LIFECERSUDS. VALIDATION OF THE PERMEABLE CERAMIC FLOORING SYSTEM

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ABSTRACT

LIFECERSUDS is a project carried out over the period 2016-2019 and funded by the LIFE Programme 2014-2020 of the European Union for the Environment and Climate Action under project number LIFE15 CCA/ES/000091, in collaboration with the *Generalitat Valenciana* through the Valencian Institute for Competitive Business (IVACE).

The main objective of the project was to improve the ability of cities to adapt to climate change by promoting the use of green infrastructures in the renewal of urban environments. Under the project, a Sustainable Urban Drainage System (SUDS) was built as a demonstrator in the town of Benicàssim, using ceramic tile stock of low commercial value to manufacture an innovative permeable floor (hereinafter, CERSUDS flooring), a subject already dealt with in an earlier presentation at this congress[i].

Once the demonstrator had been built, a monitoring period was run between August 2018 and July 2019, which enabled both the CERSUDS floor and the demonstrator's value as a rainwater management system to be validated.

The main results of the project are discussed hereunder and relate to: environmental and economic assessment of the CERSUDS system, users' validation of the system, monitoring of the system's mechanical performance and permeability, and monitoring of the demonstrator's hydraulic response in terms of the quantity and quality of run-off water.

1. ENVIRONMENTAL ASSESSMENT

1.1. EVALUATION OF THE ENVIRONMENTAL IMPACTS OF THE CERSUDS SYSTEM

Life Cycle Assessment (LCA) studies are based on an iterative method for assessing the environmental loads associated with the life cycle of any product, process or activity, in which its consumption of resources and emission of waste to the environment are identified and quantified in order to analyse impact on the environment and thus assess and implement possible improvement measures.

Within the framework of the LIFE CERSUDS project, an LCA study was carried out following the recommendations and requirements of international standards ISO 14040:2006[ii] and ISO 14044:2006[iii], and also taking UNE EN 15804+A1[iv] into consideration. LCA modelling was performed with the support of GaBi software and its associated databases[v,vi]. LCA studies comprise 4 phases, as shown in Figure 1.

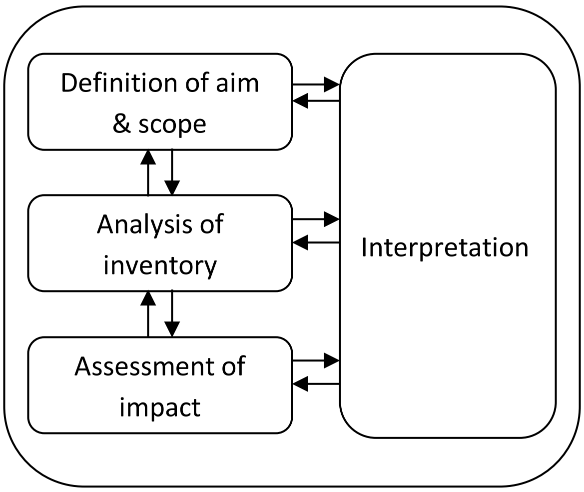

Illustration 1**. Stages in an LCA according to UNE-EN ISO 14040:2006* ***¡Error! Marcador no definido.

First of all, the assessment considered the estimated environmental impact of the CERSUDS system, which takes existing stocks of ceramic tiles of low commercial value and turns them into an aesthetically positive product with high drainage capacity. Secondly, the LCA enabled the strong and weak environmental points of the CERSUDS flooring to be identified and compared to other products on the market, with the same purpose of implementing improvement actions. The scope of the LCA is from cradle to grave and it refers exclusively to the CERSUDS system, since the environmental advantages of the rest of the parts of an SUDS are already widely known.

The environmental results relate to one functional unit, which in this case was defined as one square metre of sustainable urban drainage floor. The stages in the CERSUDS life cycle included in the assessment are: supply and transport of the glazed stoneware tiles of low commercial value, their manufacture (cutting, drying, transportation, packaging, etc.), their installation (transport, installation, waste management), and their service life and end of life, for which a model life cycle of 40 years was taken.

In this cradle-to-grave LCA, more than 95% of all the material and energy inputs and outputs to/from the system were included and only unavailable or unquantified data were excluded. Specifically, what was excluded were data concerning the industrial equipment and machinery used in the installation. Similarly, the treatment of water used for cutting (closed circuit), road transport infrastructure, plant lighting, management of assembly process waste, and possible tile and strip scrap during the cutting process was also excluded.

The inventory analysis used data provided by members of the project consortium and bibliography such as specific Environmental Product Declarations (EPDs) for glazed stoneware. Likewise, to obtain indirect data, for example, about the environmental loads associated with transportation, electricity production, etc., commercial databases were used, namely DBs developed by Thinkstep[5] and the technical data sheets for those products. ISO 14040-44 and UNE EN 15804 standards[3,4] were followed in regard to defining the rules for assigning inputs and outputs to the system.

Without going into too much detail in this inventory analysis, it is significant to point out that the main raw material in the CERSUDS flooring are glazed stoneware tiles. The tiles came from a stock of low commercial value, manufactured between the years 1999 and 2017. About 15% of the total amount of this raw material are "leftovers" (tiles of which only 1 pallet or less of each model exist and which therefore cannot be sold profitably given the small amount available), while the sales value of the other 85% of the raw materials had diminished considerably.

For the project demonstrator, glazed stoneware tiles measuring 33x33 cm and 9 mm thick were used. For every square metre of CERSUDS flooring, 9 square metres of tiles were required. They were installed dry, by hand, on a 2-6 mm sized gravel base and 1-2 mm grain sand used as grouting for the joints. 48 kg of gravel and 2 kg of sand were used per functional unit.

Turning to the methods used to calculate and allocate loads, the average between 3 EPDs for glazed stoneware tiles, the dimensions and characteristics of which were similar to those used in the demonstrator, was taken as the starting point. An economic criterion was applied when allocating environmental loads, which considered the reduction of costs for all tiles, as well as the load avoided by the 15% of leftovers no longer having to be inevitably disposed of in landfills. In any case, all associated transportation was taken into consideration.

The key methodological parameters described in international standards ISO 14040-44:2006 were applied to define the impact assessment method, together with the recommendations of the ILCD/ELCD to support decision making.

The methods based on midpoint indicators proposed in UNE EN15804+A1[4] were used. The characterisation factors applied are those included in the January 2016 revision of the CML-2001 method, while two additional indicators were chosen to define water and energy consumption.

Impact		Units
GWP	Global Warming Potential	kg CO_2 equivalent
AP	Acidification Potential	kg SO_2 equivalent
EP	Eutrophication Potential	kg PO_4^{-3} equivalent
POP	Photochemical Ozone formation Potential	kg C_2H_4 equivalent
ODP	Ozone Depletion Potential	kg CFC-11 equivalent
ADPE	Depletion of Abiotic resources Potential – Elements	kg Sb equivalent
ADPF	Depletion of Abiotic resources Potential – Fossils	MJ
PENRT	Use of non-renewable primary energy, excluding non-renewable primary energy resources used as raw materials	MJ
FW	Net use of fresh water	m^3

Table 1. *Impacts assessed*

It should be remembered that the results obtained are relative expressions and do not predict impacts on endpoint categories or the surpassing of any levels, safety margins or hazards. The results shown include both the inputs and outputs of direct material and energy during manufacture, as well as those from previous and subsequent processes that are implemented during the life cycle envisaged for the product.

Table 2 hereunder presents the total impact of all phases in the life (cradle-to-grave) cycle of the CERSUDS system. The same information is displayed graphically in Figure 2. As can be seen, the raw materials are the prime source of the environmental impact generated and that stage is therefore where possible improvement measures were focused.

Life Cycle Phases	ADPF	ADPE	AP	EP	GWP	ODP	POCP	PENRT	FW
Raw Materials	185.0	2.5E-04	5.5E-02	6.4E-03	14.6	9.8E-07	4.0E-03	301.0	1.3E-01
Transport	4.3E-01	6.4E-10	1.5E-04	3.0E-05	3.1E-02	6.3E-11	1.4E-05	4.4E-01	3.0E-06
Cutting	15.8	1.5E-07	3.1E-03	3.1E-04	2.1	8.2E-09	2.7E-04	14.7	2.2E-02
Assembly	14.3	3.4E-06	5.2E-03	6.4E-04	1.6	3.8E-08	5.5E-04	13.1	1.1E-02
Distribution	5.2	7.7E-09	1.8E-03	3.6E-04	3.7E-01	7.6E-10	1.6E-04	5.2	3.6E-05
Installation	10.9	8.9E-07	2.1E-03	5.4E-04	1.4	-5.0E-09	1.8E-04	14.7	2.3E-03
Use	7.3	2.7E-08	3.3E-04	5.7E-05	4.4E-01	6.0E-14	4.5E-05	7.4	1.0E-03
End of life	4.2	-1.1E-07	7.2E-03	9.3E-04	8.7E-03	-6.2E-12	6.6E-04	4.7	1.6E-03
TOTAL	243.1	2.54E-04	7.49E-02	9.27E-03	20.5	1.02E-06	5.88E-03	361.2	1.68E-01

***Table 2**. Total impacts of the CERSUDS system for each life cycle phase*

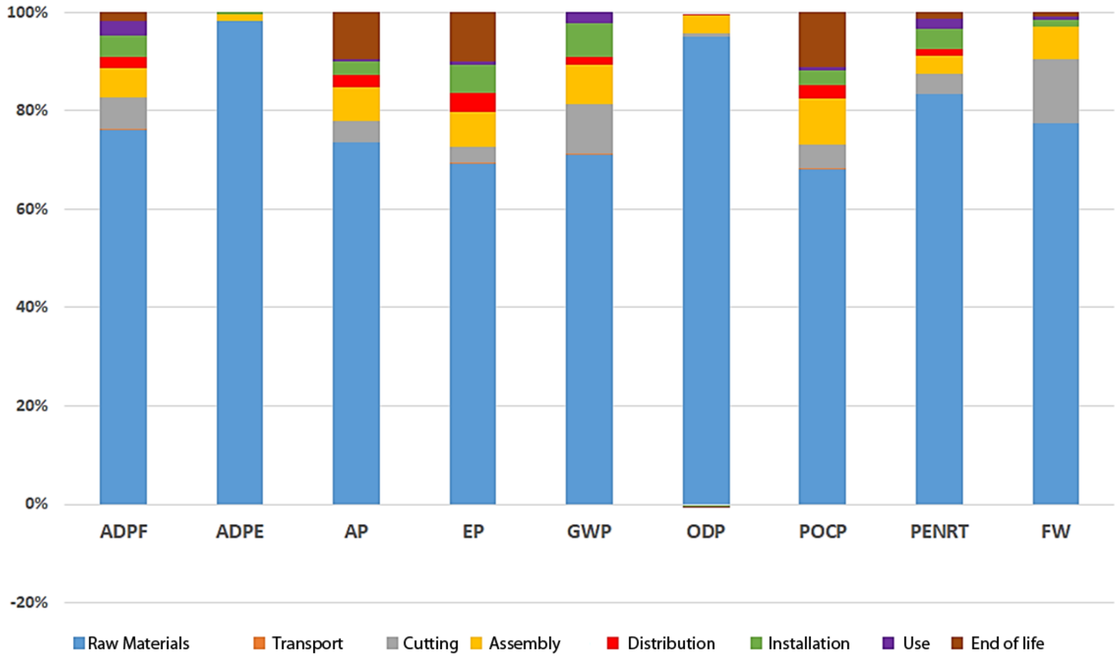

***Illustration 2**. Impacts of the CERSUDS system*

2. ECONOMIC ASSESSMENT

A comparative economic assessment was performed of the Sustainable Urban Drainage System (SUDS) installed on Torre Sant Vicent street in the town of Benicàssim within the framework of the LIFE CERSUDS project in comparison to an equivalent system with conventional drainage (separate stormwater system).

For that purpose, the surface area of the demonstrator installed in Benicàssim was taken and a series of standard construction sections that represent each of the systems was identified. For each standard solution, the costs associated with constructing 1m^2 over the model life cycle of 40 years were analysed. The costs of one square metre in either case multiplied by the surface area of each of the spaces under consideration gave us the total economic costs for each system.

2.1. METHOD

In order to carry out the economic assessment, the costs used in the reckoning were those associated with each of the life cycle stages contemplated in Sustainability in Construction standards (UNE-EN 15978:2012 and UNE-EN 15804:2012), following the calculation method developed in the SOLCONCER project[vii]. This assessment included module B7 Operational water use, which refers to the need to water the garden, plus a new module, called B8 Run-off Treatment, which refers to the costs of treating excess run-off water. The data relating to these two stages in the life cycle were drawn from the analysis using the computer tool developed in the framework of the E2STORMED project[viii]. In addition, multicriteria analysis was also carried out with the same tool.

The economic assessment did not consider all those elements common to both systems (public lighting circuit, telecommunications, street furniture...), and also omitted all elements forming part of the wastewater network (common to both systems).

In the case of the conventional system, the concept used was of a separate sewer system and thus only the stormwater drainage network was assessed. Therefore, elements that form part of a traditional stormwater collection system (mains, drains, scuppers...) were considered. In the SUDS system, the role played by those parts is assumed by a series of other components, such as: the CERSUDS floor, the polypropylene cells and drain boxes.

2.2. RESULTS

The graph below shows the costs per square metre associated with each of the two systems and broken down according to the different stages in the life cycle considered in the calculation over a period of 40 years.

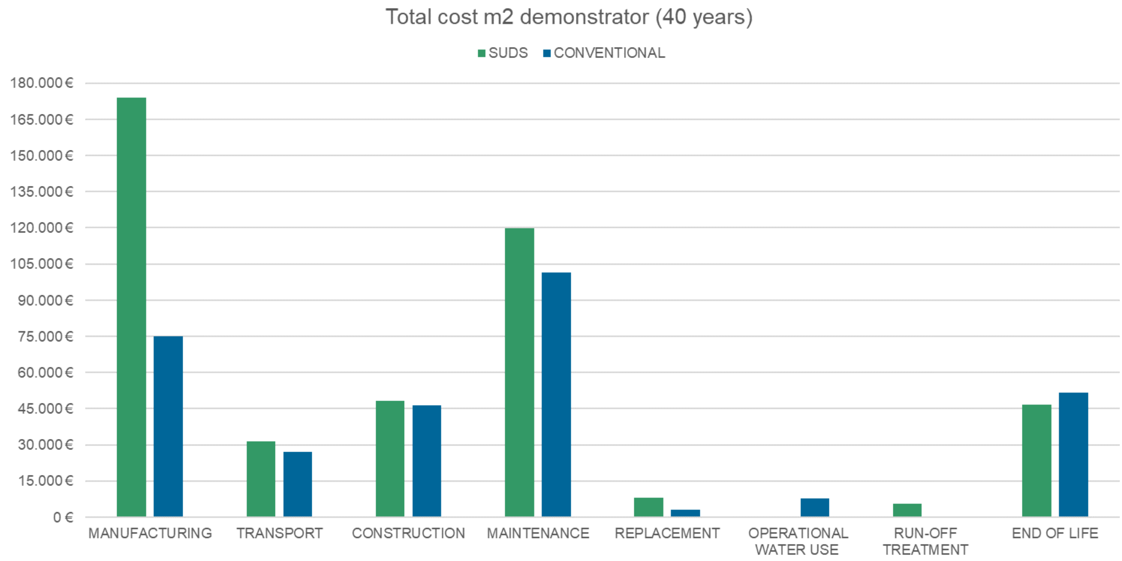

Illustration 3*. Costs associated with each stage in the life cycle per type of system*

The square-metre cost of urbanisation in the demonstrator using the SUDS system was approximately 30% higher than for a conventional system. This difference is mainly due to the higher manufacturing cost of a permeable ceramic floor compared to a conventional cement tile, since a handmade ceramic tile was considered for the SUDS (costing €44.80 per m^2), while a standard street tile is a standardised industrial product (€10.58 per m^2).

With respect to the costs associated with treating excess run-off, the SUDS solution proffers annual savings of 70%, which come from the significant reduction in run-off compared to the conventional system. As far as the costs associated with the need to use potable water for irrigation are concerned, in the irrigation scenario proposed for the project, the SUDS solution would enable 95% of that cost to be saved by making use of the water collected in the tank.

Finally, the multicriteria analysis (Figure 4) carried out to compare both systems considered not only purely economic criteria but other equally important factors of a significant environmental nature. The results of the analysis show how the intangible benefits of the SUDS system (eco-system services, aquifer recharge, water quality) gain capital importance in the comparison and clearly off-set the criteria of a purely economic nature. The criteria and weighting assigned to each were the result of discussions with sector experts within the Project Working Group. The absolute value given to the variable that each criterion adopts in each scenario was transformed to a dimensionless scale by matching the range [0-1] to the absolute range of variation for the criterion variable. The weighted sum total of utilities and weighting per criteria thus yielded a combined utility value for the scenario, where the relative contribution of each criterion to the comparison was taken into account.

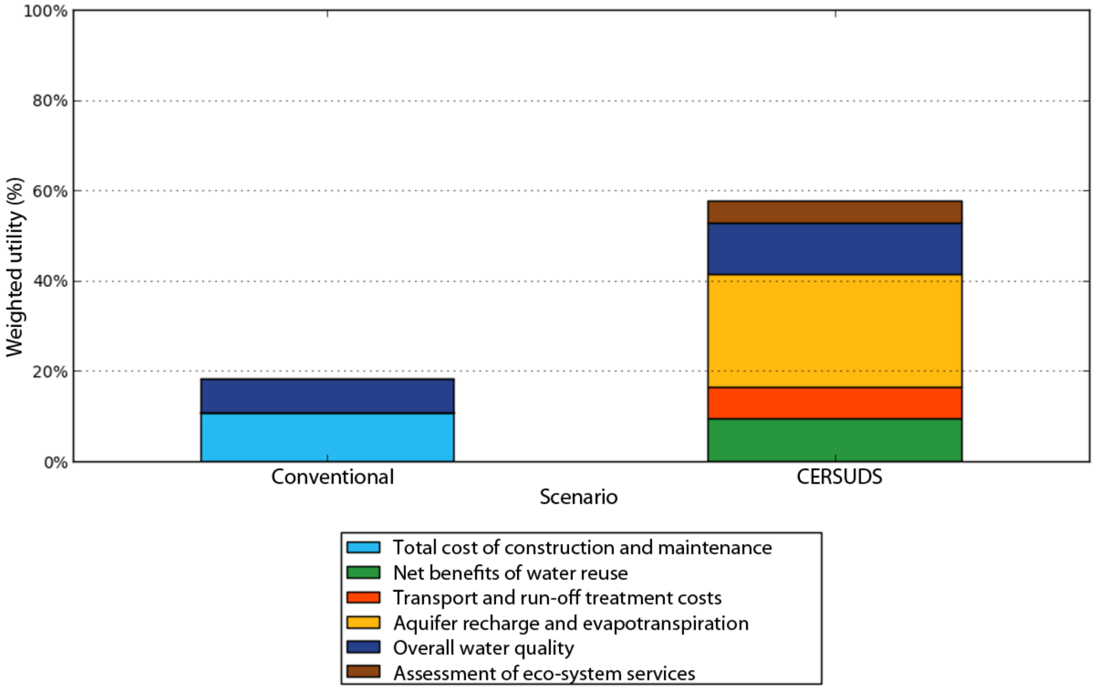

Illustration 4. *Results of the multicriteria analysis*

3. USER VALIDATION

In order to assess the degree of user satisfaction, a number of individual local inhabitants from the town were surveyed in Torre Sant Vicent street, where the LIFECERSUDS prototype was installed, and asked to answer a series of multiple-choice questions on a tablet and with an interviewer to explain the questionnaire. Construction of the demonstrator was completed in August 2018 and six months later, in February 2019, 100 surveys were conducted on the 7th and 12th of that month. The results can be considered representative of the entire population (i.e. the population of Benicàssim), with an error margin of less than 10% for a confidence level of 95%.

The questions dealt with aspects such as comfort when walking, absence of run-off water during periods of heavy rain, general quality of the infrastructure, improvement of the urban space, etc. The survey included a total of ten questions in all and when any negative answers were given, the causes of dissatisfaction were investigated through an open question. The statistical mean of all the questions was 4 (on a scale from 1 to 5, where 1 was the worst score and 5 the best), indicating that a large majority of the interviewees considered the quality of the intervention to be good or very good.

4. DEMONSTRATOR MONITORING

4.1. MECHANICAL BEHAVIOUR

In the previous edition of this congress, the design and validation process for the CerSUDS system[1] was presented, in which the ceramic system's healthy response to frost, flexion, impact and other factors was displayed. However, finished product lab testing could not guarantee the system would function properly in a public space, given the difficulty of reproducing actual usage situations in terms of loads and impacts, as well as structure, materials and thicknesses of the different layers that comprise the system.

During the year this system has been in service, the CERSUDS system has performed satisfactorily and only the following defects have been detected in places: a few slight bulges or soft spots and chipping on the end edges of the ceramic strips.

Illustration 5*. Photo of the demonstrator in service*

In the case of the bulges, the main cause is the gravel in the underlay resettling when subjected to loads because, as it has no fines to allow water to circulate through it, proper compaction is prevented. Experiments in other countries on the use of this type of system show that it is a frequent pathology that could be minimised by installing geocells or geogrids[ix,x]. It is planned to include that type of mesh in future installations of the system.

As for the ends of the tiles breaking, that has only happened in areas where the ceramic modules were not separated from each other or the modules were not separated from the metal profiles that held them in place. In those cases, when the ceramic modules descend due to the aforementioned settling, the top edges of the modules were pressed together, causing those edges to break. Therefore, as in any installation using ceramics, it is important to respect joint spacing.

4.2. PERMEABILITY OF THE SYSTEM

To monitor permeability, five set points on the demonstrator street were chosen, as shown in Figure 6.

Illustration 6. *Permeability Monitoring Points*

The procedure described in ASTM C1781/C1781M-13 was used for the assessmentxi. The results of the measurements can be seen in Illustration 7.

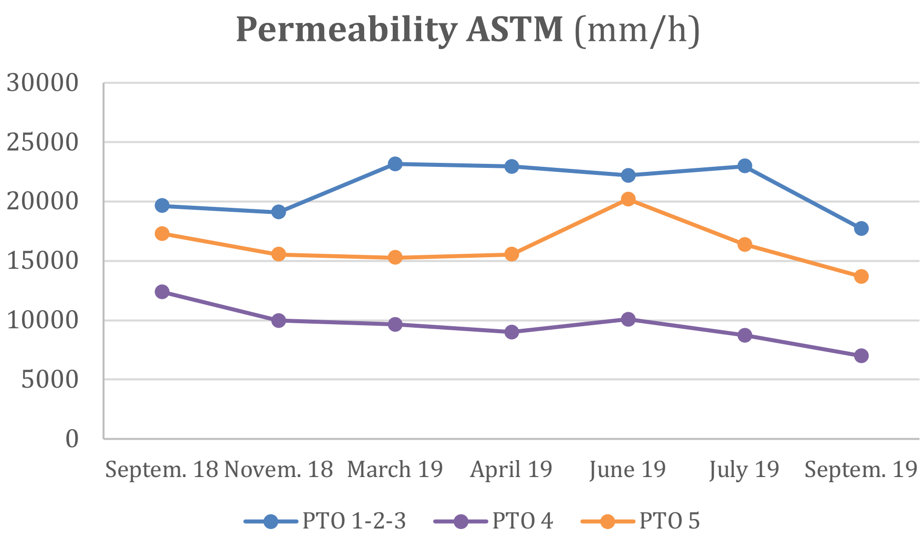

Illustration 7. *Permeability readings*

As the graph shows, the readings exceeded 10,000 litres per square metre per hour at four points and only dropped slightly below that figure at one point (point 4). Bearing in mind that the minimum values were 2,500 mm/h, the system exhibited magnificent performance.

4.3. HYDRAULIC BEHAVIOUR

To monitor the demonstrator's hydraulic behaviour in terms of both quantity and quality of water, control equipment – comprising an automatic sampler, flow meters and level probes – was installed at three points along the street, as shown in Illustration 8.

Illustration 8. Location of control equipment

Point TM1 was located outside the demonstrator and served as a means of comparison to assess how the system was operating. Point TM2 was an intermediate control, while Point TM3 was located just before the point where the waters collected and treated by the demonstrator exited towards the conventional drainage system.

During the period under analysis (August 2018 to July 2019), 28 episodes of rainfall with a volume greater than 1 mm/day were recorded – see Table 3.

Fecha	P (mm) 24 horas	V (l) Zona demostrador	V (l) Caudalímetro (TM3)	Reducción
15/09/2018	8,2	27.060	-	100%
18/09/2018	22,2	73.260	16.415	78%
26/09/2018	1,2	3.960	-	100%
14/10/2018	17,4	57.420	-	100%
18/10/2018	48,8	161.040	119.359	26%
19/10/2018	38,4	126.720	8.580	93%
27/10/2018	11,6	38.280	-	100%
30/10/2018	7,4	24.420	-	100%
31/10/2018	11,8	38.940	-	100%
09/11/2018	13,4	44.220	-	100%
16/11/2018	21,0	69.300	-	100%
17/11/2018	6,0	19.800	-	100%
18/11/2018	22,2	73.260	3.889	95%
19/11/2018	14,4	47.520	982	98%
23/11/2018	2,0	6.600	-	100%
13/12/2018	3,8	12.540	-	100%

Fecha	P (mm) 24 horas	V (l) Zona demostrador	V (l) Caudalímetro (TM3)	Reducción
19/03/2019	5,0	16.500	-	100%
31/03/2019	5,4	17.820	-	100%
02/04/2019	3,6	11.880	-	100%
08/04/2019	1,4	4.620	-	100%
18/04/2019	28,6	94.380	-	100%
22/04/2019	2,2	7.260	-	100%
03/05/2019	1,6	5.280	-	100%
21/05/2019	1,8	5.940	-	100%
24/05/2019	8,6	28.380	-	100%
07/07/2019	4,6	15.180	-	100%
08/07/2019	6,2	20.460	-	100%
14/07/2019	3,6	11.880	-	100%
Litros totales		1.063.920	149.225	

Table 3. *Summary of logged rainfall*

The data collected shows that the system was able to handle 100% of the rainwater falling on its surface and that only 14% (149,255 litres) was discharged (once the water had been filtered) into the conventional drainage system. The remaining 914,695 litres (86%) was returned to the land once filtered. Illustration 9 depicts annual water balance in the system graphically.

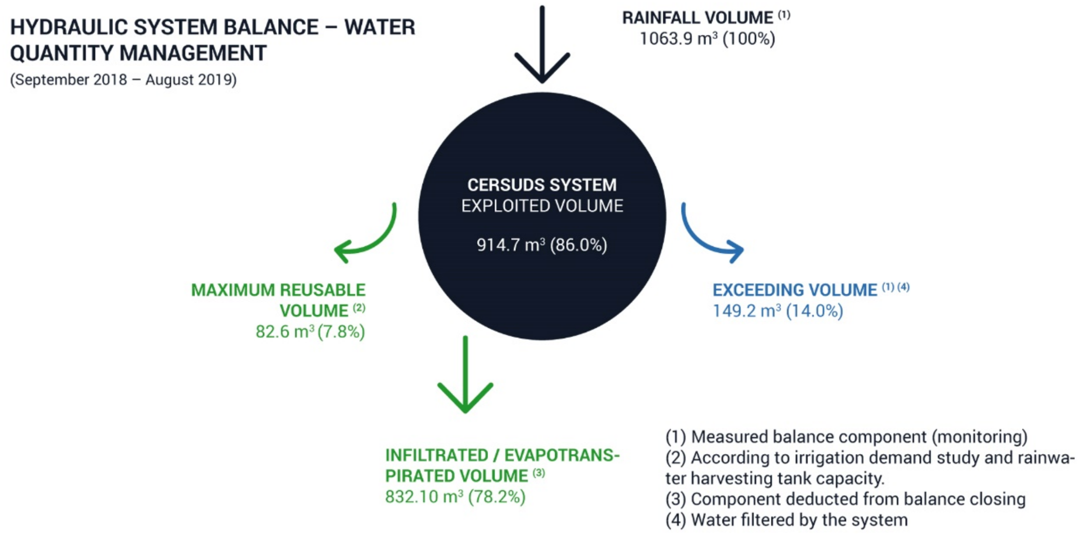

Illustration 9. *Water balance in the demonstrator*

In regard to the quality of the waters analysed, no conclusive data is available yet. However, from the data collected thus far, everything seems to indicate that salt reduction is close to 80%, filtering has led to all organic matter being eliminated, and reduction in bacteria-forming units has had two different orders of magnitude (between $9.5x10^4$ at control point TM1 and $3.2x10^2$ at control point TM3).

It is planned to continue this hydraulic monitoring to corroborate the above data over a larger series of rainfall events.

5. CONCLUSIONS

- The life cycle stage in the CERSUDS system that has the biggest influence on all environmental impact categories is the supply of raw materials, i.e. the ceramic tiles used as raw material - its contribution exceeds 75% of the full life cycle in any impact.
- Using a larger proportion of "leftover" or end-of-stock tiles would have a drastic influence on reducing environmental impacts. In this sense, in order to reduce environmental impacts, the production process would have to be industrialised in order to permit the use of ceramic tiles with a wider range of sizes.
- The cost per square metre of the system implemented in the LIFECERSUDS demonstrator is higher than the cost of the conventional system, mainly due to the increase in the price of the CERSUDS flooring compared to conventional paving. However, the proposed system provides intangible benefits (eco-system services, aquifer recharge and water quality, among others), which clearly offset the purely economic criteria.
- Validation by users of the LIFECERSUDS Demonstrator has been satisfactory, with an average score of 4 for all questions on a scale of 1 to 5.
- As far as mechanical behaviour goes, it is essential to respect the joints between ceramic modules to minimise chipping on the edges.
- The system's average permeability after one year of monitoring is very high (over 8,000 mm/h), well above minimum prescribed values (2,500 mm/h).
- The system has displayed excellent hydraulic behaviour over the year's monitoring, as about 86% of the water handled has been returned to the water cycle. Likewise, on the basis of data available so far, all the filtered water is of good quality, both in terms of reduced organic matter and colony-forming units (CFUs).

6. REFERENCES

[1] [i] J. Corrales, J. Mira (2018). *LIFECERSUDS, Sistema cerámico urbano de drenaje sostenible*. XV Congreso Mundial de la Calidad del Azulejo y del Pavimento Cerámico. Qualicer 2018.

[2] [ii] ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework.

[3] [iii] ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines.

[4] [iv] UNE-EN 15804:2012+A1:2014 Sustainability in construction. Environmental Product Declarations. Basic product category rules for construction products.

[5] [v] Thinkstep, 2018a. Database for Life Cycle Engineering, copyright Thinkstep AG. 1992-2016 (DB version 8007).

[6] [vi] Thinkstep, 2018b. GaBi Software-system. Compilation 8.6.0.20.

[7] [vii] Beltrán, A., Celades, I., Corrales, J., Mira, J., Muñoz, A., Rioja, A., Ros, T., Agost, V. (2016). *Solconcer, herramienta de ayuda para la caracterización de soluciones constructivas.* XIVth World Congress on Ceramic Tile Quality. Qualicer 2016.

[8] [viii] A. Morales-Torres, I. Escuder-Bueno, I. Andrés-Doménech, S. Perales-Momparler. *Decision Support Tool for energy-efficient, sustainable and integrated urban stormwater management*. ISSN 1364-8152. https://doi.org/10.1016/j.envsoft.2016.07.019.

[9] [ix] Gourav Dhane, Dhiraj Kumar, Akash Priyadarshee. *Geocell: An Emerging Technique of Soil Reinforcement in Civil Engineering Field*.

[10] [x] Gh Tavakoli Mehrjardia, R. Behrada, S.N. Moghaddas Tafreshib. *Scale effect on the behavior of geocell-reinforced soil*.

[11] [xi] ASTM C1781/C1781M−13. Standard Test Method for Surface Infiltration Rate of Permeable Unit Pavement Systems.