Results show how SUDS application is more effective with the peak than with the volume, and that surface with SUDS applied on a 35% of the surface may reduce the outflow peak to its greenfield value.

Keywords:SUDS; SWMM; urban planning; SUDS allocation.

1. INTRODUCTION

Urbanisation and varying precipitation regimes derived from climate change threaten long-term reliability of urban drainage networks. Sustainable Urban Drainage Systems (SUDS), which manage surface runoff at source by enhancing infiltration, evaporation and detention, are helpful instruments to address those future challenges.

Although there are several SUDS practices with different hydraulic and quality performances, space limitations constraint those that can be applied in highly urbanised environments without reducing the operating area for pedestrians and vehicles. Permeable pavements, for example, allow runoff control without reducing the hard surface, especially important if there is little available space for stormwater detention (Kuruppu et al., 2019). On the other hand, and although bioretention cells do not meet that requirement, bioretention systems are some of the most commonly used SUDS practices (Skorobogatov et al., 2020).

Urban environments often have two very different types of plots, private and public, with very different design and development processes. In that regard, an increasing number of authorities are supporting the use of green roofs in private buildings. In addition, as private plots also have areas with surface use easement, permeable pavements may also be applied in those private plots.

But, regardless the SUDS or plot type, SUDS selection, design, and location is a high-level complexity problem (Ferrans et al., 2022). In that regard, strategic planning approaches can be very helpful tools to help in the spatial allocation of SUDS, but the urban planners are reluctant to use them (Kuller et al., 2019).

On the other hand, as flood control will be a critical planning issue in the future (Kong et al., 2017), hydrological issue will play a critical role in that allocation process. Hence, it is common to analyse SUDS requirements hydrologically, usually comparing it with a greenfield scenario with no urbanisation in it.

Previously, Palla and Gnecco (2015) studied how some hydrologic performance parameters varied under several SUDS application scenarios. Just considering one single scenario for permeable pavements and four scenarios for green roofs, they established a linear relation between the applied SUDS area and the peak and volume reduction, compared to a scenario where no SUDS was applied. They found that peak reduction was 45% and volume reduction was 24% when implemented SUDS occupied 36% of the area.

This study deepens on the reduction of those parameters (runoff volume and peak) with the random application of different SUDS percentages. The performance of the SUDS application percentage is compared with a greenfield baseline scenario. This analysis is made to help urban planners deciding how much space shall be allocated for SUDS in a new urban development if certain hydraulic objectives are to be fulfilled, in the very early stages of the planning, when there is limited information about the drainage network or even the space type distribution.

2. METHODS

2.1 Case study

The case study has been conducted in a new development located in the city of Donostia/San Sebastián (Spain), as shown in Figure 1. The new development was built in a plot with some buildings, lawns and gardens, with a total area of 15.5ha. The area had numerous flooding problems in the past, as it is located at the Urumea river mouth. The study was conducted because the city council aims to promote the use of SUDS at the municipal level.

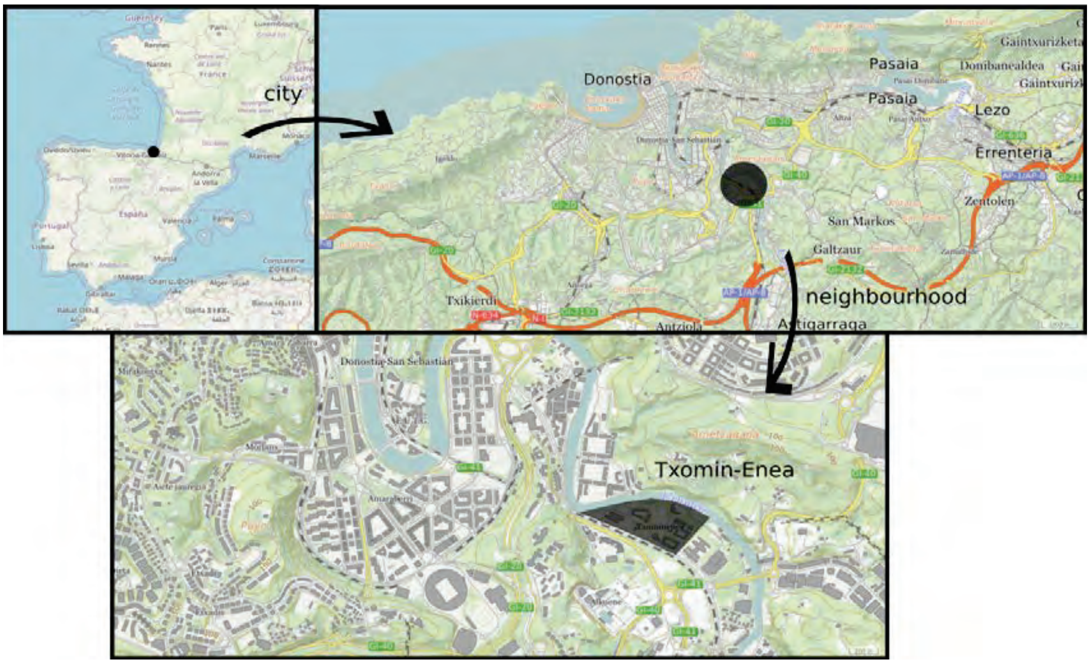

Figure 1. Case study location.

Donostia/San Sebastian has an Atlantic climate, and average annual rainfall is 1474 mm. Rainfall is evenly distributed throughout the year, the monthly average is between 90-120 mm in the less rainy months, and between 140-175 mm in the rainiest months. For this study, IDF curves from Igeldo weather station were selected, as it has a long historical record. For the analysis, 30 minutes duration constant rainfalls were considered, with these intensities for each return period (Tr): 40 mm/h (Tr = 2 years), 52 mm/h (Tr = 5 years), 61 mm/h (Tr = 10 years) and 70 mm/h (Tr = 20 years).

As the new development is located by the Urumea river, it has several drainage outflows to the river, with 3 independent subcatchments on the plot that direct the flow to the river. For this study, only the area contributing to one of the catchments has been selected, with a total of 3.2 ha(see Figure 2, where the area contour is drawn in red).

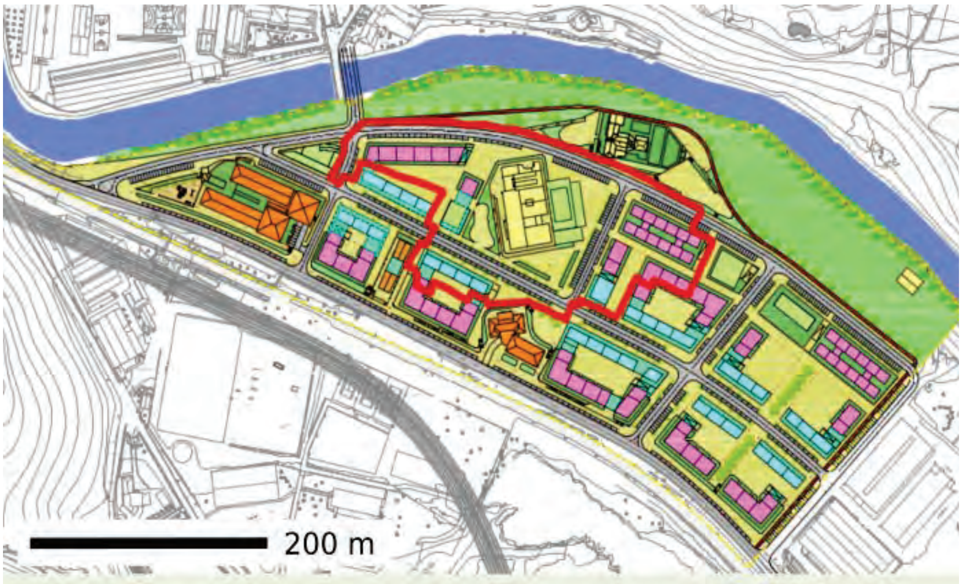

Figure 2. New development and the area selected for the analysis (contour is drawn in red).

2.2 **SUDS implementation analysis**

To carry out the analysis, a detailed model of the catchment was created in SWMM, with 372 subcatchments (see Figure 3). Private and public spaces were considered in the urban plot. The private ones, which were 55% of the total area, included private plots with public use easement on the surface. Public space was divided in sidewalks (24%), roads and parking lots (19%), bike lines (1%), and green areas (1%). Except the last one, all of them were sealed with conventional pavement on the surface. For the analysis, bike lines were considered as pathways.

The drainage network of the area has a total of 152 pipes and 153 manholes. The pipe diameter ranges from 0.25 m to 0.80 m. The smallest ones are PVC pipes located in the begging of the network, to direct water from the catchment basins to the main pipes. Water from private lots is collected in PVC pipes with a diameter of 0.30 m. Rest of the pipes are the ones from the main pipe, which direct water to the river outlet (on the left upper side of Figure 3). Biggest pipes, from 0.50 m diameter, are concrete pipes.

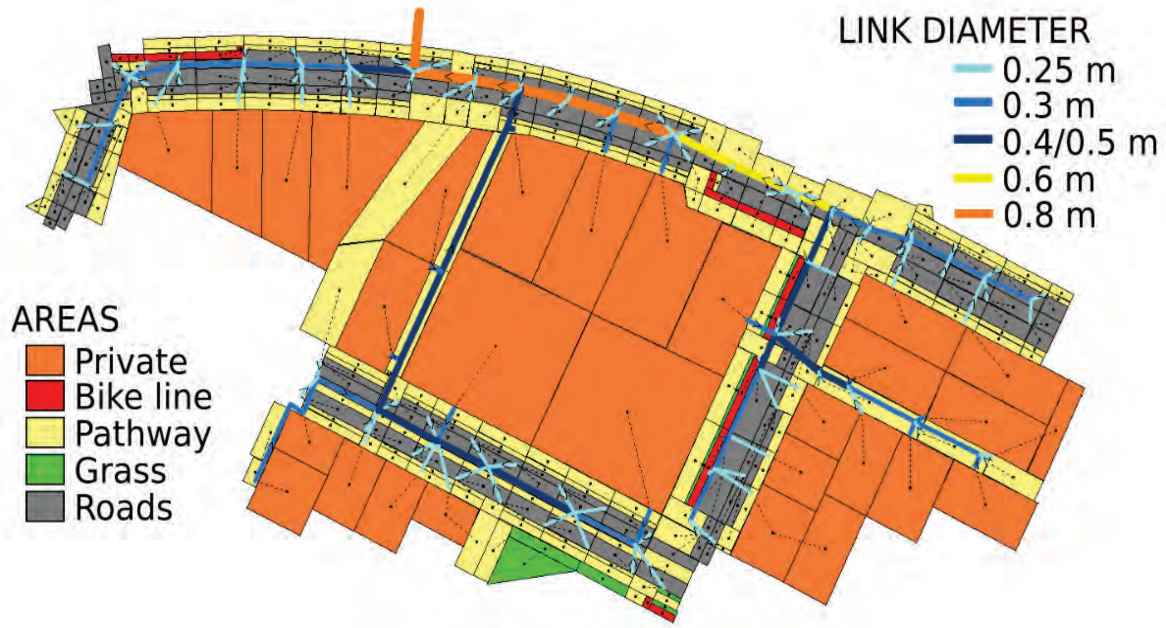

Figure 3. SWMM model of modelled area, with different colours for each considered subcatchment typology and pipe diameter.

The SUDS implementation analysis was made based on a greenfield scenario, which was considered as a baseline to compare runoff volumes and peak values in the outflow from the subcatchment. That greenfield scenario was characterised by a CN equal to 78, correspondent to a cultivated land, with conservation treatment and an hydrologic soil group C.

For SUDS application scenarios, it was considered a CN equal to 98 for all impervious surfaces (road, pathways, cycle paths and private plots), and 78 for green spaces (same as greenfield case). For application of the CN method, a depression storage of 2.5 mm was used over green areas, 1.6 mm for impervious areas and 6 mm for greenfield case (Rossman and Huber, 2016a).

For SUDS implementation analysis, three SUDS types were considered: permeable pavement, green roof and bioretention cell. Used parameters are given in Table 1, which are commonly used for SUDS design (Rossman and Huber, 2016b) No drain was considered for any of the SUDS, neither clogging conditions.

Table 1. SWMM parameters for considered SUDS types.

LAYER / PARAMETER	UNITS	GREEN ROOF (GR)	PERMEABLE PAVEMENT (PP)	BIORETENTION CELL (BR)
SURFACE				
BERM HEIGHT	mm	10	0	100
VEGETATION VOLUME	fraction	0.15	0	0.1
SURFACE ROUGHNESS	$s/m^{1/3}$	0.1	0.1	0.1
SURFACE SLOPE	%	1	1.5	1
PAVEMENT				
THICKNESS	mm	-	80	-
VOID RATIO	V/S	-	0.97	-
IMPERVIOUS SURFACE	fraction	-	0.9	-
PERMEABILITY	mm/h	-	10000	-
SOIL				
THICKNESS	mm	100	0	400
POROSITY	fraction	0.5	-	0.4
FIELD CAPACITY	fraction	0.2	-	0.2
WILTING POINT	fraction	0.1	-	0.1
CONDUCTIVITY	mm/h	100	-	100
CONDUCTIVITY SLOPE	-	30	-	40
SUCTION HEAD	mm	60		60
STORAGE				
THICKNESS	mm	-	400	300
VOID RATIO	V/S	-	0.80	0.75
SEEPAGE RATE	mm/h	-	10	10
DRAIN MATERIAL				
THICKNESS	mm	3	-	-
VOID FRACTION	fraction	0.5	-	-
ROUGHNESS	$s/m^{1/3}$	0.1	-	-

The SUDS application was done considering different plot types and SUDS percentages (see Table 2). In private plots two types of SUDS were applied: green roof and permeable pavement. In public spaces two types of SUDS were also applied: permeable pavement (just on pathways and bikes lines) and bioretention cells (just in road surfaces). The SUDS implementation analysis was done selecting a percentage of application for each type, done randomly, and that SUDS was applied to all subcatchments of the same type (road, sidewalk, etc.). Each percentage was selected independently (four in total), and the global SUDS percentage calculated later. This last value was the only one considered in the following analyses.

Table 2. Percentage ranges applied in the subcatchments for each SUDS type.

	PRIVATE PLOT MINIMUM	PRIVATE PLOT MAXIMUM	PUBLIC SPACE MINIMUM	PUBLIC SPACE MAXIMUM
GREEN ROOF	0%	50%	-	-
PERMEABLE PAVEMENT (PP)	0%	20%	0%	40%
BIO-RETENTION CELL (BRC)	-	-	0%	10%

Some SUDS were designed to collect a certain amount of impervious area of the same type, considering regular design standards. Permeable pavement collected an impervious surface equal to its area (Woods Ballard, 2015). For bioretention cells, the collected extra impervious surface was 4 times the biorentention area.

Analysis of SUDS scenario was done comparing these hydrologic performance indexes for all simulations: runoff peak and runoff volume. The considered parameters for the analysis were the increase of peak and volume over the greenfield scenario, given as a percentage. The simulations were performed 50 times for each return period, thus, a total of 200 simulations were performed.

3 RESULTS AND DISCUSSION

3.1 Outflow peak

If a new urban plot is designed without any SUDS solution in it, see Figure 4, peak flow is increased between 75% and 150% for a certain storm event, compared to greenfield scenario. Those two values correspond to 0% of SUDS implementation for returns periods equal to 20 and 2.Figure shows how that peak increase, compared to greenfield scenario, decreases with the application of SUDS into the urban catchment. The relation between the applied SUDS percentage and the peak flow is linear and, obviously, decreases if the percentage of applied SUDS is increased.

The figure also shows that greater return periods give lower peak increases over greenfield scenario. That is probably related to the precipitation intensity, as greenfield scenario can not manage high water volumes in low time intervals. Hence, peak increase over greenfield scenario is lower for higher return periods. The figure also reveals that the smaller the return period, the faster the peak is reduced with the application of SUDS or, graphically, that decreasing slope is higher for lower return periods.

The figure also shows that, for the analysed three highest return periods, the flow peak is equal to the greenfield case when the SUDS application is around 35%, although the value is a bit different for each return period. However, that value is considerably higher for the lowest return period, which is around 45%. In any case, it can be concluded that an application of a SUDS surface equivalent to the 45% of the total area shall not increase the peak volume compared to greenfield case.

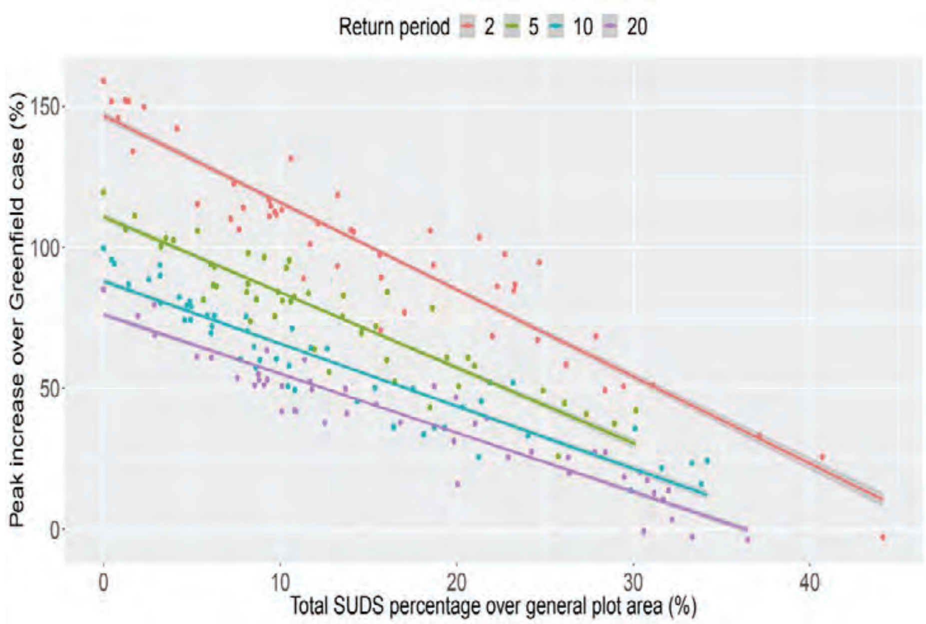

Figure 4. Relation between peak flow and SUDS percentage application into a urban plot, with different colours for considered return periods.

3.2 Outflow volume

Similarly to peak analysis, Figure 5 shows how the runoff volume increases, compared to greenfield scenario, from 175% to 400% if no SUDS solution is applied (value corresponding to 0% of SUDS implementation). Thus, runoff volume increase over the greenfield scenario is considerably higher than the peak increase. Also, in this case, volume increase over greenfield scenario decreases with SUDS application, and it does faster for lower return periods. But, contrary to what happens with the peak, a SUDS application within the 35-45% range does not reduce the outflow volume to the greenfield case. For the volume case, that value only decreases the volume until it doubles the greenfield case, which corresponds to the 100% value in theordinate axis of the figure.

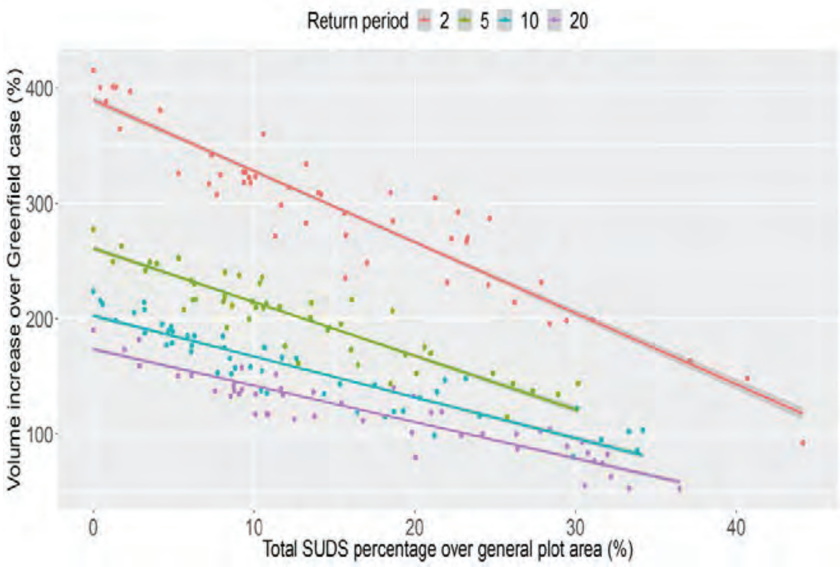

Figure 5. Relation between runoff volume and SUDS percentage application into a urban plot, with different colours for considered return periods.

If both peak and volume results are compared with those obtained by Palla and Gnecco (2015), it can be observed that SUDS are effective even if the implementation level is low, although Palla and Gnecco identified a minimum reduction of 5% was required to obtain noticeable hydrologic benefits. As Palla and Gnecco (2015) compared the reduction based on 0% SUDS implementation, or “do nothing” scenario, comparison is not direct, but findings are in line with those obtained previously.

4 CONCLUSIONS

This study has analysed how SUDS application influences outflow from a dense urban plot. The results show, consideringthe bioretention cell as the only one reducing available space, that it is not necessary to allocate a huge amount of space to get some reasonable reduction on runoff peak and volumes. With these results, urban planners have one more tool to decide, in the very initial stages of urban developments, how much space shall be dedicated to SUDS. Planners can further detail SUDS implementationin future planning stages: what type, management trains, exact location, and other specific details, which are difficult to set in the very beginning of the planning process.

However, this study has some limitations. First, the analysis has been performed with three types of SUDS, but it shall be interesting to check how the output shall perform with other types of SUDS. In addition, SUDS were applied uniformly into the subcatchments, effect shall be different if SUDS were applied randomly over the different subcatchments. Also, this study has just introduced one type of SUDS that decreases the available space for pedestrians and vehicles in dense urban environments: the bioretention cell. Other types of SUDS do not have such limitations, and it would be interesting to analyse this factor. Secondly, the analysis was based on a constant single event storm, but the effect of a continuous modelling should be explored. The study was limited to a certain urban plot and drainage network as well, the effect those late is also recommend to be explored. Finally, individual devices were explored, but management trains shall improve obtained results.

5 ACKNOWLEDGEMENTS

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