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RAINWATER HARVESTING AND REUSE AND RAINWATER RUNOFF IN BARCELONA THANKS TO THE WSUDs (Water Sensitive Urban Design Systems)

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Abstract

"Water sensitive urban design (WSUD) is an approach to planning and designing urban areas to make use of this valuable resource and reduce the harm it causes to our rivers and creeks"[2] WSUDs (Water Sensitive Urban Design Systems) try to integrate the urban water cycle in the urban design to improve the environmental behavior in the urbanization of the cities. When we urbanize we transform pervious surfaces into impervious surfaces. With WSUDs pervious surfaces are implemented.

Water presence should allow rainwater harvesting, decrease water runoff and improve surfaces thermal behavior. The two first hypothesis will be shown in this research. Thus the main question is: could it be possible to reduce water consumption and rainwater runoff thanks to WSUDs in the city of Barcelona? This paper shows a study case trying to answer this question in a flood area. The last question, about surfaces thermal behavior was explained last year in the CTV'2018 [3.] This two articles are a part of the current thesis taken by the author of which Dr.Josep Roca and Dr.Dolors Martínez are tutoring. This part of the research uses a calculation methodology (while the CTV2018 Congress showed an experimental methodology).

As climate change preview more intense rains in our territory the last IDF curves registered by the Fabra Observatory will be used instead of the IDF curves calculated with the MaxPluWin previously by the author due to the fact that the Fabra ones are more precise. Some considerations will be taking when using the "project rain" in order to approach it to the real pluviometry. Thus, reserve period of the water depos will have to be modified in the future and floods in the streets might be increased.

Trying to improve flood effects, water scarcity and the heat island effect, the WSUDs with better thermal effect could be used in some cases harvesting rainwater and reducing the rainwater runoff. This better thermal effect means that WSUDs surface temperature, in some cases, is lower in summer than the environmental temperature[2].

This WSUDs implementation can be used as an urbanistic micro-acupuncture practice. Rainwater runoff also gets to the depuration central station much more polluted after urbanizing if WSUDs are not considered. Therefore, WSUDs allow to improve water quality when it arrives to the water treatment plant as well and reduce energy in its transportation to the sewage treatment plants.

Another question is in which area is better to harvest water if we need a good water quality. It will be possible to treat it, always or with hypochlorite or with ozone but the numbers of molecules required if we need to clean rainwater mixed up with oil or gasolines or without them reduce are much less. Also studies of water quality in blue roofs or green-blue roofs show that the best construction system is a green-blue roof. It's been studied previously although it won't be explained in this paper for not being the main goal.

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[2] Melbourne Water Corporation: https://www.melbournewater.com.au

[3] PÉREZ CAMBRA, M. y ROCA, J. (2018).

The research is focused to work on the most flooded areas in Barcelona by changing impervious surfaces into pervious ones getting rainwater to be reused and removed from the streets. In the studied area results show a not negligible water quantity which could supply some domestic uses of the dwellings in the flood area, in this study case.

Although reducing rainwater with WSUDs is not new for the Barcelona Municipality, using their constructions as a complementary system to reduce water consumption in the city using systems which, at the same time, reduce surface temperatures, are added values studied in this paper. Currently Barcelona has some WSUDs in some areas just to minimize rainwater runoff but reduces water consumption thanks to phreatic waters. The study case shows an alternative, another way to reduce rainwater runoff and water consumption while improving surface temperatures of the city.

Brief, this preliminary communication tries show how we could reduce water consumption, rainwater runoff and "heat island" effect thanks to the WSUDs construction systems.

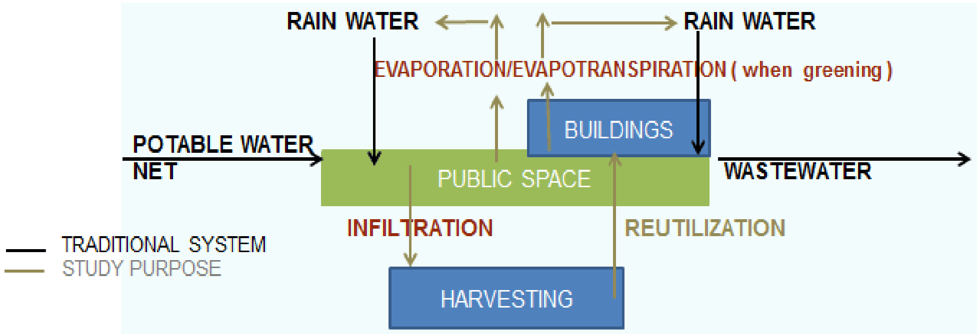
Key words: WSUDs; water harvesting; water reuse; water runoff

1. Introduction

"Water sensitive urban design (WSUD) is an approach to planning and designing urban areas to make use of this valuable resource and reduce the harm it causes to our rivers and creeks" [4] This approach tries to use a better planning, urbanization and construction systems to recuperate water cycle and reuse water.

When we urbanize we break water cycle: pervious surfaces become mainly impervious; thus rainwater runoff increases after urbanizing much more than before this process and aquifers are hardly recharged. Rainwater runoff also gets to the depuration central station much more polluted after urbanizing if WSUDs are not considered. Therefore, WSUDs approach tries to recuperate a water circular cycle life as it's shown in next figure while planning, urbanizing and constructing.

Figure 1. **Comparison between WSUDs and traditional planning and design system**



Source: "Sustainable Construction of Public Space", CTV2013. Author: Mar Pérez Cambra. [5]

2. Objectives

What happens with rainwater runoff when we urbanize? If we plan the city including pervious surfaces, is it a guarantee to reduce water consumption in values which are worth to change streets construction systems? These same WSUDS construction systems could avoid or

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[4] Melbourne Water Corporation: https://www.melbournewater.com.au
[5] PÉREZ CAMBRA, M. (2013)

minimize floods areas? And last, but not least: could we improve surface temperatures (helping to decrease the Island Effect) thanks to these WSUDs systems?

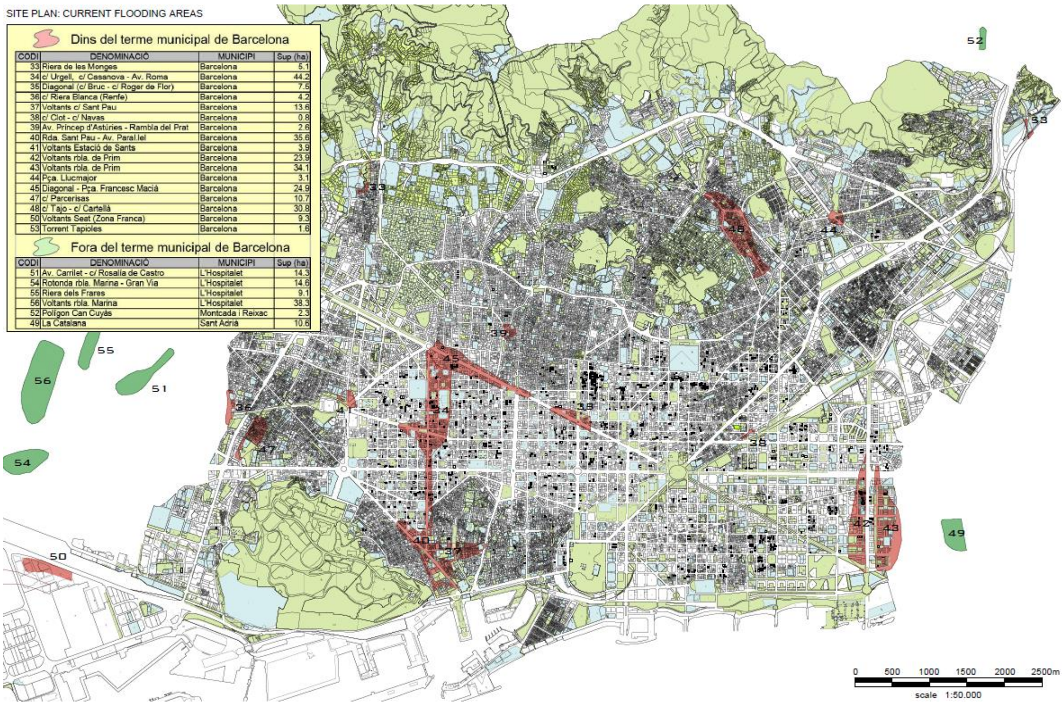
3. Methodology

A calculation-based methodology has been used for this research. Two different methodologies and rainwater data have been used for the calculations according to two different goals: rainwater harvesting and reducing rainwater runoff. It's going to be explained further in the next sections in detail.

3.1 Study case area

These are the flood areas in Barcelona (red color).

Figure 2. **Barcelona Flood areas**



SITE PLAN: CURRENT FLOODING AREAS

🟥 Dins del terme municipal de Barcelona

CODI	DENOMINACIÓ	MUNICIPI	Sup (ha)
33	Riera de les Monges	Barcelona	5.1
34	c/ Urgell, c/ Casanova - Av. Roma	Barcelona	44.2
35	Diagonal (c/ Bruc - c/ Roger de Flor)	Barcelona	7.5
36	c/ Riera Blanca (Renfe)	Barcelona	4.2
37	Voltants c/ Sant Pau	Barcelona	13.6
38	c/ Clot - c/ Navas	Barcelona	0.8
39	Av. Princep d'Astúries - Rambla del Prat	Barcelona	2.6
40	Rda. Sant Pau - Av. Paral.lel	Barcelona	35.6
41	Voltants Estació de Sants	Barcelona	3.9
42	Voltants rbla. de Prim	Barcelona	23.9
43	Voltants rbla. de Prim	Barcelona	34.1
44	Pça. Llucmajor	Barcelona	3.1
45	Diagonal - Pça. Francesc Macià	Barcelona	24.9
47	c/ Parcerisas	Barcelona	10.7
48	c/ Tajo - c/ Cartellà	Barcelona	30.8
50	Voltants Seat (Zona Franca)	Barcelona	9.3
53	Torrent Tapioles	Barcelona	1.6

🟩 Fora del terme municipal de Barcelona

CODI	DENOMINACIÓ	MUNICIPI	Sup (ha)
51	Av. Carrilet - c/ Rosalía de Castro	L'Hospitalet	14.3
54	Rotonda rbla. Marina - Gran Via	L'Hospitalet	14.6
55	Riera dels Frares	L'Hospitalet	9.1
56	Voltants rbla. Marina	L'Hospitalet	38.3
52	Polígon Can Cuyàs	Montcada i Reixac	2.3
49	La Catalana	Sant Adrià	10.6

Source: BCASA (Barcelona Cicle de l'Aigua), Ajuntament de Barcelona redrawn for this paper using the Barcelona Municipality cartography and the BCASA information.

During the research period for this paper two different flood areas were analyzed. The one that goes from Frances Macià to Avda. Paral·lel and the other one, the one of Rambla Prim. Both of them have been analyzed in terms of reducing the rainwater harvesting and reusing water. Both of them are on former creeks. This is a situation that helps to flood these areas when there are heavy rains. And both of them are on main arteries of the city. Thus, if we reduce rainwater runoff we'll reduce difficult situations for the inhabitants of Barcelona.

However, there is a main difference between both of them which is the number of persons who live in both flood areas. While the axis Pça.Francesc Macià- Avda. Paral·lel is a high-density area for residential use, Rambla Prim flood area is a lower density area (in terms of residential

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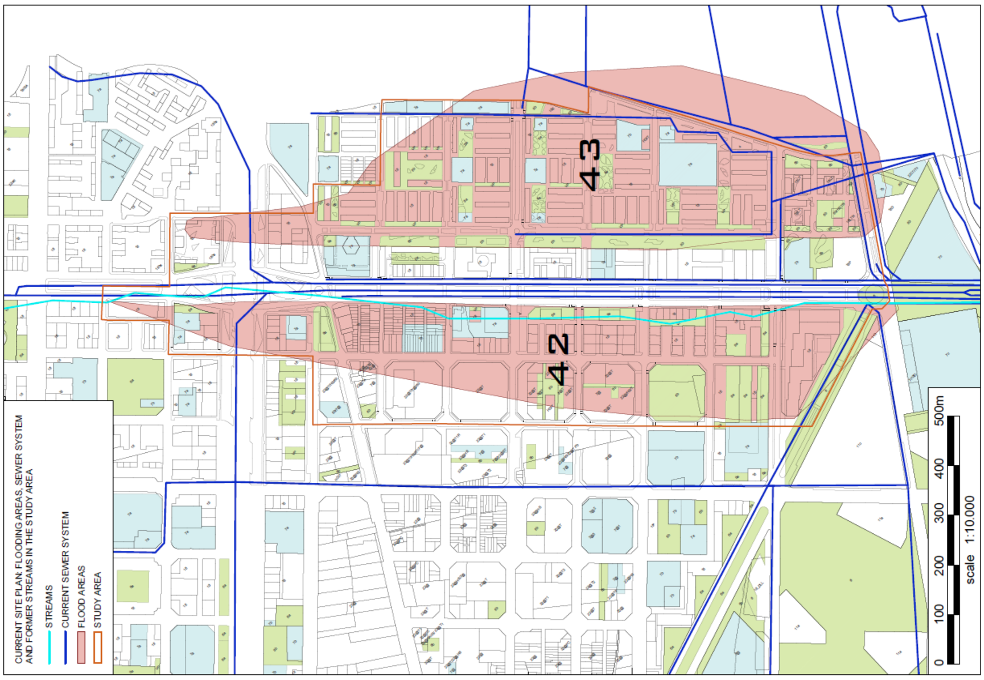
use). If the reuse of water is targeted to domestic use, then results will be more profitable in lower density areas (in terms of people/block) because there will be less rainwater harvesting requirements. However, in both cases the absolute value of rainwater harvesting was not negligible (whatever the future use is) and in both cases the runoff decrease is also relevant.

In this case, as BCASA decided to use water from the phreatic level to clean the streets and water the green areas of Barcelona, I chose the area of Rambla Prim because it was more profitable to reuse the rainwater harvesting for dwellings.

Figure 3. **Rambla Prim Flood area study case**



Source: BCASA (Barcelona Cicle de l'Aigua), Ajuntament de Barcelona redrawn for this paper using the Barcelona Municipality cartography and the BCASA information.

3.2 *WSUDs data*

To calculate the rainwater harvesting to be reuse we'll use the current data published by the Fabra Observatory during the last ten years.

Figure 4. **Pluviometry Fabra Observatory during the last ten years, 2008-2018**

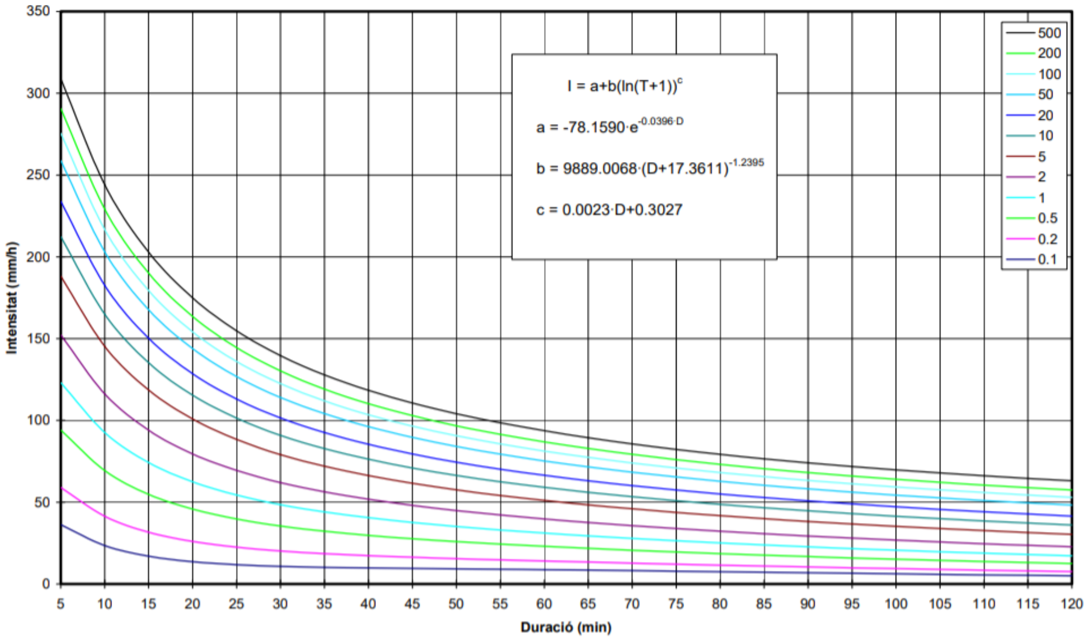
YEARS	Jamuary	February	March	April	May	June	July	August	September	October	November	December	Total rainwater per year	Monthly average per year
2009	67,60	42,70	67,30	93,30	17,40	6,80	45,00	0,40	29,30	103,80	4,80	45,90	**524,30**	43,69
2010	62,20	96,10	76,90	23,50	154,70	35,70	13,00	24,50	95,50	91,50	14,20	32,80	**720,60**	60,05
2011	41,60	24,40	185,20	18,40	83,40	115,10	104,80	0,80	7,30	81,40	203,10	0,00	**865,50**	72,13
2012	4,80	11,10	33,00	83,20	33,40	2,90	21,90	17,40	81,60	145,90	38,80	5,70	**479,70**	39,98
2013	32,5	27,2	145,2	90,7	67,4	19	14,9	5	22,6	28,8	110,5	16,2	**580,00**	48,33
2014	43,00	22,80	30,00	76,50	50,80	27,80	85,00	25,10	155,60	10,20	142,80	22,80	**692,40**	57,70
2015	13,50	11,30	48,00	12,50	53,20	10,80	18,20	49,00	60,70	29,60	38,70	0,30	**345,80**	28,82
2016	1,10	39,90	35,00	77,30	28,70	19,40	16,90	17,60	95,70	75,80	38,50	34,30	**480,20**	40,02
2017	32,00	31,20	136,30	48,20	20,40	25,90	7,20	17,40	53,30	128,20	15,20	3,10	**518,40**	43,20
2018	63,6	103,3	113,8	58,9	54,4	53,1	51,5	36,5	44,4	195,6	208,1	4,8	**988,00**	82,33
Monthly verage last 10 years	**36,19**	**41,00**	**87,07**	**58,25**	**56,38**	**31,65**	**37,84**	**19,37**	**64,60**	**89,08**	**81,47**	**13,83**	**616,73**	**51,62**

Source: Figure made by the author frome the Fabra Observatory data source: http://www.fabra.cat/meteo/

However, in order to calculate the runoff-abatement we need a project rain and the IDF curves[6]. "An intensity-duration-frequency curve (IDF curve) is a mathematical function that relates the rainfall intensity with its duration and frequency of occurrence."[5]

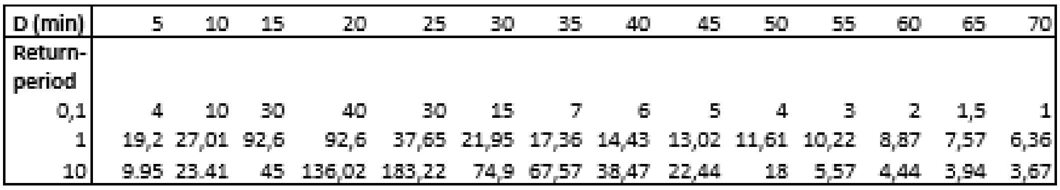
The IDFs show the time concentration or time-structure of the rainfall. There is a problem with this matter. The main problem is that the data published by BCASA of the IDF curves only arrive until 1993.

Figure 5. **IDF curves and Return periods until 1993 (from 1923)**



Source: BCASA: www.bcasa.cat

Figure 6. **Project rain: Intensity in mm/h and the 0,1, 1 and 10 Return periods**



D (min)	5	10	15	20	25	30	35	40	45	50	55	60	65	70
Return-period														
0,1	4	10	30	40	30	15	7	6	5	4	3	2	1,5	1
1	19,2	27,01	92,6	92,6	37,65	21,95	17,36	14,43	13,02	11,61	10,22	8,87	7,57	6,36
10	9.95	23.41	45	136,02	183,22	74,9	67,57	38,47	22,44	18	5,57	4,44	3,94	3,67

Source: own source by the author from BCASA data.

In order to get more recent IDF curves I made the calculations of the pluviometry with MaxPluWin included in "*Máximas lluvias diarias en la España Peninsular*[7]; however, this software only supplies data until 1997.

The methodology used is the formula of intensity precipitation shown in the norm 5.2.-I.C. about Surface Drainage published by the former Spanished norm for drainage:"Orden de 14 de mayo de 1990 por la que se aprueba la Instrucción de carreteras 5.2.-1C. Drenaje superficial". [8]:

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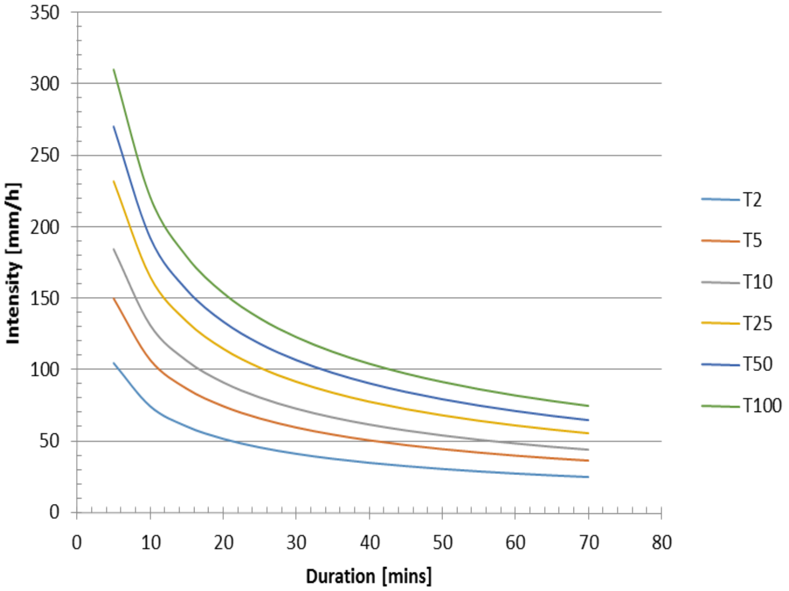
[6] "Wikipedia: https://en.wikipedia.org/wiki/Intensity-duration-frequency_curve

[7] Ministerio de Fomento. España. Dirección General de Carreteras (1999). *Máximas lluvias diarias en la España peninsular. 1999.*

Figure 7. **IDF curves and Return periods graphics until 1997**



Source: own source, IDF curves calculated from the data of MaxPluWin.

The formula of the normed used for the calculations is $\frac{I_t}{I_d} = \left(\frac{I_1}{I_d}\right)^{\frac{28^{0,1}-t^{0,1}}{28^{0.1}-1}}$

Results obtained by the two methods are very different. The results of the Fabra Observatory are more precise than the calculated by de Spanish norm. However, the Spanish norm allows to get more recent data.

During the research of this paper I've found a more recent pluviometry data but I'm still working on it to get a more precise pluviometry. In queries with specialists in meteorology I've been told I can use the data from the end of the XX century to estimate intensities of the first part of the XXI century.

The return-period used are three for the WSUDs: 10 years, the legal return-period required in Barcelona and 1 year and 0,1 years since the goal is trying to obtain a good surface drainage as a complementary draining system instead of assuring an excellent drainage in extraordinary situations.

3.3 Calculations

In order to see if WSUDs can reduce rainwater run-off I'll make a hypothesis about where we can infiltrate rainwater. The easiest way to infiltrate water is making pervious surfaces in the sidewalks leaving an impervious pavement sidewalk for the pedestrians of minimum 2m in order to avoid stepping on the WSUDs. This is the current state of the Rambla Prim flood area:

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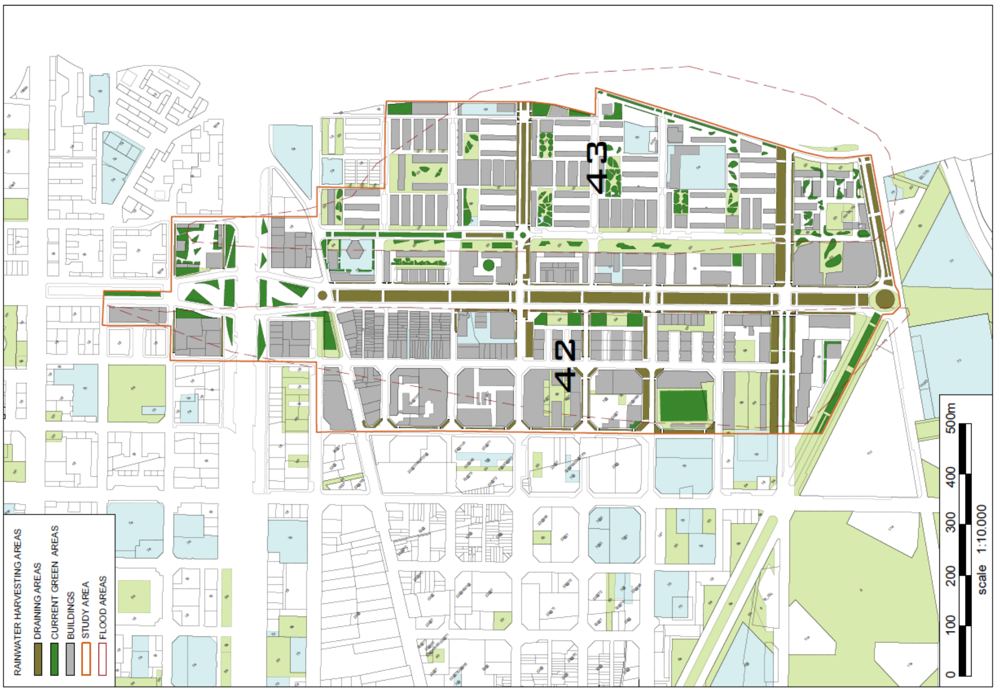
[8] "BOE" núm.123, de 23 de mayo de 1990: *Orden de 14 de mayo de 1990 por la que se aprueba la Instrucción de carreteras 5.2.-1C. Drenaje superficial.*

Figure 8. **Rambla Prim Flood area study case. Current green flood areas**

Source: BCASA (Barcelona Cicle de l'Aigua), Ajuntament de Barcelona redrawn for this paper using the Barcelona Municipality cartography and the BCASA information.

And the proposed pervious surface is:

Figure 9. **Rambla Prim Flood area study case**



Source: Own source concept proposed by the author.

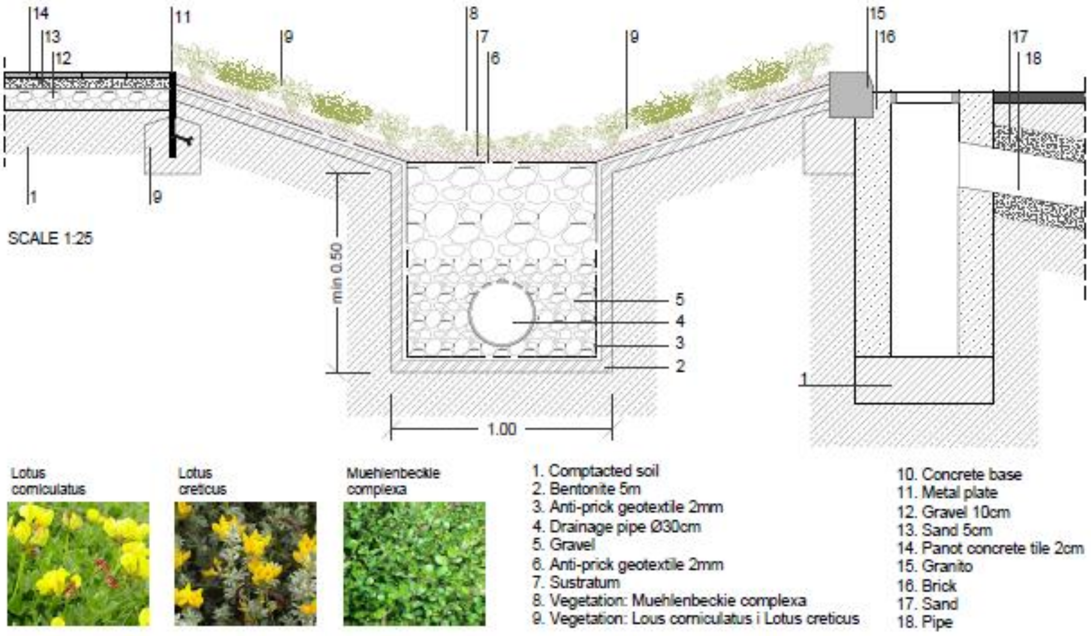
The areas proposed are:

TOTAL AREA m2	BUILDING SURFACE m2	Current "6a" m2	Current green m2	Proposed green in the sidewalks m2	Proposed green between buildings m2	TOTAL INFILTRATING AREAS m2
764544,53	233838,86	93672,21	22213,04	57844,35	35789,75	209519,35

Source: Own elaboration.

The pervious surfaces are WSUDs which are, in this case, infiltrating surfaces which allow to transport water (they are dry green swales) until the water depos. These water depos have a capacity of 4000m3 according to the calculations (the reason why will be explained after the calculations) When they are full, instead of having a pipe to the spillway there is a pipe which conducts the exceeding water of the flood (the overflow) to the water harvesting installations (and thus, rainwater harvesting depos). This WSUDs take the rainwater to a different transportation system (green swales) separated from the traditional sewage:

Figure 10. **Rambla Prim WSUDs proposed**



Source: Own source concept by the author.

These are complementary drainage systems. The vegetation proposed are “dunes plants” which means that they have a high resistance to rainwater scarcity. Besides, they can live with saline substrates. Rambla Prim is close to the sea; thus, these plants could live even if the underground water contained NaCl.

Why are these WSUDs greened? During two years and a half, surface temperatures of different WSUDs of Barcelona were measured by the author. The research summarized was exposed in the CTV'18. [9] This article explained how water presence, when the rainwater runoff can be retained by the WSUDs, reduces the surface temperatures. Besides, it's a CO2 drainage (reducing the island effect).

Therefore, the lower the water gets infiltrated (because of the more water retained), the lower surface temperatures we reach for the city and vice versa. This situation conflicts with the requirement of a high-speed infiltration by the WSUDs.

There is an experimental research which compares different parameters of two plants, one of them is "lotus corniculatus", with three different substrates.[10]

This is an important research for the conflict explained because it shows the composition of the substrate, allowing to calculate the runoff coefficient, and also shows how each substrate lows the surface temperature. This second research has last one year and a half.

The three substrate were composed by: 70% brick, 10%sand, 20%coconut fiber; 70% brick, 10%thick sand and 20% compost; 70% commercial substrate (natural pozzolans and expanded clay at a 50%) and a 30% of peat. The best thermal behavior is shown by the third substrate. It means that it's a 12,76% lower than number 1 and an 8,88% lower than the substrate number2 in summer (June, the 12th). In absolute values, substrate number 3 is about 41ºC while the impervious roof cover is about 50ºC which means that it decreases almost 10ºC.

The values of the runoff coefficient of the three substrate are 0,68m/s for substrate1 (very high speed surely achieved by the 70% brick, and the thick sand) 0,07m/s (the compost has a lower runoff coefficient) and finally, substrate 3 has a 0,00017535m/s. The best balance between surface temperature and infiltration speed is given by substrate 3.

If we use the rational method and the formula shown in the "Instrucción 5.2. IC Drenaje Superficial":

$$Q = \frac{c \times I_t \times A}{K}$$

Where:

- "C" is the draining surface runoff coefficient. I'll use 0,9 for high density areas although in Barcelona it's 0,7.
- "It" is the average intensity pluviometry in mm/h
- "A": draining surface in m2.
- "K": permeability coefficient
- "Q": flow m3/seg

As it's explained by Pau Codolà in its research: "Calculation methodology and experiences in urban areas" [11]a WSUDs is usually with a little depth, the hydraulic gradient of the Darcy Law:

$$q = K\frac{dh}{dl}$$

can be neglected.

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[9] PÉREZ CAMBRA, M. y ROCA, J. (2018)
[10] PEDRO VALERA GARCÍA (2016)
[11] PAU CODOLÀ ç. (2015)

Thus, the formula can be simplified as Qi = A · k which is going to be shown in the calculations. Here we can see the importance of coefficient k to obtain an efficient infiltration. During this research, while calculating the rainwater runoff abatement with the substrate 3 the author has checked the high infiltration capacity. In fact, with substrate number 3 the whole rainwater runoff could be infiltrated. However, in order to be more conservative, and to low a bit more surfaces temperatures the calculations have been made considering as k= 0,00001 instead of k=0,000175 which is still a fast infiltration coefficient but allows thin sands according to the UN permeability coefficients depending on generic soil types, by FAO, although substrate 3 allows using a more precise permeability coefficient.

Figure 11. **Permeability coefficients depending on generic soil types** [12]

Source: FAO. United Nations.

The calculations of how much water can be managed by the WSUDs, according to these formulas already explained:

Figure 13. **Rainwater runoff infiltrated by the WSUDs. Return-period=0,1**

Duration (min)	Intensity (mm/h)	C	K	Area Sector(m2)	A Wsuds (m2)	Q rain (m3/seg)	Rain Volume (m3)	Q infiltrated (m3/seg)	Vfiltrated (m3)	Vnot filtrated (m3)	V accumulated (m3)	V overflow to the rainwater harvesting system (m3)
5	4	0,9	0,00001	764.544,53	209.519,35	0,76	229,36	2,10	628,56	0,00	0,00	0,00
10	10	0,9	0,00001	764.544,53	209.519,35	1,91	573,41	2,10	628,56	0,00	0,00	0,00
15	30	0,9	0,00001	764.544,53	209.519,35	5,73	1.720,23	2,10	628,56	1.091,67	1.091,67	0,00
20	40	0,9	0,00001	764.544,53	209.519,35	7,65	2.293,63	2,10	628,56	1.665,08	2.756,74	0,00
25	30	0,9	0,00001	764.544,53	209.519,35	5,73	1.720,23	2,10	628,56	1.091,67	3.848,41	0,00
30	15	0,9	0,00001	764.544,53	209.519,35	2,87	860,11	2,10	628,56	231,55	4.000,00	79,96
35	7	0,9	0,00001	764.544,53	209.519,35	1,34	401,39	2,10	628,56	0,00	4.000,00	0,00
40	6	0,9	0,00001	764.544,53	209.519,35	1,15	344,05	2,10	628,56	0,00	4.000,00	0,00
45	5	0,9	0,00001	764.544,53	209.519,35	0,96	286,70	2,10	628,56	0,00	4.000,00	0,00
50	4	0,9	0,00001	764.544,53	209.519,35	0,76	229,36	2,10	628,56	0,00	4.000,00	0,00
55	3	0,9	0,00001	764.544,53	209.519,35	0,57	172,02	2,10	628,56	0,00	4.000,00	0,00
60	2	0,9	0,00001	764.544,53	209.519,35	0,38	114,68	2,10	628,56	0,00	4.000,00	0,00
65	1,5	0,9	0,00001	764.544,53	209.519,35	0,29	86,01	2,10	628,56	0,00	4.000,00	0,00
70	1	0,9	0,00001	764.544,53	209.519,35	0,19	57,34	2,10	628,56	0,00	4.000,00	0,00
							9.088,52		8.799,81	4.079,96	4.000,00	79,96

Source: Own elaboration.

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[12] http://www.fao.org/home/en/

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Volume infiltrated show the capacity of the WSUDs to infiltrate rainwater flood. For this return-period the WSUDs potential capacity to manage the runoff is a 96,8% and only 79,96m3 would go to the overflow pipe and could be reused. The overflow volume would go directly to the rainwater harvesting, so that all the water which can be managed by the WSUDs and be absorbed by the 4000m2 water depo will go to the rainwater harvesting installation.

Figure 14. **Rainwater runoff infiltrated by the WSUDs. Return-period=1**

Duration (min)	Intensity (mm/h)	C	K	Area Sector(m2)	A Wsuds (m2)	Q rain (m3/seg)	Rain Volume (m3)	Q infiltrated (m3/seg)	Vfiltrated (m3)	Vnot filtrated (m3)	V accumulated (m3)	V overflow to the rainwater harvesting system (m3)
5	19,2	0,9	1E-05	764.544,53	209.519,35	3,67	1.100,94	2,10	628,56	472,39	472,39	0,00
10	27,01	0,9	1E-05	764.544,53	209.519,35	5,16	1.548,78	2,10	628,56	920,22	1.392,60	0,00
15	92,6	0,9	1E-05	764.544,53	209.519,35	17,70	5.309,76	2,10	628,56	4.681,20	4.000,00	2.073,81
20	92,6	0,9	1E-05	764.544,53	209.519,35	17,70	5.309,76	2,10	628,56	4.681,20	4.000,00	4.681,20
25	37,65	0,9	1E-05	764.544,53	209.519,35	7,20	2.158,88	2,10	628,56	1.530,32	4.000,00	1.530,32
30	21,95	0,9	1E-05	764.544,53	209.519,35	4,20	1.258,63	2,10	628,56	630,07	4.000,00	630,07
35	17,36	0,9	1E-05	764.544,53	209.519,35	3,32	995,44	2,10	628,56	366,88	4.000,00	366,88
40	14,43	0,9	1E-05	764.544,53	209.519,35	2,76	827,43	2,10	628,56	198,87	4.000,00	198,87
45	13,02	0,9	1E-05	764.544,53	209.519,35	2,49	746,58	2,10	628,56	118,02	4.000,00	118,02
50	11,61	0,9	1E-05	764.544,53	209.519,35	2,22	665,73	2,10	628,56	37,17	4.000,00	37,17
55	10,22	0,9	1E-05	764.544,53	209.519,35	1,95	586,02	2,10	628,56	0,00	4.000,00	0,00
60	8,87	0,9	1E-05	764.544,53	209.519,35	1,70	508,61	2,10	628,56	0,00	4.000,00	0,00
65	7,57	0,9	1E-05	764.544,53	209.519,35	1,45	434,07	2,10	628,56	0,00	4.000,00	0,00
70	6,36	0,9	1E-05	764.544,53	209.519,35	1,22	364,69	2,10	628,56	0,00	4.000,00	0,00
							21.815,32		8.799,81	13.636,35	4.000,00	9.636,35

Source: Own elaboration.

For this return -period a 40% can be managed and 9636,35m3 could be reused. The water depo is 4000m2 because it’s useful for a return-period of 1years and the exceeding water goes to the rainwater harvesting. It’s a way to take advantage of all the flood waters to be reused.

Figure 15. **Rainwater runoff infiltrated by the WSUDs. Return-period=10**

Duration (min)	Intensity (mm/h)	C	K	Area Sector(m2)	A Wsuds (m2)	Q rain (m3/seg)	Rain Volume (m3)	Q infiltrated (m3/seg)	Vfiltrated (m3)	Vnot filtrated (m3)	V accumulated (m3)	V overflow to the rainwater harvesting system (m3)
5	9,95	0,9	1E-05	764.544,53	209.519,35	1,90	570,54	2,10	628,56	0,00	0,00	0,00
10	23,41	0,9	1E-05	764.544,53	209.519,35	4,47	1.342,35	2,10	628,56	713,79	713,79	0,00
15	45	0,9	1E-05	764.544,53	209.519,35	8,60	2.580,34	2,10	628,56	1.951,78	2.665,57	0,00
20	136,02	0,9	1E-05	764.544,53	209.519,35	26,00	7.799,50	2,10	628,56	7.170,94	4.000,00	5.836,51
25	183,22	0,9	1E-05	764.544,53	209.519,35	35,02	10.505,99	2,10	628,56	9.877,43	4.000,00	9.877,43
30	74,9	0,9	1E-05	764.544,53	209.519,35	14,32	4.294,83	2,10	628,56	3.666,27	4.000,00	3.666,27
35	67,57	0,9	1E-05	764.544,53	209.519,35	12,92	3.874,52	2,10	628,56	3.245,96	4.000,00	3.245,96
40	38,47	0,9	1E-05	764.544,53	209.519,35	7,35	2.205,90	2,10	628,56	1.577,34	4.000,00	1.577,34
45	22,44	0,9	1E-05	764.544,53	209.519,35	4,29	1.286,73	2,10	628,56	658,17	4.000,00	658,17
50	18	0,9	1E-05	764.544,53	209.519,35	3,44	1.032,14	2,10	628,56	403,58	4.000,00	403,58
55	5,57	0,9	1E-05	764.544,53	209.519,35	1,06	319,39	2,10	628,56	0,00	4.000,00	0,00
60	4,44	0,9	1E-05	764.544,53	209.519,35	0,85	254,59	2,10	628,56	0,00	4.000,00	0,00
65	3,94	0,9	1E-05	764.544,53	209.519,35	0,75	225,92	2,10	628,56	0,00	4.000,00	0,00
70	3,67	0,9	1E-05	764.544,53	209.519,35	0,70	210,44	2,10	628,56	0,00	4.000,00	0,00
							36.503,18		8.799,81	29.265,27	4.000,00	25.265,27

Source: Own elaboration.

In this case the manage rainwater runoff is a 24% of the floods and 25265,27m3 of water would go to the rainwater installations to be reuse. The 76% should be absorbed by the traditional drainage. There is still something which can still improve this WSUDs management which is considering which is adjusting the runoff coefficient to the table published by the Metropolitan Corporation of Barcelona (1981) and published by Manual Gómez Valentín in his “Curso de Hidrología Urbana”. [13]This would increase the rainwater runoff managed by the WSUDs. For Rambla Prim flood area it could be taken a 0,7.

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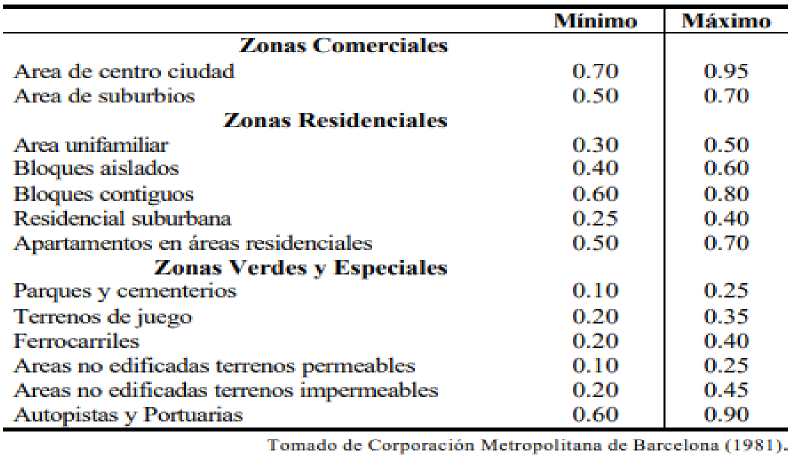
[13] GÓMEZ VALENTÍN, MANUEL (2008)

Figure 16. **Runoff Coefficients according to the different uses**



	Mínimo	Máximo
Zonas Comerciales		
Area de centro ciudad	0.70	0.95
Area de suburbios	0.50	0.70
Zonas Residenciales		
Area unifamiliar	0.30	0.50
Bloques aislados	0.40	0.60
Bloques contiguos	0.60	0.80
Residencial suburbana	0.25	0.40
Apartamentos en áreas residenciales	0.50	0.70
Zonas Verdes y Especiales		
Parques y cementerios	0.10	0.25
Terrenos de juego	0.20	0.35
Ferrocarriles	0.20	0.40
Areas no edificadas terrenos permeables	0.10	0.25
Areas no edificadas terrenos impermeables	0.20	0.45
Autopistas y Portuarias	0.60	0.90

Tomado de Corporación Metropolitana de Barcelona (1981).

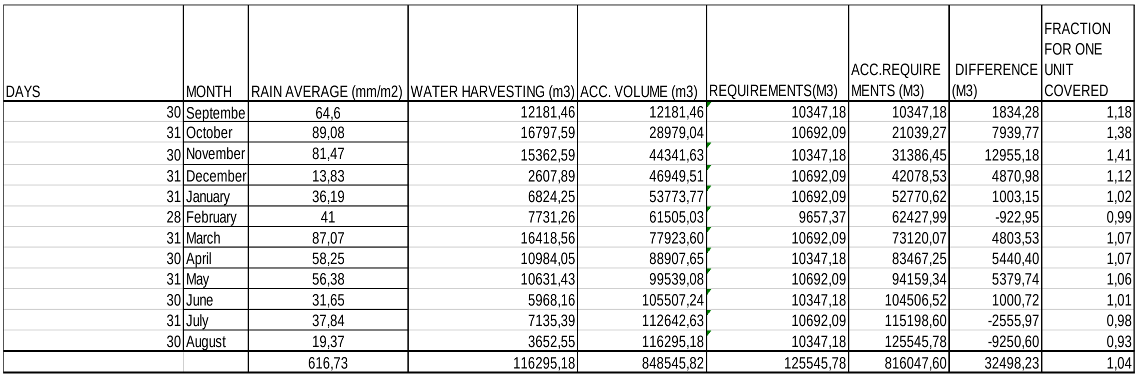
Source: Corporación Metropolitana de Barcelona (1981)

In order to calculate the water reuse the rainwater data to be used is the average of the last ten years. About rainwater harvesting, the methodology is the one published by the "Organización Panamericana de la Salud", Oficina Regional de la Organización Mundial de la Salud, in its *Guide of the design for the rainwater harvesting*.[14]

If we take de proposed plane into numbers to know what we could do with rainwater harvesting in the flood area we can see that, for instance, we could supply approximately 1/3 of the domestic water consumption, a 31%, which could be reuse for the cistern (21% according to the data published by the Ministery) [15], and for the washing machine (10%) in the 83% of the dwellings of this area. These would be those which have more than 400persons by block.

In terms of persons it would be less, because the blocks with the highest densities have been removed. Then, it means that this supply could be done to the 43,55% of the inhabitants of the area.

Figure 17. **Rainwater harvesting: water supply of a 31% in the 83% of the dwellings. 20m2 of rainwater harvesting surface per person**



DAYS	MONTH	RAIN AVERAGE (mm/m2)	WATER HARVESTING (m3)	ACC. VOLUME (m3)	REQUIREMENTS(M3)	ACC.REQUIREMENTS (M3)	DIFFERENCE (M3)	FRACTION FOR ONE UNIT COVERED
30	Septembe	64,6	12181,46	12181,46	10347,18	10347,18	1834,28	1,18
31	October	89,08	16797,59	28979,04	10692,09	21039,27	7939,77	1,38
30	November	81,47	15362,59	44341,63	10347,18	31386,45	12955,18	1,41
31	December	13,83	2607,89	46949,51	10692,09	42078,53	4870,98	1,12
31	January	36,19	6824,25	53773,77	10692,09	52770,62	1003,15	1,02
28	February	41	7731,26	61505,03	9657,37	62427,99	-922,95	0,99
31	March	87,07	16418,56	77923,60	10692,09	73120,07	4803,53	1,07
30	April	58,25	10984,05	88907,65	10347,18	83467,25	5440,40	1,07
31	May	56,38	10631,43	99539,08	10692,09	94159,34	5379,74	1,06
30	June	31,65	5968,16	105507,24	10347,18	104506,52	1000,72	1,01
31	July	37,84	7135,39	112642,63	10692,09	115198,60	-2555,97	0,98
30	August	19,37	3652,55	116295,18	10347,18	125545,78	-9250,60	0,93
		616,73	116295,18	848545,82	125545,78	816047,60	32498,23	1,04

Source: Own elaboration.

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[14] ORGNIZACIÓN PANAMERICANA DE LA SALUD. 2004, *Guide of the design for the rainwater harvesting.* Lima, Perú. Oficina Regional de la Organización Mundial de la Salud.

[15] https://www.miteco.gob.es/es/ceneam/programas-de-educacion-ambiental/hogares-verdes/preguntas_hv.aspx

Or we could also choose reusing water in all the dwellings of the area. In this case, as we have some high-density blocks, if we want to supply water to all the dwellings we should also harvest water in the roofs. Thus, we would convert the 90% of the roofs in blue roofs we could cover the 21% of the domestic consumption of all the buildings. It means that if the number of inhabitants per block increases the rainwater surface would increase. In this case, a 34% would exceed the requirements.

Figure 18. **Rainwater harvesting: water supply of a 21% all the dwellings of the flood area. 16m2 of rainwater harvesting surface per person**

DAYS	MONTH	RAIN AVERAGE (mm/m2)	WATER HARVESTING (m3)	ACC. VOLUME (m3)	REQUIREMENTS(M3)	ACC.REQUIREMENTS (M3)	DIFFERENCE (M3)	FRACTION FOR ONE UNIT COVERED
30	Septembe	64,6	24417,31	24417,31	16096,15	16096,15	8321,15	1,52
31	October	89,08	33670,18	58087,49	16632,69	32728,85	25358,64	1,77
30	November	81,47	30793,78	88881,27	16096,15	48825,00	40056,27	1,82
31	December	13,83	5227,42	94108,69	16632,69	65457,69	28650,99	1,44
31	January	36,19	13678,98	107787,67	16632,69	82090,38	25697,29	1,31
28	February	41	15497,05	123284,72	15023,08	97113,46	26171,26	1,27
31	March	87,07	32910,45	156195,17	16632,69	113746,15	42449,02	1,37
30	April	58,25	22017,15	178212,32	16096,15	129842,30	48370,02	1,37
31	May	56,38	21310,34	199522,66	16632,69	146475,00	53047,66	1,36
30	June	31,65	11962,97	211485,63	16096,15	162571,15	48914,48	1,30
31	July	37,84	14302,65	225788,27	16632,69	179203,84	46584,43	1,26
30	August	19,37	7321,41	233109,69	16096,15	195300,00	37809,69	1,19
		616,73	233109,69	1700880,88	195300,00	1269449,97	431430,90	1,34

Source: Own elaboration.

It shows that if we want to reuse rainwater we should first know in which areas of the city it would be more profitable. So, if we supply again the blocks which have a lower density (800 persons/block) and we harvest water in the 90% of the roofs surface and in the rest of the WSUDs proposed we could achieve a 57% of the domestic supply of these blocks.

Figure 19. **Rainwater harvesting: water supply of a 57% of water to an 88% of all the dwellings of the flood area. 50m2 of rainwater harvesting surface per person**

DAYS	MONTH	RAIN AVERAGE (mm/m2)	WATER HARVESTING (m3)	ACC. VOLUME (m3)	REQUIREMENTS(M3)	ACC.REQUIREMENTS (M3)	DIFFERENCE (M3)	FRACTION FOR ONE UNIT COVERED
30	September	64,6	24417,31	24417,31	22587,39	22587,39	1829,92	1,08
31	October	89,08	33670,18	58087,49	23340,30	45927,69	12159,80	1,26
30	November	81,47	30793,78	88881,27	22587,39	68515,08	20366,18	1,30
31	December	13,83	5227,42	94108,69	23340,30	91855,39	2253,30	1,02
31	January	36,19	13678,98	107787,67	23340,30	115195,69	-7408,02	0,94
28	February	41	15497,05	123284,72	21081,56	136277,25	-12992,53	0,90
31	March	87,07	32910,45	156195,17	23340,30	159617,56	-3422,39	0,98
30	April	58,25	22017,15	178212,32	22587,39	182204,95	-3992,62	0,98
31	May	56,38	21310,34	199522,66	23340,30	205545,25	-6022,59	0,97
30	June	31,65	11962,97	211485,63	22587,39	228132,64	-16647,01	0,93
31	July	37,84	14302,65	225788,27	23340,30	251472,94	-25684,67	0,90
30	August	19,37	7321,41	233109,69	22587,39	274060,33	-40950,65	0,85
		616,73	233109,69	1700880,88	274060,33	1781392,16	-80511,28	0,95

Source: Own elaboration.

4.Conclusions:

This is a preliminary study about how WSUDs can be used to reduce rainwater runoff and also to harvest water as it's been shown in the calculations. To do so, it's crucial to choose a correct WSUDs system which allows a balance between rainwater infiltration and surface temperatures. As we have seen, the better soil infiltration, the worse surface temperatures in summer.

Therefore, the composition or section of this substrate is extremely important and consequently, its permeability coefficient.

The same WSUDs used to mitigate the rainwater runoff are used to harvest rainwater. All the water which exceeds of the water depo goes to the rainwater harvesting installations. As it's shown, the absolute values of the total rainwater harvesting are not negligible at all; nevertheless, it's more profitable building these systems in the areas of the city where there is not a high number of persons per block; these areas should be analyzed. In this research some new scenarios have been opened: about how to build public space and its arteries in flood areas, with some water crisis criteria, and considering climate change and about how to urbanized as recuperating water cycle, cleaning rainwater “in the origin”, and building areas with a certain autonomy in water consumption.

These WSUDs are just a first step to a possible alternative to the current systems (phreatic water and traditional sewerage) used in Barcelona. It’s a part of the global thesis of the author.

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