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Evaluation of water footprint of urban renewal projects. Case study in Seville, Andalusia

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A B S T R A C T

This publication presents a methodology for the evaluation of the water footprint of urban renewal projects. The indirect water footprint is obtained by adding together the embodied or virtual water of the materials incorporated in the 12-month project, while the direct footprint is mainly due to the green areas and rainwater collection system over its 40-year life span. The methodology, originally defined for the agricultural sector, is adapted to an urban system that includes gardens and sustainable urban drainage systems. In an innovative way, the present work analyses the amortisation of the indirect water footprint of the construction products by improvements in the city water cycle. The project involves street renewal with water-sensitive criteria, with five green areas, and road and pavement construction. The methodology identifies changes in garden designs, soil drainage, and rainwater-collecting systems in terms of blue, green, and grey water footprints. Five scenarios of a project in Seville, Spain are studied. The indirect water footprint of the project is 2.6 times higher than that in a standard project, but, due to annual savings of 65% in its direct water footprint, the breakeven point is reached in the 10th year.

1. Introduction

Urban water management systems, although increasingly efficient, respond to two basic needs: one is sanitation, which refers to the disposal of used water; and the other is the control of flood risks. However, these systems seldom take other objectives into account in the design processes (Chocat et al., 2001; Fletcher et al., 2015). One limitation is its linearity in capturing, conducting, and discharging water as quickly as possible. Nevertheless, a significant environmental improvement is given a circular functional approach, where the water is recirculated, reused, and recycled. To this end, it is necessary to match the quality of the water to the demands of each use, and the water can therefore be recycled or reused multiple times. In a cascade process, water is first consumed in high-quality requirements and through recycling it gradually decreases in quality for uses of less demanding requirements. This implies the incorporation of new assets, grey water and rainwater, to increase the system efficiency and reduce the hydrological impact. Strategies should be developed to expand rainwater storage capacity, use alternative sources, decentralise sewer systems, infiltrate rainwater into the ground, and efficiently manage overflows and runoff (IPCC, 2013).

A new perspective for the improvement of the renewal of urban spaces involves imitation, as far as is feasible, of the natural water cycle, by promoting and conserving natural ecosystems and optimising the use of water resources, or *urban water-sensitive design* (UWSD). This term, created in Australia (Mouritz, 1996), is being progressively introduced into the design of urban water-cycle management since it favours the transition process towards new, more sustainable, circular economy models (Lloyd et al., 2002; Suárez López et al., 2014). The term *water-sensitive cities* is used in parallel, which, unlike UWSD which describes the process, refers to the destination (the objective) (Brown and Clarke, 2007).

Several case studies can be found in the literature: for example, the urban regeneration project in the Augustenborg neighbourhood in Malmö (Sweden) stands out for its interesting approach. It is an area that suffers from seasonal floods, and has increased its green space and biodiversity by 50%, while its urban drainage system collects 90% of runoff, thereby supplying water to an attractive landscape. This approach won the 2010 World Habitat Award from the United Nations (de Santiago Rodríguez, 2014). Other models of architecture and urban environments are addressed in the proposal for the first forest city, in Liuzhou (China). The city has offices, houses, hotels, hospitals, and

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schools completely covered by plants and trees of all sizes and functions, with 40,000 trees and almost 1 million plants of more than 100 distinct species. The design accommodates 30,000 people, absorbs 10,000 t of CO_2 and 57 t of other pollutants per year, and produces approximately 900 t of oxygen (Kucherova and Narvaez, 2018). Other initiatives include the plan of the San Francisco Public Utilities Commission (SFPUC), which implements a series of technological policies aimed to develop a circular economy of water, and to mitigate greenhouse gas emissions and improve resilience to climate change (SFPUC, 2020). The E2STOTMED Project develops a decision support tool to promote improvements in rainwater management and its energy efficiency in six locations: Benaguasil, Pisa, Malta, Hersonissos, Centinje, Zagreb, and Dronero (Maira Valley) (Lara García, 2019).

Moreover, in Spain, urban planning towards a more sustainable water strategy can be found, for example, in the Municipal Water Demand Management Plan in Madrid, the Future Plan for Efficient Water Management in Vitoria-Gazteiz (Aguas_Municipales_Vitoria-Gasteiz, 2014), and in the AQUAVAL project in Xátiva and Benaguasil in Valencia (Lara García, 2019). Another example is given by Trinitat Nova in the Barrio del Agua (Barcelona), which consists of the rehabilitation of the neighbourhood, including gardens, permeable pavements, green roofs, and natural grey water purification, and makes the water cycle explicit in the rehabilitation of an old pumping station, "Casa del Agua" (Water House). The project was presented with the Good Practices award in 2008 by the United Nations (UN). The project of the eco-city of Sarriguren (Navarra) is equally of interest: in 2000, it was also awarded by the UN and was presented with the European Prize for Urbanism in the category of Environment and Sustainability (2008). The project has an integral approach to the management of the water cycle, which includes consumption control strategies, separative sanitisation, retrieval of runoff water for the thermal regulation of the microclimate, regaining aquifers, the application of xero-gardening and efficient irrigation systems, and urban gardens (Diego Díez, 2014; Metrópoli_Fundación, 2019).

Certain studies have estimated that measures aimed to conserve water may be sufficient to nullify the impacts of climate change in particularly sensitive regions (Escriva-Bou et al., 2015). The most effective measure involves distributing solutions strategically in the urban landscape at regular intervals and in areas of high exposure to heat in order to promote infiltration and evapotranspiration, and to maintain the health of the trees (Coutts et al., 2013).

Cities face major transformation to achieve sustainability, and it is important to select relevant indicators that can measure sustainability at local project level (Jomo et al., 2019). The innovations can include urban green spaces, and models have been defined for the calculation of the water use, particularly in private gardens. Landscape water use among households and businesses has been assessed in Utah, United Sates. By means of a classified mosaic of landscape type and area, from airborne multispectral digital imagery and the integration of this information in parcel boundary data, landscape vegetated areas can be determined per lot and irrigation needs using weather data have been estimated (Endter-Wada et al., 2008).

In a similar way, Salvador et al. (2011) estimated the domestic garden needs in Zaragoza, Spain, by employing aerial photographs for the identification of vegetation, estimated its water use, and compared it to the water billing records. Overirrigation was common in the three years of study. Also in Spain, Parés-Franzi et al. (2006) evaluated irrigation performance of 315 urban parks in the Barcelona metropolitan region, using the WUCOLS approach and concluded that unsustainable park management strategies were mainly due to irrigation designs being based on the water demand of turf grasses. More recently, a similar analysis has been carried out in Santiago, Chile, whereby public and private spaces are included. The water use for irrigation was compared with that expected using a hydrological model. The monthly water use was obtained from a database of drinking water meters provided by the private water utility. The irrigation rate of public spaces is lower than the rate of private spaces, and similar to the modelled demand (Reyes-Paecke et al., 2019). Guo et al. (2021) determined the water use of China's parks by employing statistical reports. Nouri et al. (2019) evaluated the blue and green water footprint (WF) of a 10-hectare parkland in Adelaide, South Australia, through empirical data. Evapotranspiration of the urban vegetation was estimated by monitoring soil water inflows, outflows, and storage changes at an experimental site with varied species, microclimates, and plant densities.

In addition to the correct estimation of water needs of the urban green areas for the improvement in their design, another strategy involves improving the management of grey water. Sustainable urban drainage systems (SUDS) have been incorporated in the cities under study. A systematic review of over 120 papers can be found in Ferrans et al. (2022), where decision support systems are evaluated. They studied how SUDS are designed, built, and used, by means of modelling, multi-criteria matrices, and optimisation tools. Furthermore, the Urban Water Resources Research Council of the American Society of Civil Engineers published a database of best practices, as well as data entry software for standardised reporting and performance evaluation protocols. The data is accessible via the Internet at www.bmpdatabase.org along with associated data evaluation reports and other project documentation (Clary et al., 2002).

There is a body of literature on city WF (direct and indirect), and this work focuses on the scale of urban water redevelopment project. The WF is evaluated, direct and indirect, in terms of the volume of water use and/or of contaminated water per unit of time (m^3/year). The term water use refers to the water consumed in irrigation. The direct water footprint (dWF) is divided into blue, green, and grey water; and indirect or virtual water footprint (iWF), refers to the water embodied in the construction materials employed in urban renovation projects which include green spaces and SUDS. To this end, local information on precipitation, soil characteristics and greenery microclimate, density, and species, are assessed together with water harvesting, for the evaluation of street renovation projects. Construction cost databases are employed for the resource inventory and the assessment of the iWF.

In this respect, the present study evaluates and adapts the WF indicator to the design analysis of the project in Avenida El Greco, Seville, Spain. For the first time in the renovation of streets, this innovative project in the city incorporates rainwater collection systems for the maintenance of new gardens. The work also analyses the amortisation of the indirect or virtual water of the construction materials used in the project. Five scenarios of street projects are studied. The proposed methodology considers the inputs and outputs of the system limited by the area covered by the street renovation project.

1.1. Water footprint indicator

The first work related to the WF dates back to 1968, when Lofting and McGauhey (1968) calculated volumes of "incorporated" or "embedded" water using input-output analysis. It was not until the early 1990s, however, that concepts such as water scarcity were developed (Falkenmark, 1989) and J. A. Allan introduced the concept of virtual water, which was defined as the volume of water required to produce a given element (Allan, 1998, 1994, 1993).

The concept of WF was created in 2003 by Professor Arjen Y. Hoekstra of the University of Twente, Netherlands (Hoekstra, 2003). Since then, several initiatives have emerged, such as the Water Footprint Network (WFN) in 2008, and ISO 14,046 in 2014, which includes the concept of WF (ISO, 2014; WFN, 2020). Its development and standardisation is published in "The Standard Methodology of Calculation" (Hoekstra et al., 2009) and the "Manual of Water Footprint Assessment" (Hoekstra et al., 2011).

This calculation differentiates according to their origin: blue water (blue WF), refers to the consumption of fresh water, whether surface or groundwater; green water (green WF) arises from the evaporation and transpiration of plants; and grey water (grey WF) is contaminated water, and is defined as the volume of freshwater needed to dilute pollutants, and return them back to their natural concentrations and quality standards in the area of study. In summary, the WF evaluates both direct and indirect water use in terms of the volume of water use and/or contaminated per unit of time (m^3/year). The WF is geographically and temporally explicit in terms of the water used by a process, product, consumer, and/or producer.

Its definition and systematisation have favoured research in the agricultural and livestock production sectors as a decision-making tool. For example, crop WF estimates have been made at the provincial or national level with explicit spatial data (Zeng et al., 2012), in the agricultural sector in the Guadalquivir basin, Spain (Salmoral et al., 2012), and also in the industrial sector using Life Cycle Analysis (LCA) (Berger and Finkbeiner, 2010).

Furthermore, in the construction sector, the WF has been adapted to evaluate the built environment. It can be analysed from a global perspective (Chang et al., 2016) through an input-output analysis of total consumption in the country or models that analyse components of construction projects (Meng et al., 2014). Following the component assessment model, the virtual water of the construction waste can be calculated (Marrero et al., 2020a) as can that of the products consumed in the building life cycle (Rivero Camacho, 2020). The urbanisation process has been assessed by employing Building Information Modelling (BIM) (Marrero et al., 2020b) and the project budget (Ruíz-Pérez, 2020). The direct WF, due to the building occupants' consumption or to city gardens, has also been analysed in the work of Rivero Camacho (2020), Ruíz-Pérez et al. (2020), and Alba-Rodríguez et al. (2021).

2. Methodology

The calculation methodology for the quantification of the WF in the renovation of urban infrastructure is presented below and considers both the quantity of water required to produce the building-material resources (indirect water) and the water use related to its direct use in the study area (irrigation, green areas, wastewater, etc.). Therefore, the methodology presented includes various phases of the water cycle: extraction and the manufacturing of materials, transportation, construction, and management of municipal services.

2.1. Direct water footprint (dWF) calculation

The WF is estimated from of its three components, differentiated by colour: green, blue, and grey water footprints (Hoekstra et al., 2011); these serve to distinguish water qualities since they are not entirely equal in terms of access, usability, and quality.

The blue WF is defined by Eq. (1) in Table 1, where the volume of water that is incorporated and that which evaporates in a process is considered. For its calculation, a water balance is proposed (Eq. (2) in Table 1), since, in most cases, no exact data of the evaporation volume is available.

The grey footprint is determined by Eq. (3) in Table 1. Water pollution is a consequence of human activities that alter the quality of water, thereby affecting the viability of its consumption. The quality standard of the pollutant concentration is defined by the legislation in place in the region of analysis, which applies a degree of protection about subsequent uses (C_{max}) or its ecological function according to the intended destination (receiving water body) (C_{nat}), depending on where the discharge is located. For the calculation of the footprint of grey water, the assimilation capacity of the receiving stream is considered regardless of whether the concentration quality standards have been exceeded. When there are several pollutants, the grey footprint of the most significant pollutant is considered (WFN, 2020). In Spanish Legislation, Royal Decree 849/1986 regulates the management and control of the hydraulic public domain and hydrological planning and establishes environmental quality standards. The limits of natural concentrations in Seville can be found in the reports of the SAICA Network

Table 1
Equations for the calculation of the WF of a production process.

	Equation nº
WF OF A PRODUCTION PROCESS	
$WF_{process}$: Volume of water consumed and/or polluted by a process per unit of time (m^3/year)	
$WF_{blue\ i}$: Volume of freshwater consumed from surface or groundwater source extraction for conducting a process i per unit of time (m^3/year)	
$WF_{grey\ i}$: Volume of freshwater necessary to assimilate the pollutants produced in a process i by a receiving water body per unit of time (m^3/year)	
$WF_{green\ i}$: Volume of water consumed from precipitation that is not converted into runoff for conducting a process i per unit of time (m^3/year)	
Blue water Footprint	
WF_{blue}: Blue water footprint (m^3/year) (Hoekstra et al., 2011)	
$WF_{blue} = \sum_{i=1}^{n} V_{emb\ i} + V_{evap\ i}$	**1**
$WF_{blue} = VOL_{aff} - VOL_{eff}$	**2**
$V_{emb\ i}$: Volume of water incorporated in process i (m^3/year)	
$V_{evap\ i}$: Volume of water evaporated in process i (m^3/year)	
VOL_{aff}: Volume of water entering the system per unit of time (m^3/year)	
VOL_{eff}: Volume of water leaving the system per unit of time (m^3/year)	
Grey water footprint	
WF_{grey}: Grey water footprint (m^3/year) (Hoekstra et al., 2011)	
$WF_{grey} = \frac{C_{cont}}{C_{max} - C_{nat}} = \frac{(VOL_{eff} * C_{eff}) - (VOL_{affe} * C_{aff})}{C_{max} - C_{nat}}$	**3**
C_{cont}: Concentration of pollutant used for the quantification of WF_{grey} (mg/l)	
C_{max}: Maximum concentration in the receiving body of the parameter used for the quantification of WF_{grey} (mg/l)	
C_{nat}: Natural concentration of the parameter for the quantification of WF_{grey} (mg/l) (without anthropogenic alterations) alterations)	
Green-water footprint	
WFg: Water Footprint of a garden (m^3) (Hoekstra et al., 2011)	
WFg blue: Blue component of the WFg (m^3)	
WFg green: Green component of the WFg (m^3)	
WFg grey: Grey component of the WFg (m^3)	

of the Guadalquivir Hydrological Plan (RD_849/1986).

The total WF of the green areas is obtained from the blue, green, and grey components produced by the green areas during their growth (Hoekstra et al., 2011). In the specific urban system to be studied, consisting of a street and its gardens, three categories of inputs and outputs are considered: blue water, consumed from the urban water supply system and output through percolation; grey water, through the urban sewer system; and green water or direct inputs from the rain, and output via evaporation and the transpiration of plants.

In order to determine all the system flows and their corresponding footprints, the methodology is sequenced into four phases: (1) study of the runoff, (2) study of the soil, (3) calculation of the garden water demands, and (4) the balance of the system to estimate its irrigation efficiency or in-situ reuse.

For the first phase, it is necessary to quantify the rainfall. The local climate can be found in the FAO (Food and Agriculture Organization of the United Nations) databases (CROPWAT, 2018), but data on the total monthly precipitation cannot be used since not all the rainfall is usable. The concept of effective precipitation is therefore introduced, which considers three scenarios: very heavy rain, whereby some of the water percolates to a great depth and is not stored at root level; heavy rain, whereby not all the rainwater is absorbed by the soil and creates a runoff; and finally, the light rainfall, which evaporates at ground level. For the calculation of the effective rainfall, the simple curve number (CN) method of the United States Department of Agriculture (USDA)/SCS (P) Soil Conservation Service/Natural Resources Conservation Service (NRCS, 2004) can be used. This method applies a reduction factor which considers different precipitation intervals for 24 h rainfall and runoff records, and hence fails to explicitly consider the temporal variation of runoff.

The runoff study analyses the behaviour of the local rainfall regime. For this purpose, effective and abstract (or absorbed) rainfall is determined using the Equations from (4) to (8) in Table 2. Surfaces are classified according to their permeability and are assigned a runoff

Table 2
Equations to calculate the WF of a garden: precipitation, infiltration, and water demand.

	Equation nº
WATER FOOTPRINT OF A GARDEN	
RAINFALL	
$PEf = PTo * C$	**4**
$C = \frac{\sum_{i=1}^{n} S_i * C_i}{\sum_{i=1}^{n} S_i}$	**5**
PEf: annual effective rainfall (mm/year) (NRCS, 2004)	
PTo: average annual rainfall (mm/year)	
C: weighted runoff factor of an area (non-dimensional) (Woodward and Posey, 1955)	
$\mathbf{S_i}$: area of sub-area i (m^2)	
$\mathbf{C_i}$: average coefficient of sub-area i (non-dimensional)	
Precipitation volume	
$VTo = \frac{PTo * S}{1000}$	**6**
$VEf = \frac{PEf * S}{1000}$	**7**
$VAb = VTo - VEf$	**8**
VTo: Total precipitation volume (m^3/year) (NRCS, 2004)	
VEf: Effective precipitation or runoff volume (m^3/year) (NRCS, 2004)	
VAb: Abstraction or loss volume (m^3/year) (NRCS, 2004)	
PTo: Average annual rainfall (mm/year)	
PEf: Annual effective rainfall (mm/year)	
S: Area of the basin or surface considered (m^2)	
Infiltration	
$Rf = \frac{Sp * Cp}{(S * C * It)/Kp}$	**9**
$Vf = \frac{PTo * Sp * Rf}{1000}$	**10**
Rf: Infiltration efficiency of the SUDS per rainfall intensity (%) (Ministerio de Fomento, 2016)	
Sp: Pervious area (m^2)	
Cp: Coefficient infiltration of pervious area (Cp= 3.30E-05 m/s) (IGME, 2021)	
t: Time interval in seconds ($t = 5$ min)	
S: Area of the basin or surface considered (m^2)	
C: Weighted runoff factor of an area (non-dimensional)	
It: Average rainfall intensity for a 10-year design and 5 min intervals (mm/h)	
Kp: Coefficient that considers the effect of precipitation peaks (Kp=3600,000)	
Vf: Total infiltration volume (m^3/year) (Ministerio de Fomento, 2016)	
PTo: Average annual rainfall (mm/year)	
Water demand	
$ETc = Kc * ETo$	**11**
$ETg = Cg * ETo$	**12**
$Cg = Fs * Fd * Fm$	**13**
ETc: Crop evapotranspiration (m^3/year) (Doorenbos and Pruitt, 1977)	
Kc: Coefficient specific to each crop	
ETo: Evapotranspiration of a reference crop (m^3/year)	
ETg: Garden evapotranspiration (m^3/year) (Doorenbos and Pruitt, 1977)	
Cg: Coefficient specific to each garden (Doorenbos and Pruitt, 1977)	
Fs: Species factor (Costello and Jones, 2000)	
Fd: Density factor (Contreras et al., 2006)	
Fm: Microclimate factor (Contreras et al., 2006)	

coefficient (Woodward and Posey, 1955), which determines the volume abstracted (retained in permeable areas), and the runoff from impermeable surfaces, which drains into the sewer system. The Equations are defined in Table 2, Eqs. (4) and (5).

In the second phase, the permeability (or infiltration) of the soil, both natural and improved by the project, is analysed. First, the volume of rainwater is calculated using the Rational Method in Instruction 5.2. *IC Surface Drainage of the Ministry of Public Works (FOM/298, 2016)*. The infiltration efficiency managed by the sustainable urban drainage system (SUDS) is obtained via Eq. (9) in Table 2, and the volumes of water infiltrated into the soil are compared with the volumes of runoff water collected at 5 min intervals over one hour with a rainfall intensity, calculated for a 10-year breakeven point. To this end, the SUDS design considers a rain period of 10 years since longer periods can overextend the SUDS design. The performance or infiltration ability depends, to a significant extent, on the permeability of the soil, and the optimal is reached when the quantity of precipitated water equals the capacity of infiltration of the soil, which implies that larger infiltration surfaces are needed during periods of intense rain. The design of the infiltration profile of the SUDS is obtained for Seville (Fig. 1), for a 10-year period, and 5 min intervals are used. A moderate rainfall intensity (15 to 60 mm/h) results in 85% efficiency. Eq. (10) of Table 2 calculates the infiltration volume managed by the SUDS. The volume is temporarily stored in locally built tanks. If its maximum capacity is reached, then the overflow is sent to the sewer network.

In the third phase, the impact of green areas is determined using a crop coefficient similar to that used in agriculture (Hoekstra, 2019), but in this case it is called the garden coefficient, which takes into account the areas covered by different species, the composition of the areas, and the location within the project. All this together with the local climate determines the water demand. It has been proposed that those green areas, defined as hydro-zones, that have similar water needs be grouped under the same coefficient (Ruíz-Pérez et al., 2020). The water demand of plants, otherwise known as the evapotranspiration of green areas, is quantified using the method proposed by the FAO (Doorenbos and Pruitt, 1977). The evapotranspiration reference values (ETo) have been calculated using the Penman-Monteith Method, which is an accepted method for the estimation of the evapotranspiration of crops since it can be used without restrictions in all types of climates (Souza et al., 2014). The coefficients are obtained from the CROPWAT program developed by the FAO (CROPWAT, 2018).

However, this database does not contain information pertaining to all crops, nor is it valid for gardens, due to three major differences. First, gardens and green areas are composed of more than one species, and, within the same garden area, the different types of species are arranged at different heights (trees, shrubs, and ground-cover plants), without any predominance of one over another, each with its own irrigation needs. Secondly, the density of vegetation is also heterogeneous in all areas, with more water losses occurring in certain areas than in others, especially in areas with no vegetation where soil evaporation is increased. Ad thirdly, differences arise due to the microclimate effect from the shadows of building, paved areas, traffic, etc. The method of the Garden Coefficient or Hydro-zone (Cg) is proposed, together with that of the garden evapotranspiration (ETg) (Ruíz-Pérez et al., 2020), to take into account all the urban characteristics. Finally, the species factor (Fs) considers the climatic zone under study, because water requirements of species can vary with temperature (Contreras et al., 2006), Eqs. (11) to (15) of Table 2.

In the fourth and final phase of the methodology, the irrigation network is analysed since the volume of abstractions is insufficient to cover the garden demand. This can be supplied by tap water or from underground tanks of rainwater collected by the SUDS, see Eqs. (11) and (12) in Table 2. In order to consider the efficiency of the irrigation system, Eqs. (14) to (18) of Table 3 are applied. Finally, the garden's WF is composed of three footprints: green for abstractions, Eq. (19); blue for irrigation, Eq. (20); and grey for irrigation and rainwater surplus that cannot be stored, Eq. (21). All these are outlined in Table 3. Fig. 2 illustrates the flow diagram for the calculation of the three footprints.

2.2. Calculation of the indirect water footprint (iWF)

The methodology for the calculation of the iWF uses the resources inventory that can be found in the documents that control the costs of construction projects, that is, the bill of quantities and construction cost databases. For the temporal boundary, the impact is concentrated during the months that the construction takes place, as defined in the project planning. The project blueprints outline the physical boundaries of the activities taking place, and the results are expressed either per lot area in square metres for comparison to other previous work on construction project assessment (Freire-Guerrero et al., 2019; Rivero-Camacho and Marrero, 2022) or per hectare to compare with gardening projects (Nouri et al., 2019; Salvador et al., 2011).

The environmental impact of the resources consumed is based on LCA, obtained from international databases of construction products (Martínez-Rocamora et al., 2016), which includes the water required

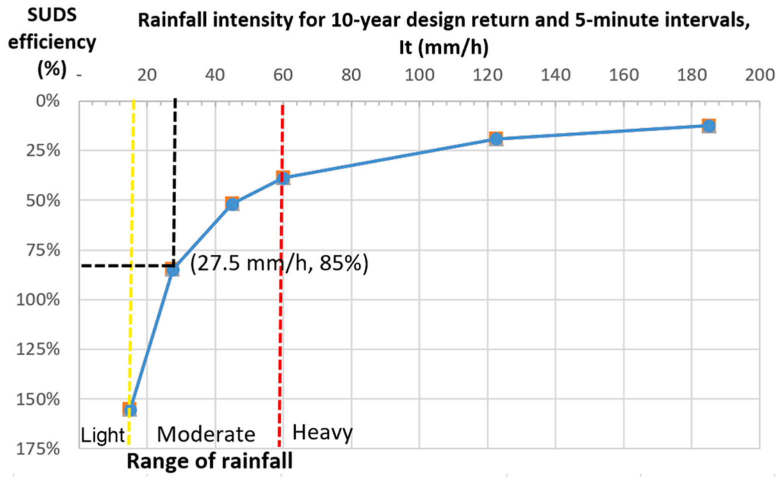


Fig. 1. SUDS: design of the infiltration profile.

Table 3
Equations to calculate the WF of a garden: effective rainfall.

	Equation nº
WATER FOOTPRINT OF A GARDEN	
EFFECTIVE RAINFALL	
$ETg = PEf + GWR$	16
Corollary:	
If ETg ≤PEf then RWA=ETg and RWS=PEf-ETg and GWR=0	
If ETg >PEf then RWA=PEf and RWS=0 and GWR=PEf-ETg	
ETg: Garden evapotranspiration (Contreras et al., 2006)	
PEf: Effective rainfall in the area (mm)	
GWR: Garden irrigation water requirement (mm)	
RWS: Rainwater surplus(mm)	
Localised irrigation (Contreras et al., 2006)	
If $Ea \le (1 - Fl)$ then : $Nb = \frac{GWR}{Ea} * 100$	14
If $Ea > (1 - Fl)$ then : $\text{Nb} = \frac{GWR}{1 - Fl} * 100$	15
Sprinkler irrigation (Contreras et al., 2006)	
If $Fl \le 10\%$ then : $\text{Nb} = \frac{GWR}{Ea} * 100$	16
If $Fl > 10\%$ then : $\text{Nb} = \frac{09 * \text{GWR}}{1 - Fl} * 100$	17
Ea: Irrigation application efficiency factor (%)	
Nb: Gross water requirement (mm)	
Fl: Washing fraction (%)	
Irrigation Water Surplus	
$IWS = GWS - - Nb$	18
IWS: Irrigation water surplus (mm) (Contreras et al., 2006)	
Components of the WF of the garden (Contreras et al., 2006; Hoekstra, 2019)	
$WFg\ green = S * \sum_{i=1}^{n} RWAi * Si$	19
$WFg\ blue = S * \sum_{i=1}^{n} GWRi * Si$	20
$WFg\ grey = \sum_{i=1}^{n} (RWSi + IWSi) * Si$	21
RWA: Rainwater available (mm)	
S: Area considered (m^2)	
S_i: Area of sub-area i (m^2)	

during the life cycle from cradle to factory gate. Material transport and commissioning impact are also calculated.

For the resources inventory, the ACCD (Andalusia Construction Cost Database) is employed (Ramírez-de-Arellano-Agudo, 2010). Fig. 3 shows an example of a unit cost (UC) that forms part of Chapter 15 on Urbanisation. The UC is formed with the combination of basic costs (BC), such as materials, machinery, and labour, or with the combination of BC with auxiliary costs (AC), whereby the latter are combinations of BC commonly employed in construction that do not form a construction unit by themselves and hence are not complex enough to be considered a UC. In the example given in the figure below, the mortar is an auxiliary cost AGM90200 which is formed of other BCs (TP00100, GW00100, and GC00200), see Fig. 3. Thanks to this hierarchical classification, it is possible to incorporate the environmental impact of all elements in the project by multiplying their quantities by the unit impact.

In the case of machinery, the average fuel consumption (differentiating between diesel and petrol) per hour worked by machinery is obtained by Eq. (22) (see Table 4). The average consumption of each construction machine is calculated by employing the conversion factor for the volume of water needed to provide one kg of fuel. This factor is extracted from the open database Ecoinvent (Frischknecht et al., 2005) (Table 4, Eq. (23)).

For electric machines, the water necessary for the production of one kWh by the Spanish electric mix (REE, 2014) is used (Table 4, Eq. (24)). Once the unit value of one hour of machine consumption is defined, it is then multiplied by the project quantities (Qi) or the time the machine is used at work, and hence the total WF of the machine is obtained (Table 4, Eq. (25)).

For the WF of construction materials or of its BC, the first step is to change its unit of measurement at the origin (m^3, m^2, metres, tons, thousands of bricks, etc.) into kg (see Fig. 3 for calculation details) (Table 4, Eq. (26)). The density is obtained from the Construction Solutions of the Technical Building Code (CSC) and the Basic Document of Structural Safety, which both form part of the Technical Building Code (TBC), Building actions DB-SE AE (TBC, 2006).

Environmental families have been defined from the LCA database by distributing each BC per similarity. Environmental families refer to groups of construction material that have the same origin in terms of raw materials, that way the over 300 products in the urbanisation project can be grouped into categories or families in order to assign the LCA data (Freire-Guerrero et al., 2019; Rivero-Camacho and Marrero, 2022). In the life cycle inventory for each of the materials, the Water Footprint Network (WFN) is the reference framework for the calculation of the WF, a concept introduced by Hoekstra (2003), and the calculation methodology used is that developed in "The Standard Calculation Methodology" and "The Water Footprint Assessment Manual" (Hoekstra et al., 2011). This makes it possible to obtain the water use of any production process expressed in the volume of water consumed (m^3/kg) (Table 4, Eq. (27)). Once each UC in the project has been obtained, the project quantities (Qi), or the quantities consumed on site (see Fig. 3, Budget quantities), are then applied, and the total WF of the construction materials is obtained (Table 4, Eq. (28)).

3. Case study

The calculation methodology is applied to an urban renewal project in Seville, Spain, which covers an area of 11,441 m^2, and corresponds to the complete layout of a street. The project is developed by the Metropolitan Water Supply and Sewer Company of Seville (*Empresa*

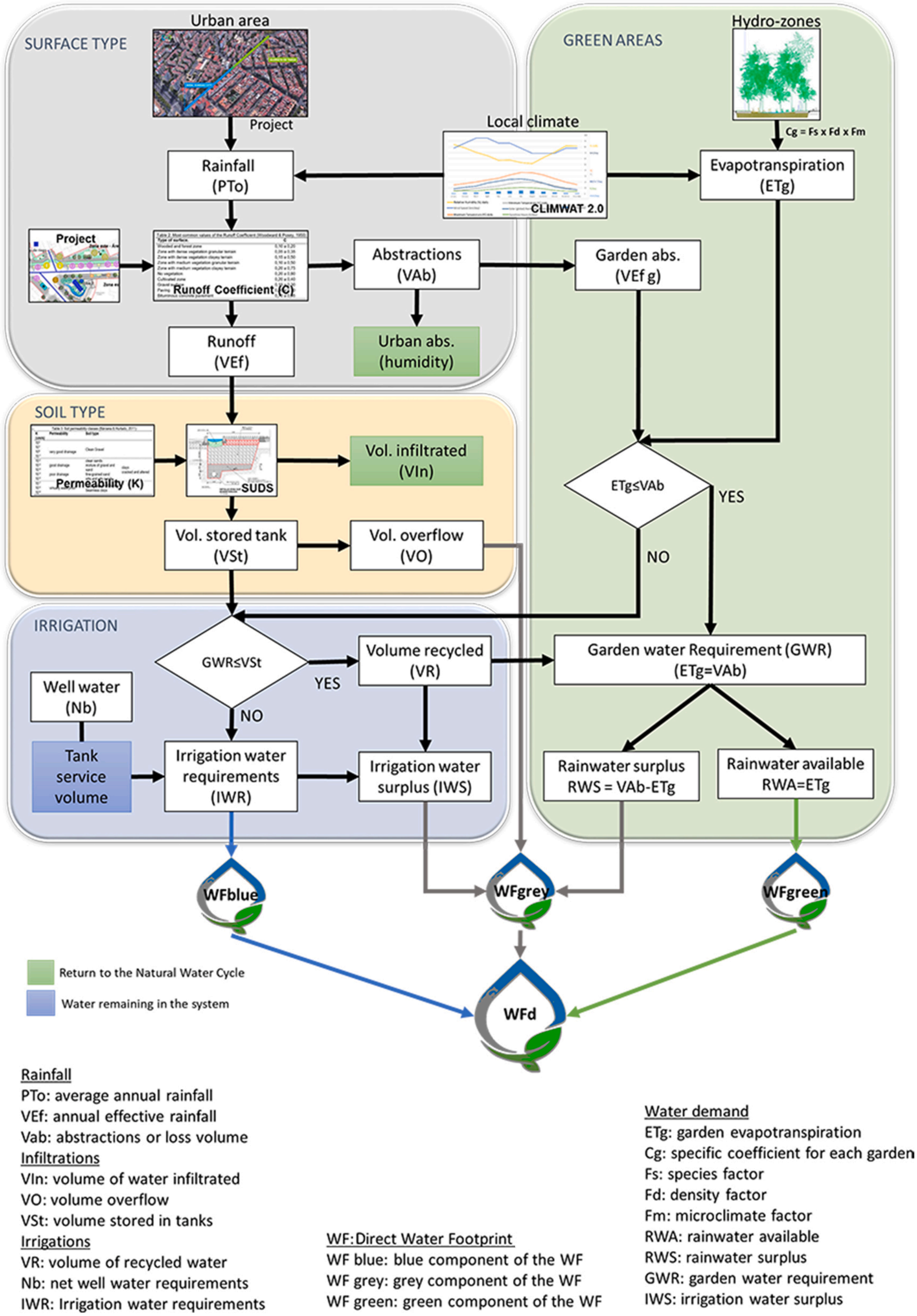
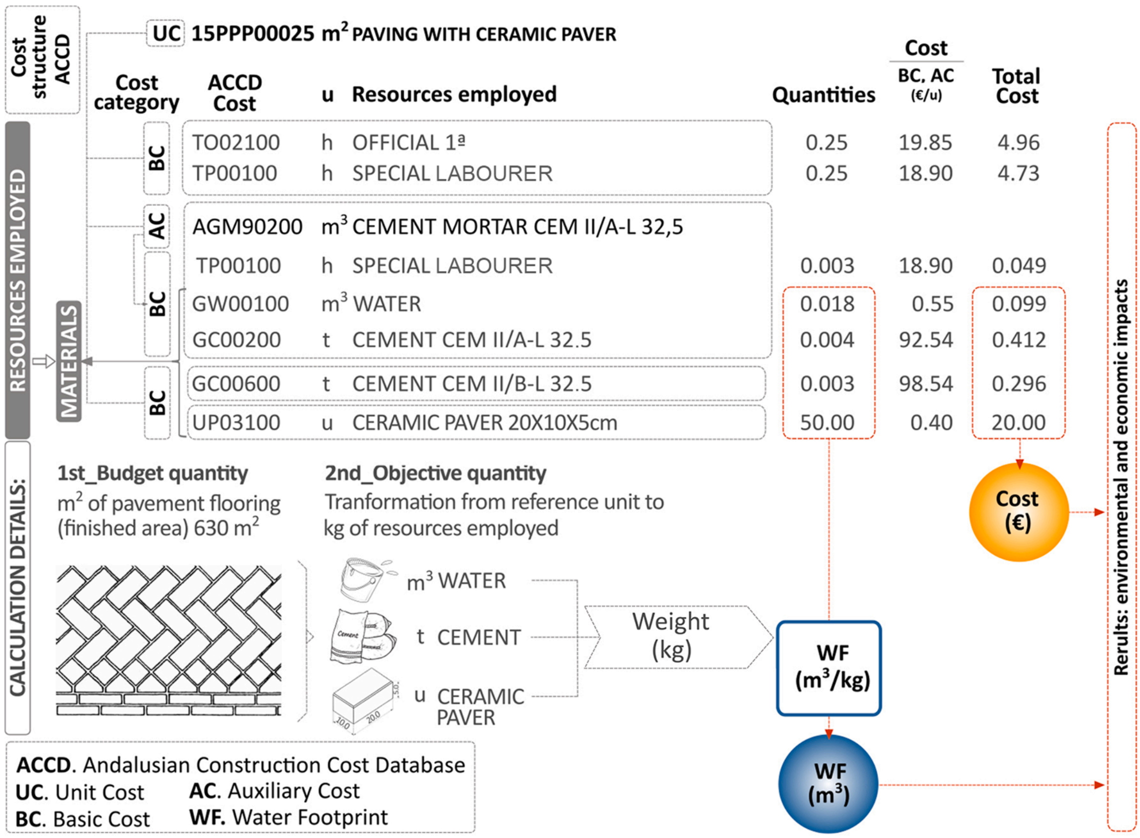


Fig. 2. Flow diagram of the direct water footprint in urbanisation works.

Metropolitana de Abastecimiento y Saneamiento de Aguas de Sevilla S. A., EMASESA), a public enterprise dedicated to the management of the urban water cycle. In Fig. 4, the new garden characteristics are represented by colour, each different group of plants is part of a defined hydro-zone. Furthermore, each hydro-zone has factors for species, density, and microclimate corrections, whereby the product of the three factors is the hydro-zone coefficient (Ruíz-Pérez et al., 2020). Fig. 5 presents the ten hydro-zones in the garden, the rain patterns, and water



ACCD code	Unit	Description	Volume (m³)			Coefficient (kg/m³)	Weight (kg)
			X	Y	Z		
GC00200	t	Cement CEM II/A-L 32.5	1.00	1.00	1.00	1000.00	1000.00
GC00600	t	Cement CEM II/B-l 32.5	1.00	1.00	1.00	1000.00	1000.00
UP03100	u	Ceramic paver20x10x5cm	0.20	0.20	0.05	2233.07	2.23

Fig. 3. Schematic summary of the ACCD, details of the calculation procedure for converting the different units into kg, and application of coefficients to obtain WF (based on Ruiz-Pérez et al., 2021).

necessities.

The analysis is based on the "ceteris paribus" approach to characterise the level of influence of each variable. Four categories are defined in accordance with two design parameters: the incorporation of green areas into the urban space, and the use of a SUDS (Table 5). Each category is hereinafter referred to as the scenario.

4. Results and discussion

4.1. Direct water footprint (dWF)

The dWF calculation is applied to the scenarios described, starting with the initial case (S1). Using the data input, the flow of the SUDS and the natural system is analysed, and the outputs are obtained.

For the initial state, the street is divided into four areas. First, the north pavement (Fig. 4) empties into the drainage ditch located between the bike lane and the road, formed by the permeable surface parking lots and the filter strip. Second, the south pavement empties into the ditch located between the roadway and the pavement, whereby both areas discharge into Tank 1. Similarly, the eastern zone is subdivided into two areas that discharge into Tank 2. The runoff coefficients, Ci, the average annual effective precipitation, and the two generating surfaces (runoff (SR) and loss or abstraction (SAb)) are described in Table 1 of the Appendix, and the corresponding volume is calculated in Table 2 of the Appendix.

The soil permeability is 3.3×10^{-4} cm/s according to the Spanish Geological Mining Institute database (Instituto Geológico Minero de España, S. F.). The SUDS manages the 85th percentile runoff volume, as defined in Fig. 1. For the calculation of infiltrations, the project proposes two scenarios: first, the rainfall regime ranges between light-to-moderate and highly intense and runoff is retained in the SUDS and infiltrated in less than 48 h; and second, runoff cannot infiltrate and runs into the tank during very heavy rainfall according to AEMET (2015), see Table 3 in the Appendix. The concept of filtration surface (SF) is used in an analogous way to that of a runoff-generating surface, and the coefficient of performance of the SUDS is applied. The outputs of the SUDS (Table 4 in Appendix) are obtained by direct infiltration to the ground (VIn) and the water stored in the gravel layer (VS_{SUDS}); subsequently, part of the water infiltrates into the ground, and the rest is stored in the tanks (VS_{TANK}).

In Fig. 6, all volumes are expressed in m³, and the percentages are calculated with respect to the green or blue input volume.

The input and output volumes of each scenario were evaluated, thereby obtaining the dWF (Table 6), in terms of total volumes for one year, and per component of the WF.

In systems without green areas (S2 and S4), if the surfaces are

Table 4
Equations for the calculation of the indirect WF.

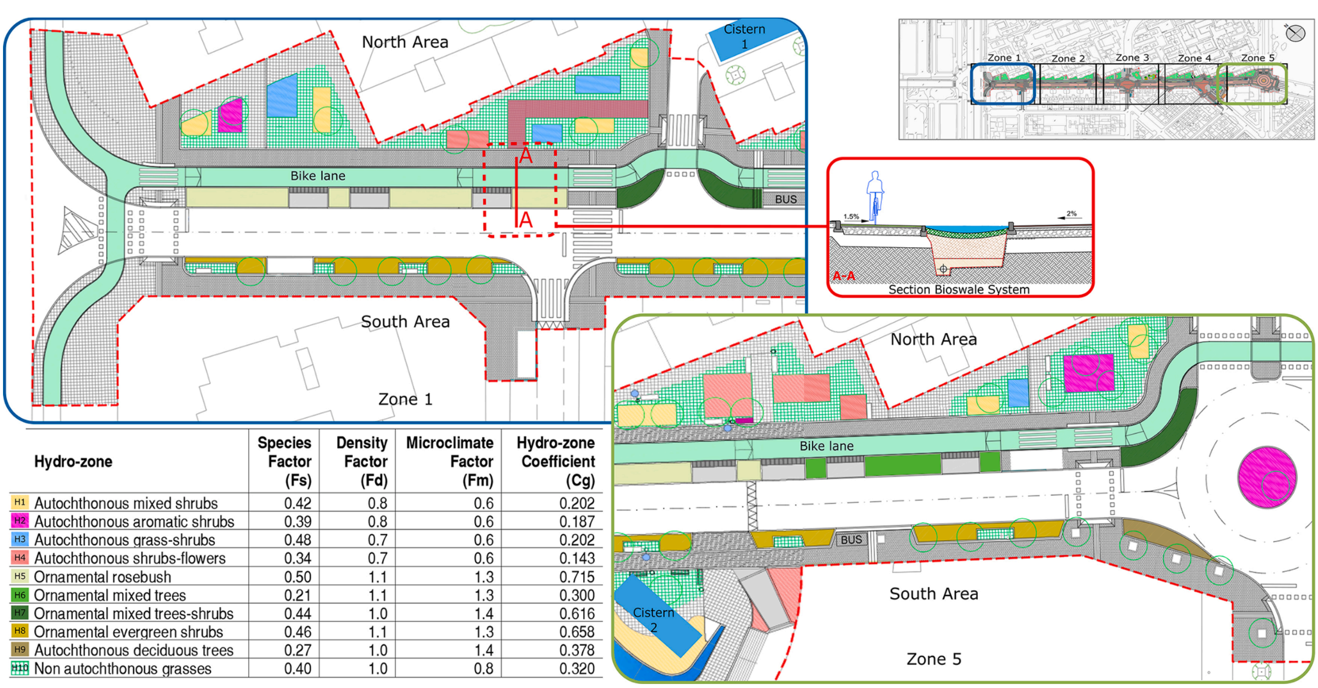
	Equation nº
INDIRECT WATER FOOTPRINT	
Machinery	
$V = \text{Pot} * \text{Rend}$	**22**
$WF_{comb\ i} = V_i * D_{comb\ i} * F_{WF\ comb}$	**23**
$WF_{elec\ i} = V_i * F_{WF\ elect}$	**24**
$WFB_{Maq} = \sum_{i=1}^{n}(WF_{comb\ i} * Q_i) + (WF_{elec\ i} * Q_i)$	**25**
V: average fuel consumption of the machinery (l/h)	
Pot: power of the machinery's engine (kW)	
Rend: fuel consumed by the machinery's engine depending on whether it is diesel or petrol (l/kWh)	
$WF_{comb\ i}$: basic water footprint of the (fossil) fuel consumption of the machinery i (m^3/h)	
V_i: average fuel or electricity consumption of the machinery i (l/h) or (kWh)	
D_{comb} i: average fuel density of the machinery i	
F_{WFcomb}: fuel water use factor (m^3/kg)	
$WF_{elec\ i}$: basic footprint of the electrical consumption of the machinery i (m^3/h)	
F_{WFelec}: water use factor of the energy mix (m^3/kWh)	
WFB_{Maq}: basic water footprint of the machinery (m^3)	
Q_i: measurement of machine use i (h)	
Construction materials	
$V = U * F_{URef}$	**26**
$WF_{m\ i} = V_i * F_{WF\ mi}$	**27**
$WFB_{Mat} = \sum_{i=1}^{n}(WF_{m\ i} * Q_i)$	**28**
V: unit of material consumed expressed in weight (kg)	
U: unit of material expressed in its unit of reference (URef)	
F_{URef}= factor for conversion from reference unit to weight of the unit of material (kg/URef)	
$WF_{m\ i}$: basic water footprint of material i (m^3/URef)	
V_i: unit of material i (kg)	
$F_{WFm\ i}$: water use factor of material i (m^3/kg)	
WFB_{Mat}: basic water footprint of material (m^3)	
$WF_{m\ i}$: basic water footprint of material i (m^3/URef)	
Q_i: measurement of material consumption i (m^3/URef).	

impermeable, as in S2, then the system is designed to quickly evacuate a large volume of rainwater, resulting in more runoff. However, if a SUDS is introduced, even if green areas are not present, as in S4, the disconnection of impermeable surfaces from the sewer network significantly reduces the volume to be evacuated (67%). Furthermore, at peak flow, water is laminated, and less runoff occurs. In the process, the water that infiltrates the ground generates the recharge of the underground aquifer and recovers part of the natural cycle, thereby reducing discharges and overloads of the city's sewer systems. However, the volume of water poured into the sewer network during periods of torrential rainfall is extremely high (89%). This could be reduced by increasing the storage capacity of the system with bigger tanks: in this case, however, the limited public space available in the street margins renders this option infeasible.

In the presence of green areas (S1 and S5) or water-consuming areas, and SUDS, the volume to be evacuated is reduced (72%) as compared to the solution that fails to implement any water-sensitive design. In addition, the decrease is most noticeable during rainy seasons, whereby peak flows are reduced during storm events, and the seasonal variation of runoff water that is to be managed is also reduced. The volume infiltrated by the SUDS accounts for 32% of the total rain (S4, S1, and S5).

A design-based strategy for the maximisation of the use of water collected from rainfall has been employed to achieve a 50% reduction of freshwater demand. The project alternates hydro-zones with different necessities, and with this system it is possible to distribute the available rainwater by compensating the surplus of the autochthonous species with the high water requirements of ornamental species. This is achieved with an irrigation system adapted and automated for each area, thus reducing the blue and grey footprint.

Gardened soils lose nutrients, and for this reason they must be periodically replenished. In the case where organic fertilisers are employed, the grey footprint caused by diffuse contamination (S1) can be disregarded. However, the use of industrial synthetic chemicals in fertilisers or pesticides produces pollutants in the drainage water (S5). The grey WF concept is applied, in which the volume of water for the dilution of contaminants, necessary to return water to its natural quality, is determined. This increases the grey WF by 800%, hence the importance of applying organic fertilisers, which also exert a positive influence on the structure of the soil (Bronick and Lal, 2005). Organic fertilisers additionally provide nutrients and modify the population of microorganisms, thereby ensuring greater water retention and the exchange of gases and nutrients at the level of the roots of the plants. Furthermore, the generic nutrient/pollutant balance raises awareness regarding the quality of the water that is discharged out of the urban



Hydro-zone	Species Factor (Fs)	Density Factor (Fd)	Microclimate Factor (Fm)	Hydro-zone Coefficient (Cg)
H1 Autochthonous mixed shrubs	0.42	0.8	0.6	0.202
H2 Autochthonous aromatic shrubs	0.39	0.8	0.6	0.187
H3 Autochthonous grass-shrubs	0.48	0.7	0.6	0.202
H4 Autochthonous shrubs-flowers	0.34	0.7	0.6	0.143
H5 Ornamental rosebush	0.50	1.1	1.3	0.715
H6 Ornamental mixed trees	0.21	1.1	1.3	0.300
H7 Ornamental mixed trees-shrubs	0.44	1.0	1.4	0.616
H8 Ornamental evergreen shrubs	0.46	1.1	1.3	0.658
H9 Autochthonous deciduous trees	0.27	1.0	1.4	0.378
H10 Non autochthonous grasses	0.40	1.0	0.8	0.320

Fig. 4. Location of cistern and drainage areas (Project: EMASESA) (based on Ruíz-Pérez et al., 2020).

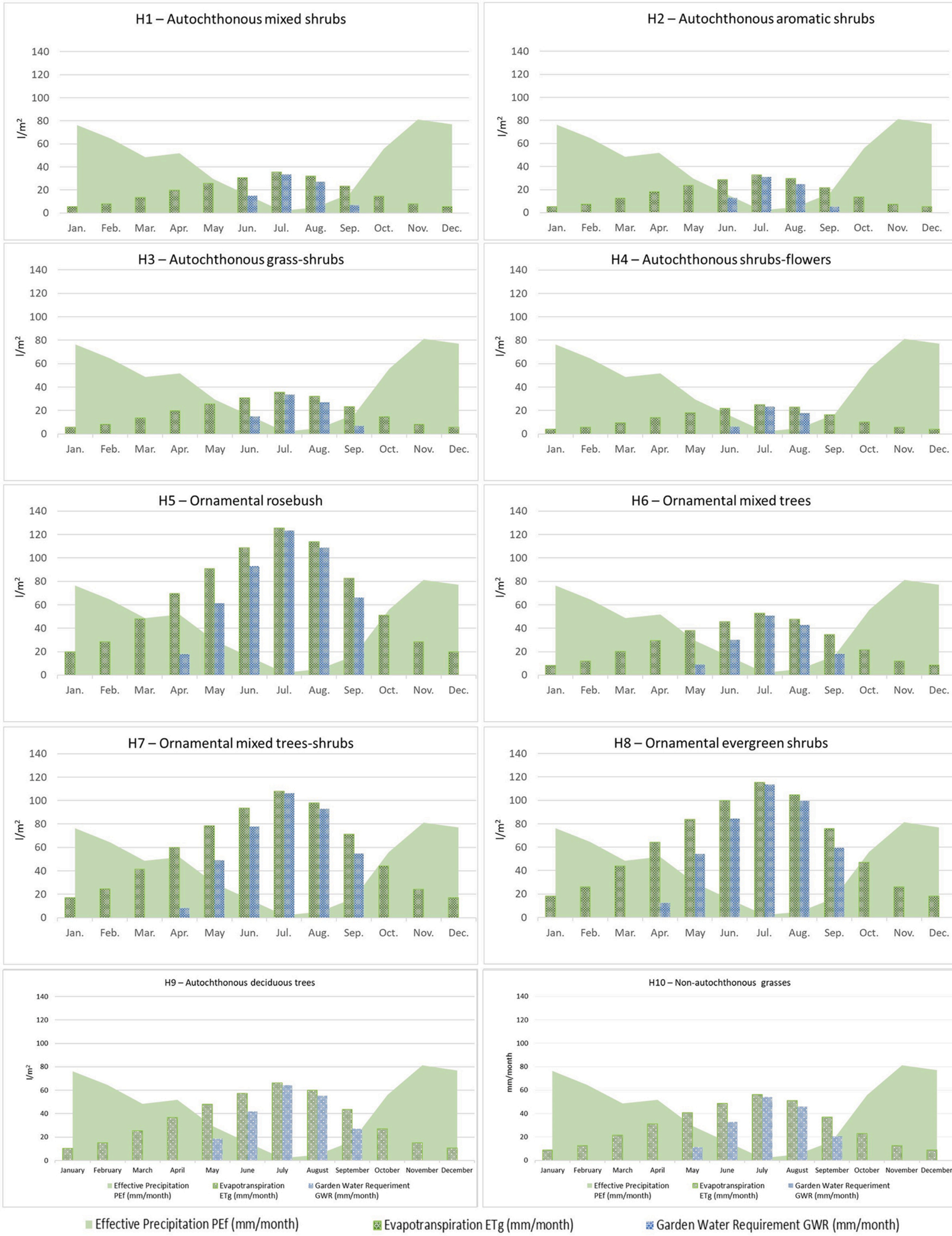


Fig. 5. Rain patterns and water necessities of the 10 hydro-zones in the garden.

system.

Treatment technologies, such as biological/chemical/physical processes, are not included since those processes take place outside the boundaries of the urbanisation project. In the case study, the grey water of the street goes to Ranilla Treatment Plant, an anaerobic/anoxic/aerobic system of activated sludge. This plant is equipped with tertiary treatment for the removal of nutrients, nitrogen, and phosphorus. The water is returned to the river at natural concentration levels, that is, without grey WF.

The blue WF in the present work is 9740 m^3 per hectare in S1, which

Table 5
Characterisation of scenarios.

General characteristics		Green areas	SUDS	Non-organic fertilisers
S1	SCENARIO 1	✓	✓	✗
S2	SCENARIO 2	✗	✗	✗
S3	SCENARIO 3	✓	✗	✗
S43	SCENARIO 4	✗	✓	✗
S5	SCENARIO 5	✓	✓	✓

Description of scenarios

S1 **Project objective:** provision of new sustainable urban drainage system (SUDS) and green areas for the urban space (street).
Rainwater catchment systems: the collection of water from the street is partly disconnected from the existing sewer system. Rainwater is collected from roads and pavements, and a percentage is channelled and stored in green areas and deposits for recycling. The other part is infiltrated into the ground and the surplus is sent to the existing sewer system.$$$$In times of scarce rainfall, an irrigation well supplies tap water to the tanks so that they can operate continuously throughout the year. In the case of torrential rain, to prevent overflow, the excess water is discharged into the general street sewer system.
System characteristics: the drainage ditches are protected by a high-density polyethylene geomembrane, and, to filter the water, a draining layer of gravel with 35% gaps also accumulates 20 cm of water in the case of torrential rainfall. The network is formed of 200mm-diameter drainage pipes of corrugated polyethylene with 360° circular grooves and directs rainwater into two buried reinforced concrete tanks. Tank 1, whose volume is 75 m^3, is located on the north-west side of road, while Tank 2 is on the south-east side. Both collect water for the irrigation system (Fig. 4).

S2 **Project objective:** the project consists of the renewal of supply and sanitation networks where the geometry and morphology of the roads and pavements remain unaltered and no new green areas or SUDS are included.
Rainwater catchment systems: the urban space leads into an impermeable platform that directs all rainfall and runoff into the general sewer system.
System characteristics: the sewer network is made up of vitrified ceramic pipes and the supply network has steel pipes.

S3 **Project objective:** renovation of the supply and sewer networks, in which the geometry and morphology of the roads are reformed by a solution that includes green areas but includes no SUDS.
Rainwater catchment systems: no tanks are used for storing rainwater, instead its treatment is directed to the general sewer system.
System characteristics: the sewer has vitrified ceramic pipes and the supply has steel pipes.

S4 **Project objective:** renovation of the supply and sewer networks, where the geometry and morphology of the affected roads is reformed through a solution that includes no increase of green areas, although it does include a SUDS.
Rainwater catchment systems: the urban space is transformed into a platform with permeable areas that control rainfall and runoff by sending it to a separate system that stores rainwater for street cleaning.
System characteristics: the same as Scenario S1, except for the green areas.

S5 **Project objective:** actions included are identical to those mentioned in the initial Scenario (S1), but non-organic fertilisers are employed, thereby renouncing the concept of sustainable agriculture (Reganold et al., 1990).
Rainwater catchment systems: the same as Scenario S1.
System characteristics: the same as Scenario S1, except for the use of industrial synthetic chemicals or organisms resulting from gene manipulation to improve the physical, biological, and chemical characteristics of the crop soil, with the consequential presence of nitrogen concentrations 18 N—NO3 mg/l in drainage water (Andreu Lahoz et al., 2006).

is slightly lower than 11,140 m^3/ha per year found by Nouri et al. (2019). They estimate the blue and green WF of a 10-hectare parkland in Adelaide, South Australia. The main differences can be due to the vegetation species and the density of the garden because the Seville case study consists of a street with side gardens. Similar results are found in China, the urban green-space water use per statistical data in southern and northern cities, is 12,570 /ha and 6380 m^3/ha, respectively (Guo et al., 2021). Moreover, similar results are found in Endter-Wada et al. (2008), whose ceiling threshold results regarding the water use of gardens are 8430 m^3/ha for residential gardens and 10,620 m^3/ha for business.

4.2. Indirect water footprint (iWF)

The impact on the water footprint by the materials incorporated into the work has been evaluated, following the methodology of iWF. For this calculation, the urban area of intervention corresponds to the area of the street including pavements, roads, and gardens (see Table 7).

It was revealed that 41% of the impact is due to concrete and cement, followed by 35% to aggregates and stones, and 12% to ceramics and bricks. The prefabricated concrete and slabs for wells and storm-tank foundations are more relevant in S2 and S4, while the inclusion of reinforced concrete cisterns is relevant in S1, S3, and S5, where the drainage systems reduce the consumption of prefabricated elements in the storm drainage system.

The integral renovation of the street and the provision of improved soil that enables the drainage and filtering of rainwater to be reused for street irrigation, makes the family of aggregates and stones a critical material for S1, S4, and S5, whereas for conventional solutions (S2), these materials exert less impact. At the same time, the systems involving the levelling of land and the urban furniture mean that metals and alloys, together with the PVC pipes used in the drainage system, also constitute major families of materials.

In projects with a SUDS (S1, S4, and S5), the materials with the highest impact are fresh concrete and prefabricated concrete parts, refill soil, metallic tubes, and ceramic pipes.

In the southern part of the city of Calcutta, India, Bardhan (2011) measured the virtual water of the construction of a multi-storied residential apartment building of steel and reinforced concrete as 27 m^3/m^2 of floor area. In a similar way, based on the project data in the bill of quantities, six landmark buildings in E-town, Beijing, had a total virtual water of 20.83 m^3/m^2 of floor area (Meng et al., 2014). Also in Beijing, Han et al. (2016) determined the total virtual water of another nine projects to have an intensity of 26.5 m^3 per m^2 of floor area. In Tehran, the virtual water of six residential buildings was 18.76 m^3 per m^2 of floor area (Heravi and Abdolvand, 2019). Furthermore, the WF of the building life cycle was also determined of a social housing project in Huelva, Spain, whereby 27 m^3 per m^2 of floor area was revealed in their life cycle (Rivero-Camacho and Marrero, 2022).

Moreover, the virtual water of urbanisation projects has been calculated at 2.70–7.25 m^3/m^2 (Ruiz et al., 2021), which is a lower range than in the present work, of 6 - 11.8 m^3/m^2. This is due to the complexity of the projects, those that include only the street, and the utilities installed or other services, such as gardens, and playgrounds.

4.3. Global WF of the service life cycle

Urbanisations, such as residential buildings and infrastructures, have a life expectancy that is determined by material deterioration and/or obsolescence. Planners in Spain refer to Appendix III of the Royal Decree 1492/2011, of 24 October, which passed the law for the Regulation of Valuations of Land (RD_1492/2011): it states that roads, open-air car parks, and similar infrastructures have a life expectancy of 40 years. However, these durations may vary according to the materials used, the maintenance, and their functionality or obsolescence. In Table 8, the dWF and iWF are added together for a 40-year period.

Although the iWF of the project with water-sensitive urban design (S1) is 2.6 times higher than that of a standard project (S2), the total dWF over its entire life cycle is 43.5% less, due to the annual savings of 65%. The breakeven point, 9.65 m^3, is reached in the 10th year. When separative rainwater management (S4) is applied, the most important iWF is due to the earth works required for the new drainage and infiltration system, although with the absence of vegetation the dWF is low. As for the incorporation of green areas and irrigation without a SUDS (S3), dWF increases. Finally, the use of chemical fertilisers, which are not environmentally friendly, incorporates a grey footprint which triggers the annual dWF and nullifies all the efforts made.

Even though the combination of the three footprints, green, blue and

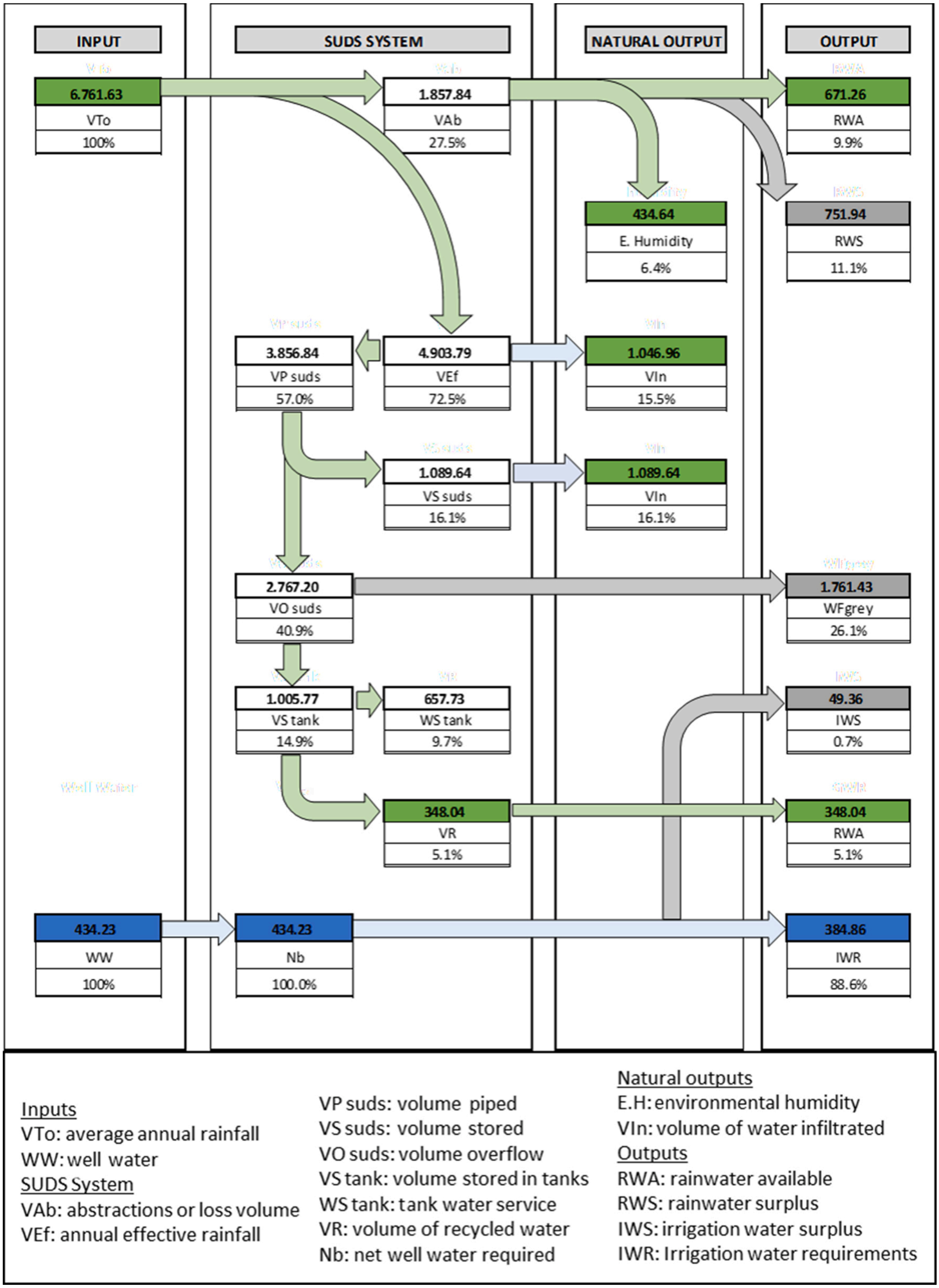


Fig. 6. Flow diagram of Scenario 1.

grey, mixes different natures, this better represents the urban system, where water is transformed when it enters and leaves the system or urban project, for example, blue water becomes grey water when the irrigation surplus is sent to the sewer system, and green water turns grey when the rain cannot be stored in tanks for the irrigation of the garden, and green water turns into blue water when infiltrated in the soil.

Other authors combine these footprints, as modelled by Hoekstra (2019), for blue and green water by Ridoutt et al. (2012), and blue and

Table 6
Inputs, outputs, and annual direct WF.

Systems	S1	S2	S3	S4	S5
Inputs					
Total precipitation (V_{to}) m^3	6762	6762	6762	6762	6762
Well water (VR_{WELL}) m^3	434	–	801	—	434
SUDS System					
Abstraction Volume (VAb) m^3	1858	1120	1768	1698	1858
Effective Volume (VEf) m^3	4904	5641	4993	5064	4904
Stored Capacity (VS_{SUDS}) m^3	1117	–	–	1117	1117
Infiltrated Volume (W_{in}) m^3	1935	–	–	1935	1935
Overflow Volume (VO_{SUDS}) m^3	2969	5641	4993	3129	2969
Irrigation System					0
Volume stored (VS_{TANK}) m^3	1006	–	–	1006	1006
Volume recirculated (VR) m^3	348	–	–	–	348
Irrigation Water Surplus (IWS) m^3	49	–	49	–	49
Outputs					
Evapotranspiration (E_{Tj}) m^3	1019	–	671	–	1019
Volume drained (VD_{RED}) m^3	1963	5641	4993	2108	1963
Components of WF	S1	S2	S3	S4	S5
Blue (m^3)	385	–	752	—	385
Green (m^3)	1019	–	671	—	1019
Grey (m^3)	2765	5641	5794	2860	23,338

* Nitrogen concentrations 18 N—NO3 mg/l in drainage water (Andreu Lahoz et al., 2006).

grey water by Penru et al. (2016). As identified by Mubako (2018) in a review of 70 publications, three approaches can be found to model blue, green, and grey water: WF assessment, LCA, and a combination of the two.

There is a discussion as to whether the components, blue, green, and grey WF, shall be added in a single indicator, mixing different elements and processes, or need to be analysed separately (Garrido et al., 2010; Garrido Colmenero and Willaarts, 2011). In the present work the discussion is done separately. The project, which includes SUDS in its design (S4), but not a garden, reduces the grey WF by half with respect to the original design (S2). The same happens with the design that has vegetation and SUDS (S1) with respect to the same project without SUDS (S3). And as expected the blue WF is also increased in the last.

The uncertainty involved in the calculation of dWF regarding the rainfall data remains low because local data is available, the soil permeability is also local, as is the evaluation of the microclimate and the garden characteristics. However, the amount of water needed by the greenery, ETo, is of high uncertainty because local and empirical data is unavailable and information pertaining to other sites is used instead (Contreras et al., 2006; Costello and Jones, 2000). Nevertheless, those sites do enjoy similarities to the weather of Seville. The iWF calculation has high uncertainty since project-specific data has not been employed due to the lack of specification of the brands in the budget, and generic LCA information is therefore employed.

5. Conclusion

The direct water footprints (dWF) of blue, green, and grey water have been assessed, as have the indirect or virtual water footprint (iWF) of urban renovation projects, which include green spaces and SUDS. To this end, local information on precipitation, soil characteristics and greenery microclimate, density, and species, are assessed together with water harvesting. Construction cost databases are employed for the inventory of resources and the assessment of the iWF.

The water footprint (WF) of an urbanisation project in the city of Seville is evaluated in full. The projects involve the incorporation of new gardens, playgrounds, street paving and new pavements, together with all urban installations, such as lighting, water supply, and sewer systems. The traditional impermeable pavement is reduced and replaced by a SUDS that allows rainwater to be harvested and reused by efficient irrigation systems that are adapted to the demand of the plant species in each area, thereby reducing water use.

Five scenarios are evaluated. The methodology is sensitive to changes in the gardens, SUDS, and fertilisers. This new approach can promote the water cycle through coexistence between natural and fabricated drainage and green areas.

As regards the footprint obtained in incorporating building materials (iWF), concrete, aggregates, and stone control the environmental impact. Stones and aggregates are used in the implementation of SUDS for the improvement of the land under the permeable surfaces to promote the infiltration, transport, and storage of rainwater. There is also an opportunity to replace these materials with recycled aggregates, thereby further reducing the impact. Another major aspect in the assessment involves the availability of information for the calculations and the degree of confidence in the data used. For this study, data has been obtained from accessible databases and inventories, although it is generic and needs to be replaced in the future by sources of a more reliable and/or more specific nature, such as environmental declarations of the products consumed in the project.

Table 8
WF at end-of-life.

Indicator	WF (m^3_{water}/m^2)				
Projects	S1	S2	S3	S4	S5
Indirect WF (construction)	7.3	2.7	6.0	6.5	7.3
Direct WF (service life)					
Blue	1.3	–	2.6	–	1.3
Green	3.6	–	2.4	–	3.6
Grey	9.7	19.8	20.3	10.0	81.8

Table 7
Impacts broken down into material families, the unit of reference is square metre of total project area covered.

PROJECTS	S1		S2		S3		S4		S5	
	WF (m^3/m^2)	Weight (kg/m^2)	WF (m^3/m^2)	Weight (kg/m^2)	WF (m^3/m^2)	Weight (kg/m^2)	WF (m^3/m^2)	Weight (kg/m^2)	WF (m^3/m^2)	Weight (kg/m^2)
Concrete and cement	1.18	564.00	1.10	441.00	1.11	522.00	1.13	535.00	1.18	564.00
Ceramics and bricks	0.62	49.30	0.32	19.40	0.62	49.30	0.62	46.60	0.62	49.30
Wood	0.05	19.70	0.02	5.03	0.04	15.30	0.04	15.20	0.05	19.70
Metals and alloys	1.00	12.00	0.10	2.71	0.93	10.10	0.95	10.50	1.00	12.00
Plastics	1.08	4.39	0.09	1.54	0.44	2.70	1.04	4.12	1.08	4.39
Water	0.35	308.00	0.11	72.60	0.30	264.00	0.33	290.00	0.35	308.00
Aggregates & stones	2.12	2880.00	0.93	1090.00	1.69	2500.00	2.08	2750.00	2.12	2880.00
Bitumen and asphalt	0.36	44.50	0.00	0.13	0.36	44.50	0.36	44.50	0.36	44.50
Others	0.01	0.07	0.01	0.03	0.01	0.06	0.01	0.07	0.01	0.07
Gardening	0.47	274.00	0.00	0.03	0.47	274.00	–	–	0.47	274.00
TOTAL	**7.26**	**4160.00**	**2.69**	**1630.00**	**5.96**	**3680.00**	**6.55**	**3690.00**	**7.26**	**4160.00**

The dWF of the built environment has been calculated by adapting the indicator developed by Hoekstra and others. The hydric balance of an urban system is explored, for the first time, which includes the street, pavements, its gardens, playgrounds, and SUDS. For the calculations, local data is employed for rain, infiltration, and weather, but no specific geographical information is available for the calculation of the water needed by the greenery. The methodology enables project designs to be differentiated in terms of their footprint. The results maximise the importance of the water quality that exits the urban system by the calculation of the grey water as the dissolution necessary to restore its quality. The methodology also combines and transforms green and blue input water into a single indicator. The iWF of the project is 2.6 times higher than that in a standard project, but, due to annual savings of 65% in its dWF, the breakeven point is reached in the 10th year.

Future work will consider the influence of climate projections in terms of temperature and precipitation, which are marked by the trends in climate change, to study the vulnerability of various gardens and of sustainable urban drainage systems.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.watres.2022.118715.

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