Advances in Sustainability Science and Technology

Jorge Filipe Leal Costa Semião
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Gonçalo Nuno Delgado Prates *Editors*

INCREaSE 2023

Proceedings of the 3rd INternational CongRess on Engineering and Sustainability in the XXI CEntury

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Preface

It is our pleasure to present the proceedings of the 3rd International Congress on Engineering and Sustainability in the XXI Century (INCREaSE 2023). This book of proceedings aims to bring together valuable and novel scientific contributions to the sustainable development in a multidisciplinary way, that have an impact in diverse and fast-changing research areas, both in academia and industry, reflected in the fields of civil, electronics, food, and mechanical engineering. This book presents 31 works from authors from different countries in several transversal areas, such as big data and data analytics, climate change and mitigation, carbon reduction, sustainable food processing and safety, sustainability in water management, sustainable energy generation and management, construction sustainability, and other subjects related to the sustainable development.

This year's INCREaSE was organized by the Institute of Engineering and hosted by the University of Algarve during July 5–7, 2023, in Faro, Portugal.

All members of the organizing committee, authors, and reviewers played a key role with their dedicated work and efforts.

INCREaSE 2023 had an excellent group of keynote speakers: Enrique Cabrera-Rochera—University of Valencia, Spain, Paulo Sérgio Duque de Brito—Polytechnic of Portalegre, Portugal, and Jorge A. Saraiva—University of Aveiro, Portugal. We are thankful to these leading experts for their participation in INCREaSE 2023.

We wish to express our gratitude to all the above participants who contributed to the success of the third edition of INCREaSE.

July 2023

Jorge Filipe Leal Costa Semião
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INCREaSE is an international congress organized by the Institute of Engineering from the University of Algarve, Faro, Portugal.

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Jorge A. Saraiva	University of Aveiro, Portugal

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Contents

Special Session on Water Management Challenges

Rainwater Harvesting in University Buildings. Feasibility Analyses in Mediterranean Climate

Armando Silva-Afonso[1,2] and Carla Pimentel-Rodrigues[1,2](✉)

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Abstract. Situations of water stress or even water scarcity are increasing in different regions of the planet, due to exponential population growth, the economic development model and/or climate change. One of the regions on the planet where climate change is causing increasingly recurrent situations of drought is southern Europe, in the Mediterranean basin. In parallel with this effect, an increase in the intensity and frequency of heavy rains is also observed, generating, for example, very significant impacts on urban environments. Rainwater harvesting systems (RWHS) in buildings are a sustainable solution that allows tackling these two effects of climate change, promoting a retention of water, which can be used for non-potable purposes and mitigating urban flooding. For this reason, RWHS are being implemented in several countries affected by climate change, such as Portugal, where the University of Aveiro promoted a study in two pilot buildings, described in this article, with the aim of assessing the feasibility installation of this system in new university buildings. The conclusions show high benefits not only from the point of view of adaptation to climate change, but also from the economic point of view, with payback periods between 10 and 12 years.

Keywords: Rainwater Harvesting in Buildings · University Buildings · Sustainable Buildings

1 Introduction

Fresh water is an essential resource for sustainable development and is fundamental for socioeconomic development, for maintaining terrestrial ecosystems and for human survival itself [1–5]. However, situations of water stress or even water scarcity are increasing in different regions of the planet, due to exponential population growth, the economic development model and/or climate change [6–14].

One of the regions on the planet where climate change is causing increasingly recurrent situations of drought or even water scarcity is southern Europe, in the Mediterranean basin [15–18]. In parallel with this effect, an increase in the intensity and frequency of heavy rains is also observed in this region, generating, for example, very significant impacts on urban environments, imposing the widespread adoption of measures to improve adaptation to more extreme climatic conditions [19–25].

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Rainwater harvesting systems (RWHS) in buildings are a sustainable solution that allows tackling these two effects of climate change, promoting a retention of water, which can be used for non-potable purposes, and mitigating urban flooding [26–29]. For this reason, RWHS is being promoted in several countries affected by climate change, even in Mediterranean climates, although in this case the reduction in total precipitation, especially in summer, may call into question the technical-economic interest of the solution.

This article presents a study carried out by the University of Aveiro, Portugal, aiming to evaluate the feasibility of installing RWHS in new university buildings, based on the results obtained in two pilot buildings. In addition to the obvious environmental benefits, in terms of constituting a reserve of water for non-potable purposes in periods of drought, reducing the consumption of traditional sources.

The use of rainwater in a Mediterranean climate is sometimes hampered by the fact that, in this climate, the periods of greatest consumption generally occur in the summer, which corresponds to a period of less or even zero precipitation. There is therefore an obvious mismatch between availability and needs.

However, school buildings, in general, constitute an exception to this rule, as school holidays occur in the summer, implying a significantly reduced use of buildings in this period. University buildings are no exception, although research activities are sometimes maintained throughout the year, regardless of the interruption of classes in the summer.

2 Materials and Methods

2.1 Characteristics of the Buildings

The application of RWHS was studied in two new buildings at the University of Aveiro: the building of the Interdisciplinary Complex of Sciences Applied to Nanotechnology and Oceanography, which will be called Building 1, and the Building of Optical Communications, Radio Communications and Robotics - Telematics, which will be designated by Building 2. These two buildings are essentially dedicated to scientific research, although they also hold classes.

Building 1 has several sanitary facilities, with a total of 21 toilets with flushing cisterns and two wash taps mainly used for cleaning floors. The use of rainwater was considered only for these uses, excluding showers and washbasin taps for reasons of health safety.

Figure 1 shows Building 1 already completed and Fig. 2 shows the types of sanitary devices that will be fed with rainwater. Building 2 is relatively similar in terms of sanitary fixtures, having a total of 15 toilets with flushing cisterns and five wash taps. As in Building 1, the use of rainwater was considered only for flushing cisterns and wash taps, excluding sinks, showers and basin taps.

Figure 3 shows the Building 2. The devices to be supplied with rainwater are similar to those in Building 1.

2.2 Design Bases and Sizing Methods

In establishing the design bases and sizing methods, the applicable technical documents were observed. In Portugal, there is a Technical Specification for RWHS in buildings, the

Fig. 1. Building 1.

Fig. 2. Type of devices to be fed with rainwater.

Fig. 3. Building 2.

ETA ANQIP 0701:2007 [30], which was the main reference used, although the European Standard EN 16941–1:2018 (*On-site non-potable water systems - Part 1: Systems for the use of rainwater*) [31] was also consulted. For the dimensioning of the piping networks, the European Standards EN 806–3:2006 [32], EN 12056–2:2000 [33] and EN 12056–3:2000 [34] were also considered, as well as other applicable bibliographies in the building hydraulic installations sector.

According to ETA ANQIP 0701, the usable annual volume of rainwater can be determined by the expression:

$$V_a = C \times P \times A \times n_f \quad (1)$$

where V_a corresponds to the annual volume of rainwater that can be used, C is assumed as a runoff coefficient that considers water retention, absorption and diversion on the collection surface (80% for flat or low slope waterproof roof, according to ETA ANQIP 0701 and EN 16941–1:2018), P refers to the average annual value of accumulated precipitation in the city of Aveiro (≈1800 mm), A is equivalent to the coverage catchment area measured in horizontal projection and η_f considers the hydraulic filtration efficiency (in general close to 90%). For the sizing of storage tanks, expression (1) can be used on a monthly basis, if monthly average precipitation values are available locally.

In the case of Building 1, the roof essentially consists of sandwich panels, but there is also a small accessible terrace area. For reasons of water quality, the area corresponding to the accessible terrace was not considered as a catchment area, considering that the total area covered with panels will be fully sufficient to meet the required consumption needs. The usable area considered totals 540 m^2, from which an annual volume of rainwater of about 700 m^3 is obtained by applying expression (1).

In the case of Building 2, only the utilization of an area of 460 m^2 was considered for the RWHS, as the full utilization of the roof was difficult for architectural reasons. The annual volume of usable rainwater obtained is around 635 m^3 in this case.

At several weather stations near Aveiro, monthly precipitation values are available. The average values calculated for the Castelo Burgães station (40.853 ºN; −8.379 ºW), which has data recorded since 1930/31, available on the website of the National System of Information on Water Resources (SNIRH), were adopted in this study. Table 1 summarizes the average values determined from the records available from 1930 to the date of the study, which was adopted in the calculations.

Table 1. Average monthly rainfall in Aveiro (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Runoff	249	233	185	142	143	68	26	33	83	173	217	247

It is likely that, due to climate change, there is a tendency for the values indicated in Table 1 to decrease over time (15% to 20% in 2100, according to IPMA - Portuguese Institute of Sea and Atmosphere), but this reduction is difficult to estimate in the present. However, it was considered that, during the useful life of the installation, the possible reductions in precipitation do not compromise the conclusions of the study.

3 Results and Discussion

Storage tank sizing is generally an important aspect of a RWHS design, especially as it is the most expensive component. Technical Specification ETA ANQIP 0701 presents a simplified sizing procedure for estimating the volume of tanks, although it recommends that, in large installations, an optimization methodology be applied, based on the average monthly precipitation in the location and on the monthly consumption diagram.

In the present study, the simplified method of ETA ANQIP 0701 was adopted, obtaining, in both buildings, tanks with a volume of 6.5 m^3 for a maximum storage period of 30 days. It should be noted that the volume has been rounded according to traditional commercial values for tanks of this type.

Regarding non-potable water demand in buildings, the values suggested in Annex 2 of ETA ANQIP 0701 were adopted, which are transcribed in Table 2. The indicated values assume the installation of efficient devices, labeled in category A or higher in the ANQIP water efficiency labeling scheme for products, as is the case of the devices installed in these buildings.

Table 2. Non-potable water demand [30]

Device	Consumption
Flushing cistern (category A) in service buildings	4400 L/ ind and year
Wash tap (dominant use for floor washing)	5 L/ m^2 of floor

In Building 1, it is estimated that there are 100 daily users, weighting weekdays and weekends. For the area covered by the washing taps, the value of 150 m^2 was considered according to the project, estimating that the washes have a monthly frequency. Based on these assumptions, the following annual demand for non-potable water was estimated in Building 1 (D_1):

$$D_1 = 4400 \times 100 + 5 \times 12 \times 150 = 449.000\, L/year = 449.0\, m^3/year \qquad (2)$$

This value corresponds to 37.40 m^3/month. However, in the months of July, August and September, half of this value (18.70 m^3/month) was considered, bearing in mind that, in these months, some research activities are continued, despite being the usual holiday months in Portugal.

In Building 2, it is estimated that there are 125 weighted daily users. In this building, the area considered for the coverage of the washing taps was 616 m^2, according to the project, and a quarterly frequency was estimated for washing, given the characteristics of the building. Based on these assumptions, the following annual demand for non-potable water was estimated in Building 2 (D_2):

$$D_2 = 4400 \times 125 + 5 \times 4 \times 616 = 562,320\, L/year \approx 562.3\, m^3/year \qquad (3)$$

This value corresponds to 46.86 m^3/month. However, as in Building 1, in the months of July, August and September only half of this value was considered (23.43 m^3/month).

Tables 3 and 4 present summarized maps with the simulation of the operation of the RWHS in the two buildings. On the security side, it is assumed that the storage tank is empty at the beginning of the simulation cycle, which was made to correspond to the hydrological year in Mediterranean climates (October 1st to September 30th).

Table 3. Simulation of the operation of the RWHS in Building 1

Month	Average monthly rainfall	Monthly demand	Available vol. of the monthly rainfall	Demand-available. Difference	Storage tank volume	Volume of water in the tank		Public network supply require
						Beg.	End	
	(mm)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
October	173	37.40	67.26	29.86	6.50	0.00	6.50	0.00
November	217	37.40	84.37	46.97		6.50	6.50	0.00
December	247	37.40	96.03	58.63		6.50	6.50	0.00
January	249	37.40	96.81	59.41		6.50	6.50	0.00
February	233	37.40	90.59	53.19		6.50	6.50	0.00
March	185	37.40	71.93	34.53		6.50	6.50	0.00
April	142	37.40	55.21	17.81		6.50	6.50	0.00
May	143	37.40	55.60	18.20		6.50	6.50	0.00
June	68	37.40	26.22	−10.96		6.50	0.00	4.46
July	26	18.70	10.11	−8.59		0.00	0.00	8.59
August	33	18.70	12.83	−5.87		0.00	0.00	5.87
September	83	18.70	32.27	13.57		0.00	6.50	0.00
TOTAL	1799	392.70						18.92

The estimated cost for the RWHS in Building 1 is € 8100.00, including the 6500 L tank, the leaf filter, the valves and connection pipes, the technical and pumping pack and the additional cost of water supply and rainwater drainage networks in the building. The RHWS for Building 2 was estimated at a similar value.

To size the pumping group (booster type), a peak flow of 1 L/s was adopted, considering the EN 806–3 standard and a pump head of 22 m was set, a value in accordance with Portuguese regulations [35] for buildings with up to three floors. The commercial power obtained for these values was 0.8 kW. With regard to Building 2, the calculation parameters were the same, whereby the same result was obtained.

With regard to the price of water in the region of Aveiro, the reference value for the University is 1.88 €/m^3. For electricity, the reference value is 0.203 €/kWh.

It can be seen that the energy consumption in the two RHWS will be very low. For the flow rate of 1 L/s (3.6 m^3/h), it can be estimated:

$$Annual\ hours\ of\ operation\ (Building\ 1) = 392.70/3.6 \approx 109\ h/year \tag{4}$$

Table 4. Simulation of the operation of the RWHS in Building 2

Month	Average monthly rainfall	Monthly demand	Available vol. of the monthly rainfall	Demand-available. Difference	Storage tank volume	Volume of water in the tank		Public network supply required
						Beg.	End	
	(mm)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)	(m^3)
October	173	46.86	57.30	10.44	6.50	0.00	6.50	0.00
November	217	46.86	71.87	25.01		6.50	6.50	0.00
December	247	46.86	81.81	34.95		6.50	6.50	0.00
January	249	46.86	82.47	35.61		6.50	6.50	0.00
February	233	46.86	77.17	30.31		6.50	6.50	0.00
March	185	46.86	61.27	14.41		6.50	6.50	0.00
April	142	46.86	47.03	0.17		6.50	6.50	0.00
May	143	46.86	47.36	0,50		6.50	6.50	0.00
June	68	46.86	22.52	−24.34		6.50	0.00	17.84
July	26	23.43	8.61	−14.82		0.00	0.00	14.82
August	33	23.43	10.93	−12.50		0.00	0.00	12.50
September	83	23.43	27.49	4.06		0.00	6.50	0.00
TOTAL	1799	492.03						45.16

$$Energy\ cost = 109 \times 0.8 \times 0.203 \approx 18\ €/year \tag{5}$$

$$Annual\ hours\ of\ operation\ (Building\ 2) = 492.03/3.6 \approx 137\ h/year \tag{6}$$

$$Energy\ cost = 137 \times 0.8 \times 0.203 \approx 22\ €/year \tag{7}$$

In economic terms, water savings at current prices, to an average year, correspond to the following values:

$$Savings\ in\ Building\ 1 = 373.78 \times 1.88 \approx 702.71\ €/year \tag{8}$$

$$Savings\ in\ Building\ 2 = 446.87 \times 1.88 \approx 840.11\ €/year \tag{9}$$

In a simplified way, the payback periods of these investments can be estimated in:

$$Payback\ in\ Building\ 1 = 8,100.00/702.71 \approx 11.5\ years \tag{10}$$

$$Payback\ in\ Building\ 2 = 8,100.00/840.11 \approx 9.6\ years \tag{11}$$

In fact, these payback times will be slightly longer, considering monetary updating as well as annual energy and maintenance costs [36]. However, as all these factors are of low value and the payback period is short, the results will not be significantly altered.

4 Conclusions

The analysis of Table 3 shows that, in an average year, 373.78 m^3 of rainwater is used in Building 1 (392.70 – 18.92 = 373.78), but it is necessary to resort to the public network in the summer months to complete the demand, with a supply of 18.92 m^3. These numbers mean that 95% of non-potable water needs in Building 1 can be met by rainwater (373.78/392.78 = 0.95).

In Building 2, 446.87 m^3 of rainwater is used (492.03 – 45.16 = 446.87), but it is also necessary to resort to the public network in the summer months to complete the demand, with a supply of 45.16 m^3. These numbers mean that, in Building 2, 91% of non-potable water needs can be met by rainwater (446.87/492.03 = 0.91).

As for the payback periods for these investments, values between 10 and 12 years can be considered. Considering that the average useful life of these installations can reach 40 years [35], these payback periods are very interesting from an economic point of view.

Although the installation of RWHS in Mediterranean climates is sometimes questioned in terms of economic viability, these two case studies from the University of Aveiro show that, in university buildings (and, in general, in school buildings), these systems are interesting not only from the point of view of environmental sustainability and adaptation to climate change but also from an economic point of view. This finding results from the fact that school holidays coincide with the dry season, nullifying the usual mismatch in the Mediterranean climate between water needs and availability.

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Stormwater Attenuation and Enhanced Infiltration System to Mitigate Flood and Drought Conditions

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Abstract. This paper describes a stormwater attenuation & enhanced infiltration system, comprising the construction of attenuation trenches, perforated pipes with gravel surround, integrated with large numbers of drilled vertical infiltrators installed through the base of the trenches.

Combining the pressure head of the collected stormwater in the attenuation trenches, with the negative suction pressure within the unsaturated vadose zone, provides the differential pressure to force the water into the ground via these infiltrators. Furthermore, by installing vertical infiltrators, higher permeable ground strata are often encountered, particularly in anisotropic ground conditions where the horizontal permeability is much greater than the vertical permeability.

Stormwater Attenuation & Enhanced Infiltration Systems (SAEIS) have been used regularly in the UK for many years, both to mitigate flooding, and to provide recharge to groundwater resources. With groundwater resources similarly in decline in Portugal, together with more frequent flooding conditions occurring during intense rainfall, such collection and enhanced infiltration systems would also be most beneficial to the hydrogeology and weather conditions of Portugal.

Mathematical modelling is presented which simulates the water flow through the infiltrator system, and into the unsaturated soil strata. Combining the storage capacity of the attenuation trenches with a large number of infiltrators, produces a highly efficient attenuation and infiltration system that not only mitigates the impact of flooding but has no requirement for ongoing energy consumption.

With stormwater collected, filtered, attenuated, and then infiltrated to the vadose zone, collected stormwater will eventually find its way down to the water table, and so mitigate drought conditions by supplementing the aquifer water resources.

The stormwater attenuation & enhanced infiltration system (SAEIS) exemplifies true low carbon sustainability, and meets with the United Nations Department of Economic and Social Affairs for Sustainable Development - Goal 6: *Ensure availability and sustainable management of water and sanitation for all.*

Keywords: Stormwater · Attenuation · Enhanced Groundwater Infiltration

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1 Introduction

Climate change and global warming are affecting all countries of the world, with more extreme weather events happening with greater frequency [8]. In the UK, one major impact of global warming has been the increase in hotter periods combined with an increasing frequency of high-intensity rainfall events [6, 7]. With more of the UK being covered with urban developments, roads and industrial parks, the available open land which enables natural infiltration to the ground is receding (Charlesworth and Booth, 2016).

Over time this means less water is being recharged back into the ground and into the major aquifers. As a consequence, the UK Government has enforced where possible the need for a developer to construct a Sustainable Drainage System (SuDS) to mitigate the peak flooding that inevitably occurs from rapid runoff from hard impermeable surfaces such as roofs, roads, car parks or other paved areas [3]. In 2010 the UK Government published Building Regulations with Part H (Drainage and Waste Disposal, 2015). Within these Regulations, Part H3 (3) describes the design of systems to manage the drainage of rainwater with the following priority:

a) An adequate soakaway or some other adequate infiltration system; or where that is not reasonably practicable,
b) A watercourse; or where that is not reasonably practicable,
c) A stormwater sewer; or where that is not reasonably practicable,
d) A foul sewer.

The building regulations guidance presented above clearly states that the priority is to discharge collected groundwater to an adequate soakaway or some other adequate infiltration system. In response to these regulations a Stormwater Attenuation and Enhanced Infiltration System (SAEIS) has been developed to provide an efficient method to collect, attenuate and infiltrate stored water into soils of variable permeability at depth. This system has been designed to infiltrate water at greater depths (typically in the range of 3 to 12 m deep) than conventional soakaway systems which means the system is more suitable in areas of the UK where low permeability anisotropic soils such as laminated sandy and silty clays are prominent, (Jarvis et al., 1984).

By enabling infiltration at depth into laminated silt or sand lenses within clay soils, an enhanced infiltration system helps to prevent local surface water flooding by minimizing the flow of water to watercourses and sewers. This in turn helps to mitigate the peak water levels in local rivers following storm events, as shown by the hydrograph in Fig. 1. This paper presents mathematical modelling undertaken to demonstrate how the enhanced infiltration system works in practice by enabling infiltration of stormwater into anisotropic low permeability soils which are most common in the United Kingdom.

With storm flood conditions occurring more frequently in areas of Portugal over recent decades, enhanced infiltration techniques have the potential of mitigating the worst impact of such flooding events. Furthermore, the resulting enhanced infiltration of storm rainwater back to the unsaturated vadose zone, will also serve to provide a contribution to the mitigation of drought conditions, as the infiltrated rainwater will eventually find its way to below the water table.

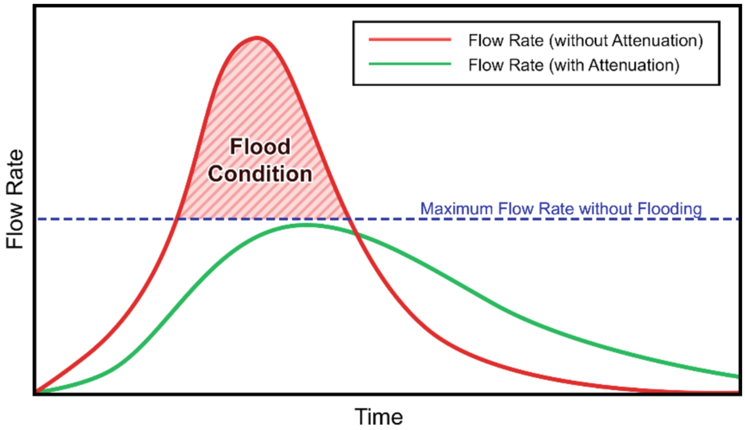

Fig. 1. Hydrograph showing the difference between non-attenuated and attenuated flow rate following a storm event.

2 Stormwater Attenuation and Enhanced Infiltration System

The Enhanced Infiltration System has been designed to attenuate and infiltrate large volumes of rainwater following storm events. The schematic in Fig. 2 shows how the system is set up and how rainwater passes through the system and into the soil. Rainwater that lands on buildings and paved surfaces such as car parks enters the drainage system through a series of gutters and drains. Water then flows through underground drains towards a silt trap where fine particles are removed from the water to prevent clogging of the infiltration system. Water then flows into a series of attenuation trenches set a minimum of 5.0 m away from any buildings. The trenches are typically in the order of 1.8 m wide and 1.7 m deep.

Each trench can contain one or two perforated pipes, designed to provide a large storage volume to attenuate rainwater following a storm event. The trench is backfilled around the perforated pipes with gravel or angular stone. At the base of the trench the pipes typically sit on a layer of 10 mm pea gravel. Gravel or stone is then backfilled around the pipes and typically to 300 mm above the crown of the pipes. Above the crown of the pipes, graded stone is often placed to provide greater bearing capacity if the land above is for vehicular use. The attenuation trench is surrounded by a specialist geotextile designed to prevent the intermixing of granular layers, thus stabilising the sub-base construction.

Beneath the attenuation trenches are a series of vertical infiltrators (Figs. 2 and 3) which are specially designed plastic pipes which aid the infiltration of water into the soil. Prior to installing the attenuation trench, each infiltrator is installed by placing it inside a 90 mm diameter drilled borehole. The top of each infiltrator is set normally 300 mm below the base of the trench (Fig. 3). The length of infiltrator normally varies between 3 m and 12 m, depending on the geology and volumes of water that need to be infiltrated, together with the ambient water table level.

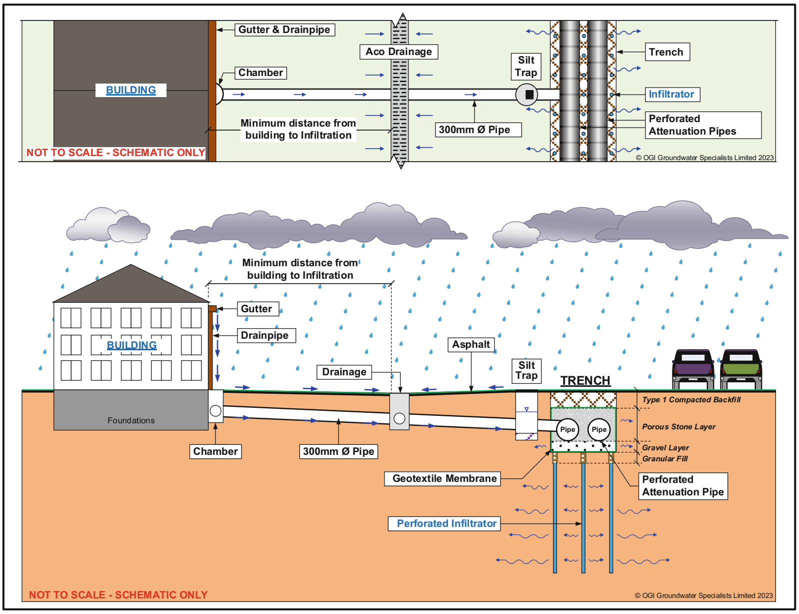

Fig. 2. Schematic of a Typical Attenuation and Enhanced Infiltration System.

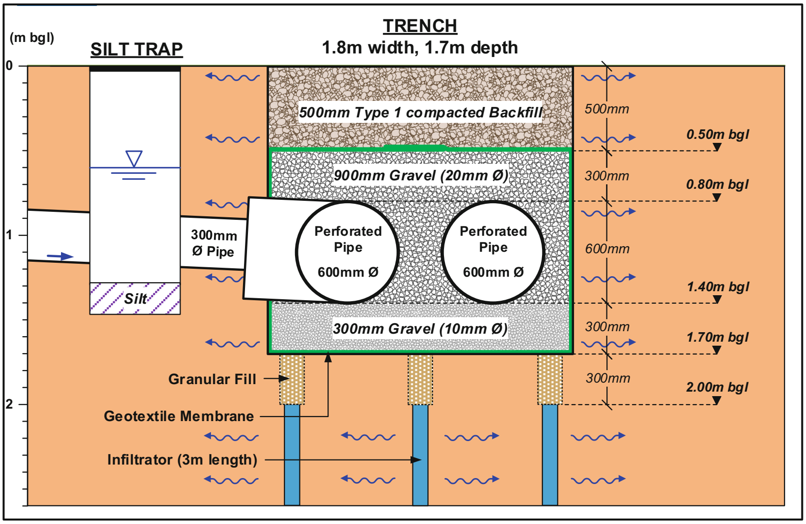

Fig. 3. Schematic of the Attenuation and Enhanced Infiltration system in section

The above enhanced infiltration system has been successfully implemented to discharge collected water at over 500 sites in the UK. The system provides an elegant and energy efficient solution to the flooding challenges of each particular site (Fig. 4).

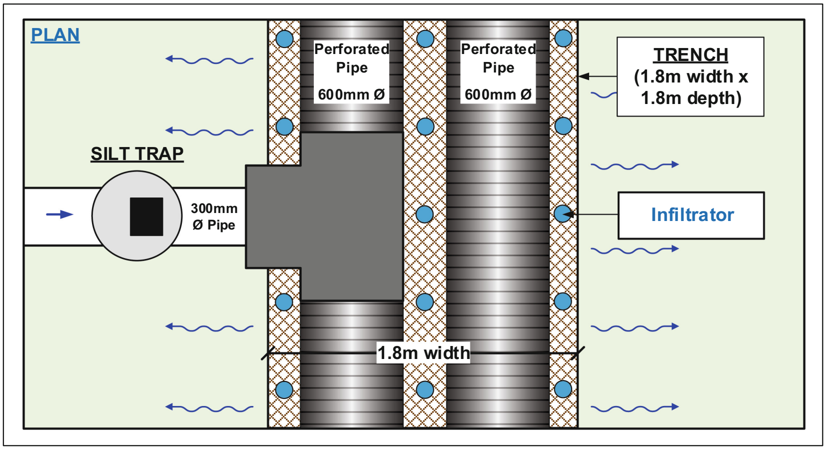

Fig. 4. Schematic of the Attenuation and Enhanced Infiltration system in plan.

The system has proved particularly successful to drain waterlogged sports fields, including rugby fields, cricket pitches and horse racing tracks. However, the main area of growth is for new build housing and commercial construction, where city councils are legislating for 100% of the collected rainfall to be put back to ground.

To illustrate the application of this attenuation and enhanced infiltration system, Figs. 5, 6 and 7 present the application at an industrial unit and car park in the northeast of England. The silty-clay ground was initially considered to be unsuitable to soakaway stormwater; but after installation, the 180 m of trench, together with c. 500 infiltrators, was sufficient to manage the rainwater over a 4 Ha area.

Fig. 5. Construction of perforated pipes within attenuation trenches.

Horizontal perforated pipes are then installed and backfilled with angular stone or gravel, typically to 300 mm above the pipe crown. The geotextile wrapping of the stone is then completed before graded stone is infilled on top of the geotextile to provide greater bearing capacity when the land above is for vehicular use.

Fig. 6. Connection of attenuation pipework to maintenance chamber.

To mitigate the potential of silts from entering the trench attenuation system, there are many silt traps and chambers constructed to intercept the silts, and these can be regularly cleaned as part of a planned maintenance program.

To degrade any possible hydrocarbon collected within the attenuation trenches, when excavated to the chosen depth, the trench is fully wrapped with a specialist geotextile (Fig. 7) before adding a 300 mm bedding layer of 10 mm pea gravel.

The combination of the geotextile of a unique fiber structure, together with the layers of pea gravel, adds a level of treatment for hydrocarbon contamination by promoting growth of a microbic biofilm which digests the hydrocarbon.

3 Rainwater Infiltration Theory into Unsaturated Ground

The theory of rainwater infiltration into unsaturated ground above the water-table is complex. When stormwater fills the underground attenuation storage volume within the trenches, this also fills the infiltrators directly beneath the trenches. This will result in high differential pore water pressure between the water filled infiltrator, and the natural suction pressure in the surrounding unsaturated ground.