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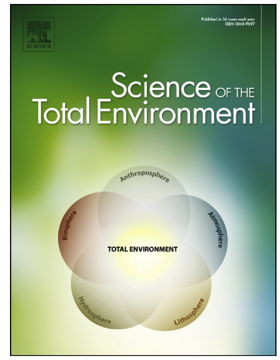

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Containing a sustainable urbanized environment through SuDS devices in management trains

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Abstract

Generating an effective and efficient sustainable drainage philosophy is imperative in alleviating the risk of flooding in a complex UK climate that is categorized by excessive rainfall. The Sustainable Drainage Systems (SuDS) approach offers a revolutionary change in using heightened flow rates and large capacities of water to our advantage, while also disguising the attenuated water into the urbanized environment. This research explores the result of integrating several SuDS devices in management trains with the sole purpose of significantly reducing overall water quantity. It will compare and contrast and prove how SuDS is more dependable than the conventional pipe based drainage system that is characterized by its ability to remove water to the outflow quickly. Furthermore, in order to determine how a SuDS device is implemented into the natural environment, a case study was conducted at a residential area in Gibside View, Winlaton in Gateshead. The research exhibits how the newly implemented Detention basin had to be retrofitted into the already inadequate drainage system that once lived there; all in thought of alleviating the significant flooding events that were once reported to have occurred prior. As a verification method in terms of effectiveness, a questionnaire was conducted through convenient and purposive sampling at the Case Study location; data was accumulated door-to-door inside a 300m radius of the detention basin and received about 180 valid responses. The results showed persistence of respondents who detailed flooding events prior to installing the Detention basin, who then recognized a fundamental change in the minimization of water quantity and flooding issues. The results of this research showed why Detention Basins continue to be identified as one of the most successful water reduction-based SuDS devices available for development nationwide implementation.

Keywords: Sustainable drainage systems; flooding; urbanized environment; management trains; UK.

1.0 Introduction

Environmental sustainability is of the utmost importance for almost all the countries in the current time (Maqbool, et al., 2020a; Maqbool, et al., 2020b; Maqbool, et al., 2020c). The establishment of Sustainable Drainage Systems (SuDS) is a drainage philosophy and strategy that has resided in UK Drainage since 1974 (Robinson, 1986). With urbanization increasing, the requirement for SuDS has grown dramatically over the last ten years. The work exhibited in this research aims to develop an understanding and improvement of knowledge based on SuDS and how effective they can be if implemented adequately. The research will concentrate on a case study regarding a Detention Basin installed into a select location in Newcastle/Gateshead, by then providing results and analysis on a questionnaire at said location, verifying the effectiveness of the device.

Flooding is a widespread common occurrence in the UK; it poses a significant risk to both people and infrastructure. One in six properties in England (around 5.2 million) are at risk of fluvial floods categorised by river flooding, whereas an additional one million are also at risk of pluvial floods due to excessive rainfall (Clark, 2021). An increase in the urban area in flood-prone zones has caused a more significant amount of overland flow (Szwagrzyk, et al., 2018). Concrete and tarmac are among surfaces that are predominantly impermeable, so the ability of rainfall to infiltrate the ground is prevented, producing heightened rates and volumes of stormwater runoff (Macdonald, 2003). The protection of floodplains throughout the UK has been limited, heightening the rate of urbanization (Gori, et al., 2019). This can be combined with an expanding number of impermeable surfaces in built-up locations, ending in the increase in the possibility of flooding and embedding unwarranted pressure on conventional drainage systems (Schneider & Goddard, 1974). Additionally, to the before-mentioned changes to UK land, the added rise of climate change influences rainfall intensity, winter-based circumstances and mainly the number of flood cases throughout the UK (Barker, et al., 2016).

The augmentation of urbanised areas is an inevitable element of our modern culture (Macdonald, 2003). Flooding is a reoccurring consequence of urbanisation due to the installation of conventional drainage systems and increased impermeable areas (Lashford, et al., 2020). Current conventional pipe-based drainage systems will effectively and efficiently guide water to an outflow; however, when flow rates intensify in short periods of time, large build-ups cause drainage systems to malfunction. This decreases the natural delay or the time it would usually take for stormwater to reach a river through ground penetration.

The Newcastle and Gateshead area is at risk from various origins of flooding; this includes the rivers, river-burns, lakes, ponds, surface-water runoff, overland flow and drain flooding (NCC, 2016). A comprehensive volume of information and flooding reports had to be examined to manufacture the Local Flood Risk Management Plan. The Flood Risk Regulations of 2009 introduced a necessity for advancing, maintaining, and implementing a Local Flood Risk Management Strategy that the varieties of flooding dangers would cause. In order to abide by such, it required asymmetry among local and national flooding objectives as it could affect local areas. In addition to the Flood Regulation, the Flood and Water Management Act 2010 complemented such, producing a more unified, inclusive, and risk-based collaborative strategy for adequately managing the effects of flooding and recognised the required restraints (NCC, 2016). The act gave Newcastle and Gateshead Council a comprehensive position of power in the management and the legal competency as Lead Local Flood Authority. The above-mentioned legislation influenced the way both councils' schemes worked concerning flood management as their overall involvement with benefitting the local resident's health and safety.

The overall purpose of this research is to analyse the effectiveness of a SuDS device to confirm whether the implementation of the philosophy has been successful. With this in mind, the aim of the research is to identify to site location which already houses a SuDS device, by then using a range of methods and techniques of understanding how and why it was installed. Accordingly, below features the objectives that will be undertaken with the goal of achieving the clarified research aims.

- To investigate the reasoning that has pushed the implementation of SuDS and what the philosophy tries to pursue.
- Dissect the elements of a SuDS management train to discover the water reduction capabilities of each device.
- Discover which device is most suitable with respect to water reduction.
- Understand why and how a particular SuDS Device is implemented into site location.
- Verify the effectiveness of a SuDS device that already resides somewhere in the UK.

The initial impetus to convey the research in the subject field was produced through the opportunity provided in the construction industry. During the searching of a topic - over the past few years - it has become apparent that SuDS systems are slowly becoming imperative to design in most residential housing developments. When the research proceeded to the general background of research, it was fascinating to uncover all the variants of SuDS systems and the management trains put in place to combat water quantity.

2.0 Literature Review

The initial stages of research showed the true extent of how SuDS is very quickly and effectively growing into an effective method of Stormwater management; this is backed up through a comprehensive knowledge bank of information that comprises the SuDS scheme as a whole. This study moved quickly onto the literature, where it efficiently discovered a realistically achievable problem and a definite focus for the research.

2.1 Flooding: due to increased urbanization

As a result of enduring a constant need for urban development, the UK proceeds to have a heightened flooding issue. The construction of more impermeable surfaces produces stormwater run-off that avoids natural storage and belowground attenuation (Wheater, 2006). The increased volume and rate of run-off creates significant flood risk, even within locations that endure modest levels of rainfall. This situation is only forecasted to worsen as the dynamic climate will yield more excessive rainfall (Rubinato, et al., 2019). The runoff also carries various pollutants like oils, sediment which is accumulated from the urbanized surfaces. The characteristics of this urban runoff have a notable impact on the state of the collecting watercourse (Macdonald, 2003).

2.2 The effects of flooding and climate change on conventional pipe-based urban drainage

The integration of conventional pipe-based drainage at most urban developments is still part of standard design culture in the England and Wales; with the continuous focus of preventing pluvial flooding and minimising the stormwater run-off induced by urbanisation (Lashford, et al., 2020). However, on days of climate change, categorised by long dry periods trailed by excessive rainfall or powerful storms, it causes rudimentary drainage systems to malfunction

(Mak, et al., 2017). Great deals of current drainage will successfully evacuate substantial amounts of rainwater at quick speeds via gully pots and, pipes. This results in an increased flooding risk though, as traditional systems are designed only to endure a limited quantity of stormwater; by the cause of run-off rapidly accumulating in the outfall (Qin, et al., 2013). Additionally, the flow of water in the conventional drainage can be obstructed by various types of debris that may fall in the mainline of pipes; this also inhibits the effectiveness of removing water. To combat flooding issues categorised by rainfall, the SuDS Stormwater Management philosophy was developed with the main objective of efficiently controlling stormwater run-off in the urban environment, representing a natural aesthetic.

2.3 Overview of SuDS

Construction project management is integral to bring a sustainable built environment (Maqbool, 2018; Maqbool & Sudong, 2018; Maqbool, et al., 2018). The way surface water is both utilised and managed in the built environment should be considered as an important aspect of construction. Sustainable Drainage Systems (SuDS) incorporate various approaches and philosophies that concern overseeing surface water management in urbanized areas. As detailed in the SuDS Triangle (Figure 1), the primary purpose is to adequately control volume and flow rate while also providing information on improving water quality, biodiversity, and amenity. In addition to this SuDS must also make the surrounding structures and landscapes more resilient to the changing climate (Woods-Ballard, et al., 2007). The increase in the creation of impervious surfaces, simultaneously with the implementation of conventional pipe-based drainage is regarded as the primary reasoning behind the creation of SuDS. These systems reverse the concept of containment and rapid transportation for stormwater runoff, making it more adequate for water to collect in the urban environment; therefore, delaying the water departing to the outfall (Jones & Macdonald, 2007). Essentially, SuDS copies the natural hydrological process such as infiltration, which was lost due to the urbanisation process and the conclusive construction of the impermeable ground (Zhou, 2014).

Figure 1 – The SuDS Triangle (Anderson, 2020)

2.4 History of the implementation and development of SuDS

As a result of a change in theory, which then favoured sustainable management over hard engineered solutions into preventing flooding, the concept of SuDS emerged through the late-1980s and early-1990s (Pompeo, 1999). The reasoning for this was driven by the push for sustainability from the Brundtland Commission. They suggested in the book "Our Common Future (1987)" that new developments should satisfy both the present and the future demands (Pompeo, 1999). Ten years later, in 1997, Butler & Parkinson (1997) both challenged the idea that traditional urban drainage systems were part of the urban environment which encouraged "less sustainable purposes"; this led to a concentration on the more long term benefits. Upon implementation, the primary focus of SuDS was source control, which was pursued by catching and inhibiting water at the building scale (Pompeo, 1999). After much change and development, CIRIA (1992) produced documentation concerning the design and impacts of implementing sustainable drainage in both the USA and UK. This documentation is only a tiny part of the CIRIA organisation, which has effectively delivered for years a wide range of collaborative guidance and initiatives based around flood risk management and development, property flood prevention strategies and direction on sustainable drainage and drainage limitations (Ellis & Viavattene, 2014). SuDS can be retrofitted or installed throughout the construction of new builds; they can be implemented as singular devices or inclusive of the much more expansive SuDS management train. It is widely regarded that SuDS management trains are much more effective and viable than alternative conventional drainage strategies (Stovin & Swan, 2007). However, existing research concerning SuDS capabilities for high volumes of runoff remains limited.

2.5 Retrofitting SuDS

Retrofitting surface water management measures can help provide cost-cost efficient solutions to some of England and Wales's flooding issues (Digman, 2012). The process occurs when an existing conventional drainage system can be disengaged and diverted into a SuDS device to manage stormwater more productively (Stovin, et al., 2013). As pluvial flooding is frequently a problem in the urban environment due to a gradual increase of impervious surfaces, devices must degrade the risk (Elliot & Trowsdale, 2007). As of 2020, according to Clark (2021), an estimated 5.2 million properties are at risk of flooding in the UK, with new developments contributing 2% of all buildings nationwide. Consequently, a dynamic plan for dealing with new and old developments is imperative to mitigate flooding (Elliot & Trowsdale, 2007). Table 2 illustrates several example developments that house various SuDS devices. Balmforth (2006) demonstrated that integrating retrofit SuDS urban environment can be problematic; this was due to current limitations of specific existing buildings, paths and roads restricting the space possible to implement a particular device (Balmforth, 2006). However, Stovin & Swan (2007) explained that fitting retrofit SuDS could decrease overall construction costs (Stovin & Swan, 2007).

There is an incompetent amount of examples to provide a wholesome case study concerning existing retrofitted SuDS systems across England and Wales. As stated by Stovin, et al., (2013), it is a result of the complexity associated with disconnecting the conventional drainage system and then routing stormwater runoff into a new SuDS device. This is why much of the current design focuses on formulating an integrated SuDS scheme with a conventional drainage system (Stovin, et al., 2013). Table 1 demonstrates the SuDS devices that are most suitable for retrofit installation. All devices, except for infiltration basins, have the potential to be installed through retrofit design. However, swales, ponds and wetlands are less suitable and have limited potential for retrofit due to their size (Woods-Ballard, et al., 2007).

2.6 SuDS Treatment and Management Trains

The SuDS Treatment and Management trains (Figure 2) are both systems that utilise a wide variety of SuDS devices in sequence, intending to reduce flow and pollution level in stormwater runoff (Woods-Ballard, et al., 2007). In a quick summary, when concentrating on water quality, sequences of SuDS devices are often determined as treatment trains. While literature section details where treatment trains implement into the management of runoff, the primary focus of this study is water reduction, which is the main objective of management trains. Knowing this, moving forward, the expression “SuDS management train” has been utilised in whole literature section.

2.6.1 SuDS Treatment Train

Enhancing the water quality of stormwater runoff is regarded as a critical aspect of design for integrating SuDS (Figure 1) (Woods-Ballard, et al., 2007). Woods-Ballard, et al. (2007) furtherly expressed that the SuDS treatment train is a compendium of good practice based on existing research. He demonstrated such by showing how the SuDS concept improved various aspects of water quality; and how it can positively affect the overall water quantity (Woods-Ballard, et al., 2007). Duffy (2009) developed a scoring scheme for the STTAT (Stormwater Treatment Train Assessment Tool). The tool established the dangers of pollution are down to the water source rather than throughout the water cycle, with the water quality treatment administered inclusive with the treatment train (Jefferies, et al., 2009). The STTAT provides direction and regulatory consistency for developers about planners and the Scottish Environment Protection Agency (SEPA) concerning road-based SuDS systems (Jefferies, et al., 2009). As a result, it was discovered that many other aspects of the SuDS triangle could be satisfied when utilised in alternative locations of the treatment train. Furthermore, the researchers remarked that additional water quality improvement was plausible using SuDS in sequence. Stovin, et al., (2013) showed that the train's success relies on the transport of stormwater runoff between various SuDS devices included in each treatment train. It was demonstrated that the thorough treatment process should continue to additional devices downstream, which would affect the success of water quality (Stovin & Swan, 2007).

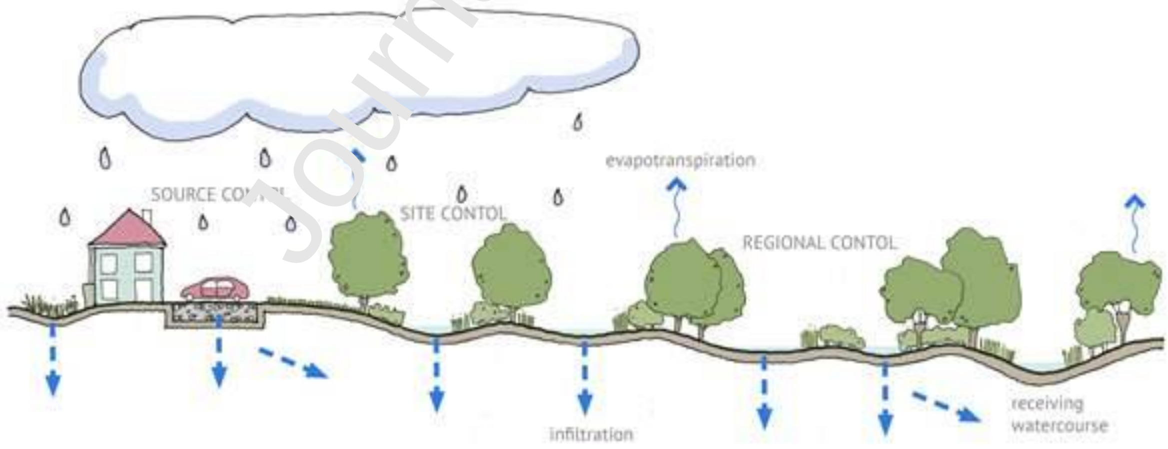

Figure 2 – SuDS Management and Treatment Trains in the Water Cycle (Susdrain, 2021b)

2.6.2 SuDS Management Trains

Instead of solely improving the water quality, SuDS can also be integrated into a management train to reduce water quantity and increase flood resilience. Typically, the increased amount of devices used within a SuDS sequence can reduce flooding. However, where the device is utilised in the water cycle may also possess effective water reduction capabilities (O'Sullivan, et al., 2012). Occasionally it is not the most suitable to use one singular SuDS device at a site location. Alternatively, a group of smaller related devices in a management train can have increased efficiency, which in effect, would still adhere to the specifications of the SuDS triangle (Figure 1). Regarding aspects of a SuDS management train, controlling water quantity from the source control may be deemed the most effective location (Shah, et al., 2021). All residual stormwater runoff in the SuDS system is carried to a device that is located in site control (Stovin & Swan, 2007). As an example, swales can be utilised as an effective device in site control; this device deals with higher quantities of runoff from multiple positions on-site; it additionally allows for infiltration to the neighbouring soil and has the potential to evaporate (O'Sullivan, et al., 2012). In some cases, stormwater can be then carried on to an alternative position for regional control to hold more excessive volumes of water from various site control SuDS devices before discharging water to some form of outflow, symbolising the final aspect of the management train. However, by this time of the water cycle, if an effective sequence of devices is in place, there should be minimal runoff situated here (Jefferies, et al., 2009). An example of a regional control device would be a detention basin or a pond system (Robinson, et al., 2010). Furthermore, runoff is either gradually delivered to a water body and progresses out of the management train or evaporates (Woods-Ballard, et al., 2007).

2.7 SuDS Devices in SuDS Management Trains

SuDS management trains have capabilities for both water reduction and water quality improvement (Woods-Ballard, et al., 2007). Subsequently, it is most suitable to integrate SuDS devices with distinct roles to ensure higher overall effectiveness than installing singular devices (Charlesworth, 2010). There is inadequate research concerning which SuDS devices are better suited to each other in a management train and how devices work integrated together. According to Susdrain (2021a), Table 2 manifests that Pervious Pavements systems, detention basins and swales are the most commonly used SuDS devices. With regard to where each device is most suitably utilised in the water cycle, Table 1 presents a categorisation of the water reduction abilities of SuDS devices regarding source control, site control, regional control and conveyance. In addition to this, the table also shows each devices' water reduction effectiveness and classification on its potential for retrofit (Woods-Ballard, et al., 2007). Note that Table 1 is produced solely from information in the SuDS Manual.

Table 1 – SUDS Devices and where they can be utilised, emphasising effectiveness of water reduction and potential for retrofit (Woods-Ballard, et al., 2007)

SUDS Device	Source	Site	Regional	Conveyance	Water Reduction Effectiveness Rating (Out of 10)	Potential for Retrofit
Rainwater Harvesting	×				1	Yes
Green Roofs	×				5	Yes
Soakaways	×				5	Yes
Infiltration Trench	×	×		×	7	Yes
Infiltration Basin		×	×		6	No
Filter Strip	×				3	Yes
Sand Filter		×	×		2	Yes
Swales	×	×		×	5	Constrained
Bioretention Devices	×	×			9	Yes
Pervious Pavements	×	×			9	Yes
Detention Basins		×	×		10	Yes
Ponds		×	×		8	Constrained
Wetlands		×	×	×	3	Constrained

✕= Suitable for installation Blank = Installation not Possible

Table 2 – SUDS Devices utilised in various SuDS management trains across England and Wales based off a case study list produced by Susdrain (2021a)

SuDS Device	Rainwater Harvesting	Green Roofs	Soakaways	Infiltration Trench	Infiltration Basins	Swales	Bioretention Devices	Pervious Pavements	Detention Basins	Ponds	Wetlands
Access Road, Chelmsford						✕				✕	✕
Alcester Care Centre	✕				✕	✕		✕			✕
Alma Roads, London	✕						✕	✕			
Aztec West Business Park									✕	✕	
Blythe Valley Park, Solihull						✕				✕	✕

Bridget Joyce Square	×					×	×			
Buckland Car Park							×			
Central Hill, highway retrofit							×			
Derbyshire Street Pocket		×			×		×			
Firs Farm Wetlands					×	×	×		×	×
Forest Way School					×				×	×
Glenbrook Wetlands					×					×
Heron Court Rain Gardens	×						×			
Hollickwood Primary School	×				×			×	×	
Hollington Primary School	×				×			×		
Houndsden Road Gardens	×			×	×					
London Road Residential							×		×	×
Middleport Pottery, Stoke	×					×				
Norwood Greening St	×						×			
Oakengates Leisure Centre								×		
Queen Caroline Estate, London	×	×			×		×	×		
Queen Mary's Walk, Llanelli					×				×	
Redland Green School, Bristol			×				×		×	
Renfrew Close, London	×							×		

Springhill Cohousing						✕		✕	✕	✕	
Stebonheath Primary School						✕	✕	✕		✕	
Strutts Centre, Belper	✕					✕					
Sustainable Drainage Estate	✕	✕	✕			✕	✕	✕			
The Surgery, Herefordshire				✕		✕				✕	
Victoria Park Health Centre		✕			✕					✕	
Total	**13**	**4**	**1**	**2**	**3**	**17**	**6**	**15**	**8**	**13**	**7**

✕= Suitable for installation Blank = Installation not Possible

2.7.1 Source Control

The incorporation of source control in SuDS management trains is associated as an essential aspect of SuDS design. Source control resides at the beginning of the urban water cycle and is further upstream from SuDS devices such as infiltration trenches, ponds, wetlands and detention basins (Susdrain, 2021b). Installing water reduction strategies at the source control can help administer interception storage, alleviating the more common pollution cases further down the line. The vast majority of SuDS source control devices will be found within private grounds or highway/main road areas. They have the idea of managing rainfall in close proximity to where it lands, encouraging attenuation, treatment and infiltration, therefore mitigating the problem on-site by improving permeability.

Table 1 shows that several SuDS devices can be utilised at Source Control level. Woods-Ballard, et al. (2007) suggests that Bioretention Systems are considered a highly effective water reduction method (Water Reduction Effectiveness Rating of 9) and were vegetated sites that significantly reduced runoff by absorbing stormwater through engineered bio-retentive soil (Figure 3). In a water reduction test conducted by Mahmoud, et al. (2019) in a semi-arid coastal climate, findings suggested that a Bioretention cell (45.7m x 1.2m x 1.2m) was competent in maintaining water retention of rainfall events ranging from Small (1.7mm of rainfall) to Large (47.1mm of rainfall). This research demonstrates the capabilities of implementing Bioretention systems into SuDS management trains. With respect to SuDS treatment trains, Bioretention systems can be retrofitted to improve water quality by utilising alternative materials that reduce pollutants (Woods-Ballard, et al., 2007). In relation to Table 2, with respect to case studies completed by Susdrain (2021a), Bioretention systems were utilised in six different developments from the sampled locations. They were most suited to public open spaces like parks and squares due to their aesthetic properties and ability to catch rainfall at its source.

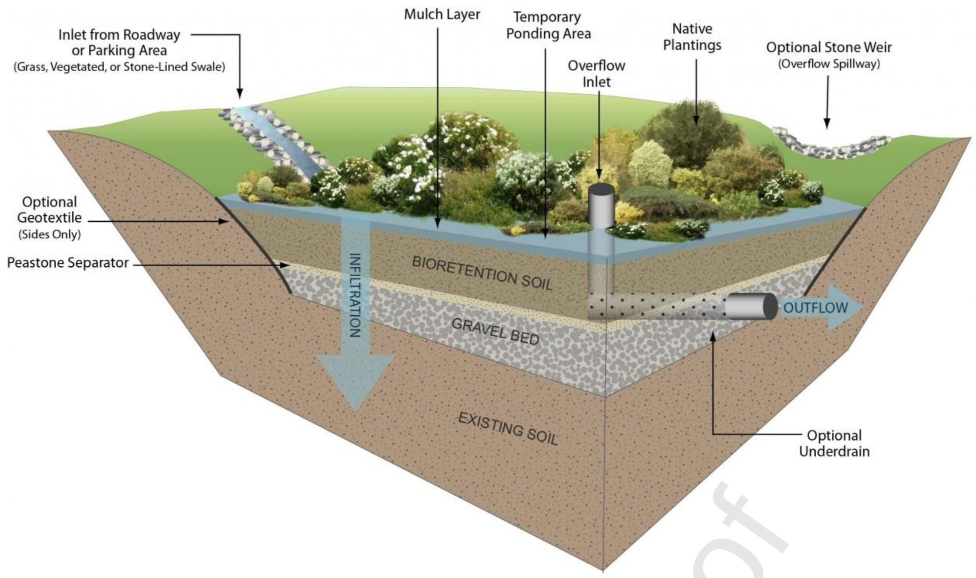

Figure 3 – Section through Bioretention System (Landtech, 2018)

In addition to Bioretention systems, pervious pavements (permeable pavements systems) (Figure 4) can also be considered as a highly effective method of water reduction (Water Reduction Effectiveness Rating of 9). Typically, the bulk of all rainfall events that land on impervious surfaces in urban catchments ends up on pavements (Ferguson, 2005). Surface water passes through various layers of material ranging from sub-base to geotextile, resulting in an improved water quality (Figure 5) (Lashford, et al., 2020). Pervious pavements are mainly utilised to alternative the traditional impermeable hard surfaces found in car parks, car roads, footpaths, and public areas (Beecham, et al., 2010). Concerning Table 1, they were implemented into fifteen different developments from the sampled locations, this is mainly due to the low load capabilities it possesses with the addition of allowing an increased level of water reduction.

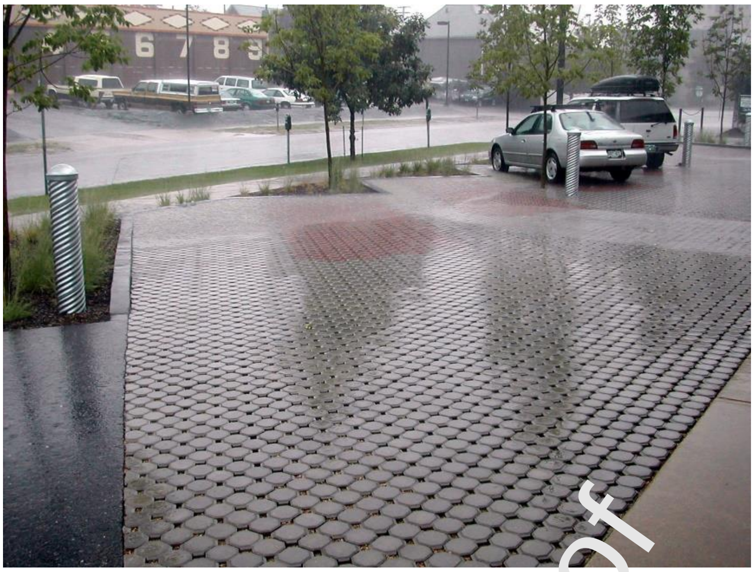

Figure 4 – The natural aesthetic of a Permeable Paving system (Eisler, 2019)

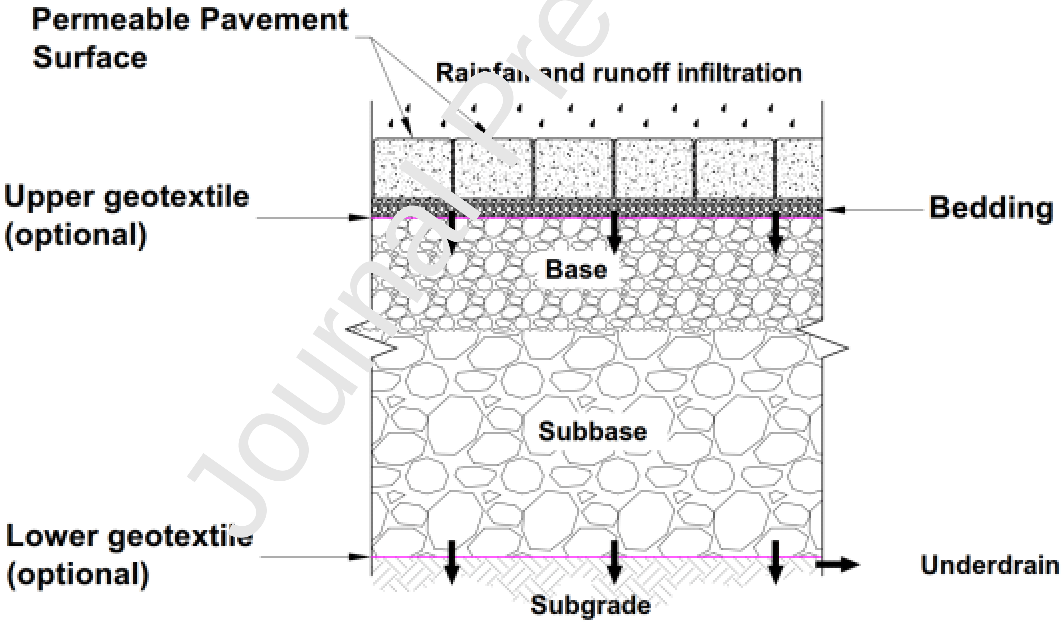

Figure 5 – Section through detailing the build-ups in a Pervious Pavement System (Tota-Maharaj, et al., 2017)

2.7.2 Site Control

Stormwater run-off collected from various source control devices is mostly conveyed to large site control devices. As demonstrated in Table 1, it recognises that several SuDS devices are capable of being utilised simultaneously as both site and source control. Devices such as Bioretention devices, swales, and infiltration trenches are among the examples; however, it depends on their size (Woods-Ballard, et al., 2007). Regarding devices that are effective at site control level, Woods-Ballard, et al. (2007) suggests detention basins are an effective method of water reduction (Water Reduction Effectiveness Rating of 10). Detention Basins have hydraulic characteristics such as storage capacity that simultaneously encourages groundwater revive through penetration (Datry, et al., 2004). In a quality control analysis of a detention pond, Guo & Adams (1999) discovered that for flow capture efficiency, the differences between both a simulation and analytical method were lower than 0.1, meaning that the results indicated that the capability of reducing the run-off rate based on various rainfall events of 20%, was deemed "practically acceptable" (Guo & Adams, 1999).

2.7.3 Regional Control

The sole purpose of regional control devices is to preserve more substantial amounts of water without dispersing it elsewhere, preventing flooding within the desired site location. As demonstrated in Table 1, it is mainly only SuDS devices with water-storing capabilities that can be utilised at this level. Concerning the most effective devices, Woods-Ballard, et al. (2007) strongly suggests Detention Basins are of the highest worth. In addition, Ponds are also considered a helpful device in retaining water and conclusively lowering stormwater runoff levels; however, the same as Detention Basins, their potential capacity of effectiveness is reliant on its size (Scholz, 2004). As alternative SuDS devices are suitable for regional-scale installation are insufficiently productive at decreasing runoff peak flows, both detention basins and ponds are preferred when assembling a SuDS management train at regional control level (Lashford, et al., 2020).

2.7.4 Conveyance

Woods-Ballard, et al. (2007) suggested that Swales are the most effective form of conveyance; this is demonstrated in Table 1 also. In addition to this, Freni, et al. (2009) stated that Swales furnish a 'medium' capacity of effectiveness for minimising flood flows in location (Freni, et al., 2009). Concerning Table 2, as part of the several case studies completed by Susdrain, Swales are considered a quite popular SuDS system and are regularly integrated into several existing management trains across the UK. Swales (Figure 4) have the unique ability to impersonate the natural aesthetic of drainage to the public eye; this is done by adopting vegetated channels with filter drains found below the surface that transport water away from a site location (Freni, et al., 2009). In an investigation into the implementation of Swales, the Colorado Stormwater Center (2018) calculated that swales decreased peak flows by roughly 22% over a two-year flow rate on a storm-by-storm basis. However, just like detention basins, information concerning modelled storms were not presented. Nevertheless, the consensus on the research recommends that swales were unsuccessful at lowering peak flows effectively and that the primary function of the device is to convey stormwater runoff around a site. Alternative devices like infiltration trenches, rainfall harvesters and wetlands can also be considered at the conveyance level; however, they are not effective at carrying water around site location as Swales (Woods-Ballard, et al., 2007).

To conclude the literature review, it is obtrusive that there is an imperative necessity for implementing SuDS devices into developments to minimise flooding risk. However, although there has been a significant improvement in the positive recognition based around SuDS in decreasing flood flows count, the research predominantly concentrates on each device's water reduction abilities. By utilising a SuDS management train, it formulates the opportunity of providing a site location with added resilience and capability to handling events categorised by excessive rainfall.

3.0 Material and Methods

The scope of this section is to explain the thought process behind the framework utilised to carry out the research. It explained the approach that undertaken to conduct the data analysis and developing on knowledge obtained from this literature review. It showed the stages engaged in the planning, designing, and implementing of the study. In addition, it incorporated the methodological strategy and methods utilised to recognise the location of the study, what SuDS device to concentrate on, suitable questionnaire participants, selection, and design, collect and analyse data.

3.1 Quantitative and Qualitative Data

The research looks at collecting both quantitative and qualitative research while ultimately looking to analyse the overall effectiveness of a SuDS device. Concerning qualitative data, research, and analysis in the form of a case study determined the profile of the SuDS device in the desired residential location; by then, the quantitative data was conducted a questionnaire sampling local resident based around the location of the SuDS device. The data collection additionally includes numeric values inclusive of the questionnaires, therefore representing quantitative information. Miller (2017) distinguished research that included both quantitative and qualitative as "neo-positivist" which uses pre-existing networks of concepts in the conclusion of forming theoretically based predictions concerning people's lives (Ramos, 2007). The literature review helped determine which SuDS device in a case study would be beneficial for the questionnaire in terms of visually realising the water reduction capabilities in the area of residents. In addition to this, the Literature review also helped limit the scope of research and identified various findings by other researchers and writers.

3.2 Research Philosophy

Research philosophy is viewed as the primary obstacle when designing research. Easterby-Smith, et al. (2002) highlighted three main ideas that emphasise the significance of problems in research philosophy. Firstly, the researcher must explain the research design and research philosophy to clarify such—secondly, the researcher can identify and understand the select research designs that will operate successfully; and which will be unsuccessful. Finally, it encourages the researcher to recognise and produce research designs that might exceed past experiences (Kulatunga, et al., 2006). While contemplating the research aim and the nature of the research, it was apparent that the investigation necessitates a thorough inspection of the scope of effectiveness after implementation of the SuDS device. Consequently, this problem required the researcher to understand how the research aim endeavours were within the people who have been observed at the desired site location. Interpretivism is an example of one of the philosophies Easterby Smith, et al. (2002) quoted. He believes that reality is subjective and interior to participants of the research (Kulatunga, et al., 2006). This one of the primary reasons the interpretivism research philosophy was modified into this research conducted in this study.

3.3 Research Approach

Upon establishing this research philosophy, a relevant and workable research approach should have to be chosen to deal with the overall research problem. Yin (2009) stated that five alternate research approaches could be accommodated to a user's research; these approaches were categorised as archival analysis, case study, experiment, history and survey. Easterby-Smith, et al. (2002) declared research approach helped organise the primary and secondary research activities, ranging from collecting data to writing analysis; consequently, this would positively contribute to achieving the research aims. The research approach was focused on both collecting quantitative and qualitative data while composing realistic assumptions about results. The literature review was undertaken initially to justify the research question further. In addition to this, it was also to determine the scope and depth of current knowledge-based around the current and upcoming flood management strategies, mainly within the UK. The primary aim of this research was to analyse the effectiveness of a SuDS device that has been implemented in the area.

3.5 Data Collection

Modelling the research questions assist in defining the direction and purpose for the processing and collection of data. Research questions that addressed research issues identified the following;

1. What are the existing flood management strategies in the UK?
2. Which SuDS devices are effective and sustainable enough to provide a worthy replacement of current flood management strategies?
3. How practical has a previously implemented SuDS system performed over a specific timescale?

With respect to the above questions, a realistic assumption can be made concerning the effectiveness of a SuDS system on the basis that it could be implemented into various new and existing construction projects across the United Kingdom. The data collection methods (Case study and questionnaire survey) were executed for particular purposes. The case study was initiated to grasp an understanding of why and how the Detention Basins was installed, whereas the questionnaire was to gather the residents' opinion to gauge the effectiveness of the device.

3.5.1 Case Study Location Selection

There are several SuDS devices that Northumbria Water uploads to their comprehensive planning portal; this inevitably helped me in choosing the Case Study location. From working through the literature review, it was identified early that the only SuDS devices that are noticeably effective (in terms of water reduction) are the basins, storage tanks, and filter drains. It became apparent through a short search that the Detention Basin located at Gibside View was an attractive selection because of its small distance to home.

3.5.2 Questionnaire survey

This research concentrated on a small sample size of personnel data from the residents of Gibside View. Due to the area of Winlaton being a limited size that holds only a limited number of residents based around the radius of the Detention Basin, it prevented from providing a more comprehensive set of questionnaire data. In terms of choosing the sample, the only proper and realistic way of doing the questionnaire was by going door-to-door.

Concerning the questionnaire questions, each one that was asked (through a face-t was carefully considered beforehand in order to guarantee a concrete set of findings could be drawn to illustrate the capabilities of the device; this was ensured by requiring respondents to evaluate the device on a 1-5 scale (measurement gauge). The data was collected through convenience and purposive sampling techniques. These data collection methodologies were adopted due to their features of quick collection of data, inexpensive methodology, easy to do research, fewer rules to apply, low cost and readily available sample for a specific purpose of research (Bornstein, et al., 2013). A total of 182 questionnaire responses were received, out of which 180 were found to be fully completed and used for data analysis and assessment purposes in this study.

Appendix A exhibits the Question Design and Format that was utilised, which comprised of 12 questions listed below:

Questions 1-3: These questions asked the respondents to provide basic information about their time length, area and type of residence. This gave a broadened understanding of some potential reasoning into how their properties may have experienced flooding issues in the past.

Questions 4-8: This segment was filled with various questions based on the potential of whether anyone has experienced any flooding problems before the instalment of the Detention Basin. The question ranged from asking about water depth, how the flooding originated and the costs of damage caused in their homes.

Question 10: This question asks the Gibside View residents about the awareness of SuDS systems. By asking them this, it provided a perception of how knowledgeable and informed they were of the device that was implemented to alleviate the flooding issues they may have experienced.

Question 9 and 11: These two questions were utilised to gauge a better understanding of how effective the SuDS device has been since the installation. By asking residents to rate their recent flooding experience out of 5, by then asking them to rate such after (out of 5), it grants the opportunity to measure the difference in scores to identify any potential improvement.

4.0 Data Analysis, Discussion and Findings

4.1 Case Study – Gibside View, Winlaton, Gateshead

Gibside View locates in the village of Winlaton, which resides in Gateshead. The area is mainly full of residential homes, which is integrated with a singular conventional drainage system into the site. The location occupies a high elevation oversees large open grassed areas to the south, which falls gradually towards the River Derwent.

4.1.1 Flooding Reports

Before the construction of the new SuDS system, there had been various reports in the news that several properties in the Gibside View area had endured internal flooding on numerous occasions in recent years. Investigations on the specific events recognised the flooding cause to be insufficiency of surface water drains within the location. On the basis that there was a green field in the site radius, the opportunity of assembling a sustainable solution arose for Northumbria Water through the retrofit of SuDS into the environment.

4.1.2 SuDS System Design & Additional Considerations

The design of the detention basin was based around the triangular open area shape of grass. According to the design, the basin renders 360m³ of attenuating storage, providing residential protection for up to a 40-year long rainfall event. In decreasing the chances of any form of flooding event in and around the location of Gibside View, the combination of NW and GC has inaugurated attenuation storage that remains discreet and considerate to the local environment. The Detention Basin has been designed and constructed in an area of amenity; the site has several old oak trees, and the occasional flower bed is scattered around. This is due to the planting scheme put in place pre-construction, meaning that the detention basin would easily camouflage itself in the surroundings and potentially institute new habitats.

4.1.3 Installation of the Detention Basin

The Newcastle city council government portal outlines that the job had two specific components: the upsizing of public drains and the installation of flow control measures, and the use of Gibside view's open grassed area building a rainwater attenuation area. The plans showed that Gateshead Council is the owners of the land where the detention basin resides. It also explains that the scheme presented the additional advantage to the local council of a significantly enhanced highway surface water drainage system. The project included two phases of construction. The initial phase was installing a new conventional drainage system ranging from 300mm to 550mm with a length of 270m; the goal of this new system was to increase the water capacity of the local channels of drainage. The installation of the detention basin itself was part of the second phase of construction; this phase involved connecting the newly established drainage system to both the inlet and outlet of the basin. As shown in the schematic plan in Figure 6, the basin locates parallel to Parkgate Lane before the T junction that connects onto Park Lane.

Figure 6 – As-Built Drawing of Detention Basin provided by Northumbria Water Archives (NorthumbriaWater, 2021)

4.1.4 How the Detention Basin and Drainage System Operates?

As provided by Northumbria Water, the As-Built drawing (Figure 6) shows how any surface water collected from areas of the catchment (e.g. road gullies) further upstream integrates into the new 450mm drainage line of Parkgate Lane. This line then connects to an overflow tank across from the detention basin, where low flowing surface water returns into the drain network through a 225mm line of conventional pipe. Water that exceeds the drainage lines maximum capacity then exits the line and is redirected into the attenuation basin for storage, therefore decreasing the likelihood of flooding in the Gibside View area. In terms of the detention basins itself, it has one inlet and one outlet. The inlet pipe has a 450mm diameter, and the outlet has a 225mm diameter. Any surface water that leaves the basin through the outflow re-engages itself with the drainage system that resides on the Park Lane Road before then diverting to the southeast area of the location — eventually unloading excess water into the River Derwent located down at Winlaton Mill. In most cases, the detention basin will be quite dry; this is because UK weather is categorised by large periods of hot summer weather and then long excessive pluvial floods. Therefore, the basin will only begin to operate upon larger rainfall events when the previous and newly implemented system exceeds its water capacity. Regarding the Basin's design, according to Northumbria Water, the geology in the area comprised of virgin clay, consequently meaning there was no need for any form of sub-base for the basin. Furthermore, the basin was designed for a maximum water depth of 1.0m.

4.1.5 Maintenance Agreement

Concerning the SuDS maintenance schedule that was agreed on pre-construction of the detention basin at Gibside view, the collaboration between Northumbria Water and Gateshead Council authorised that all future operational and maintenance matters will be acknowledged early. Gateshead Council officially owns the open grassed area in which the basin locates; they were fully supportive of the design of the basin and the principles that were the motive behind the construction. Due to this, this conclusively led to a post-construction agreement where the Gateshead council would deem themselves liable for any form of future maintenance of the basin. In contrast, Northumbria water would be accountable for managing and overseeing and sustaining the supplementary structures. The grass public space area located on the surface of the detention basin has been shaped to a gradient of 1:3; this was considered in the design stages to allow ease of maintenance in terms of cutting the grass.

4.2 Findings of Questionnaire Survey

4.2.1 Question 1

As demonstrated in the pie chart in Figure 7, over 1/3 of the sampled residents at Gibside Review have lived there for more than 11 years. Concerning the participants who answered 0-4 years, it can be argued that it indicates it provides limited evidence to add value to the overall research problem. As the detention basin was implemented into the location in 2017, results from candidates who select answers 5-7 years, 8-11 years and 11+ years are more likely to have experienced flooding.

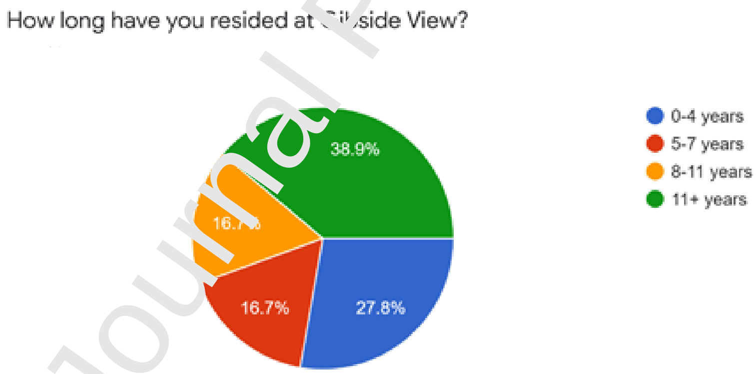

Figure 7 – Respondent residence duration

4.2.2 Question 2

Upon visiting Gibside View, it became evident that the whole location was predominantly residential buildings. As expected, demonstrated in the pie chart in Figure 8, the presumption was accurate as all 100% of the answers were people who lived in a residential property.

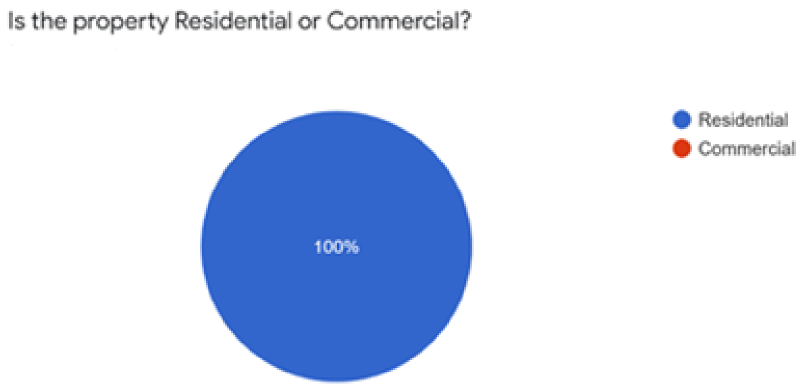

Figure 8 – Property sector

4.2.3 Question 3

Like Question 2, upon visiting the case study location, it was discovered not only what property could be categorised as but also what house type they are. As demonstrated in the pie chart in Figure 9, it came to no surprise that the houses are characterised as either Detached (27.8%) and Semi-Detached (72.2%). As a thought for future result analysis, participants who responded that they live in Detached houses may be inclined to have experienced worsened flooding damage than ones who live in a Semi-Detached property.

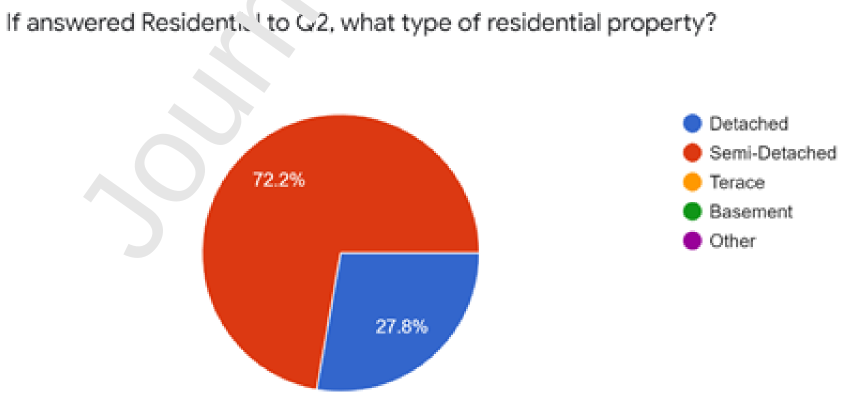

Figure 9 – Property house types

4.2.4 Question 4

Through the use of Question 4 (Figure 10), the research direction could be narrowed down to terms of only gathering results based on people who have experienced flooding issues at the location. By utilising, a dichotomous question type, any participant who answered "No" (33.3%) could be disregarded until question 11. On the other hand, anyone who answered "Yes" (66.7%) could be categorised for further analysis as future questioned can be asked.

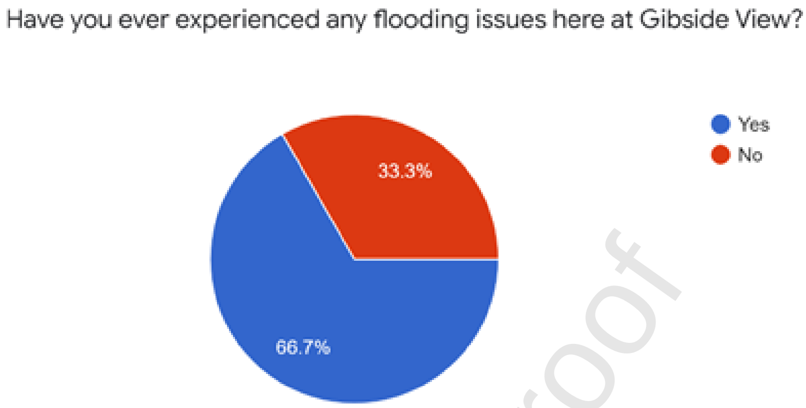

Figure 10 – Flooding experience clarification

4.2.5 Question 5

Question 5 concerned an open answered question clarifying the description of the flooding events that may have been experienced prior to the questionnaire. The responses were coded and classified into themes shown in the Table 3 and in Figure 11. From which it is apparent that the main areas affected by flooding events at Gibside View were the lower levels like the garage, basement and living areas (30 responses) and the external parts of the property (50 responses). This suggests that before the installation of the Detention Basin, there was quite significantly destructive flooding issues; this may imply that the implementation of the system was a successful decision.

Table 3 – Themed Answers in Question 5

Themed Answer Type	**No. of Answers**
Pools of water on roads outside of property	30
Water intruded lower levels of property (Garage, basement, living space)	30
Flooding of external parts of property	50

Other	10
Answered "No" to prior questions on flooding	60

4.2.6 Question 6

Question 6 outlined respondents to identify (if known) where the flooding may have come from. As indicated quite early within the literature review, the answers summarised in Figure 11 came as no surprise. Drain, Gully or Sewer Cover was answered by 33.3%, whereas surface water/overland flow was additionally answered at the same quantity of 33.3%. This suggests that there was no default in prior research and confirms that the implementation behind the SuDS device was pushed because of flooding events caused by the above responses.

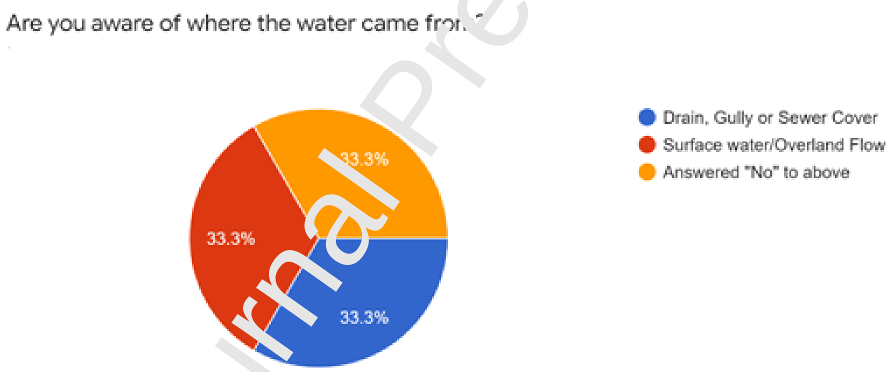

Figure 11 – Potential flooding source

4.2.7 Question 7

Figure 12 represents the responses to Question 7. By being able to grasp an understanding of how deep the floodwater may have been, it can somewhat coincide and correlate with the damage costs. Precisely 50% of residents asked estimated that the water depth exceeded 11cm (110mm). This does suggest that the damages of the previously specified flooding events could be high; however, when analysed with the results of Question 8 (Damage costs), it is understood that there was no correlation at all. This may be due to the accuracy of this question being deemed great, mainly due to it only being based on an "estimation" of water depth.

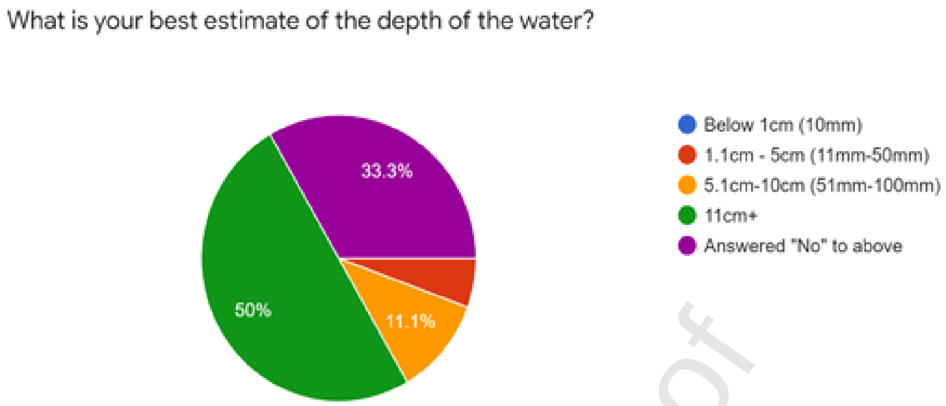

Figure 12 – Estimated water depth

4.2.8 Question 8

Figure 13 is a pie chart relating to the answers of Question 8. Firstly, through disregarding both responses, "No Damages Caused" and "Answered 'No' to above". It came as a surprise that a whole 55.6% of answers detailed that damage had occurred due to flooding at their property. This indicates the lack of flood defence necessity of installing a water reduction-based SuDS device. Most of the damage costs were relatively low and stood at lower than £5001; however, the alleviation of damage caused should have never occurred in the first place. Note that the higher damage cost-based answered correlated more extensively with residents who lived at Gibside View for a longer amount of time (Question 1). This correlation graph is demonstrated below in Figure 14. The Red Line on the displayed Correlation graph signifies the rough timestamp when the detention basin was installed. The graph suggests the success of the system as no damages have caused post implementation and only occur before.

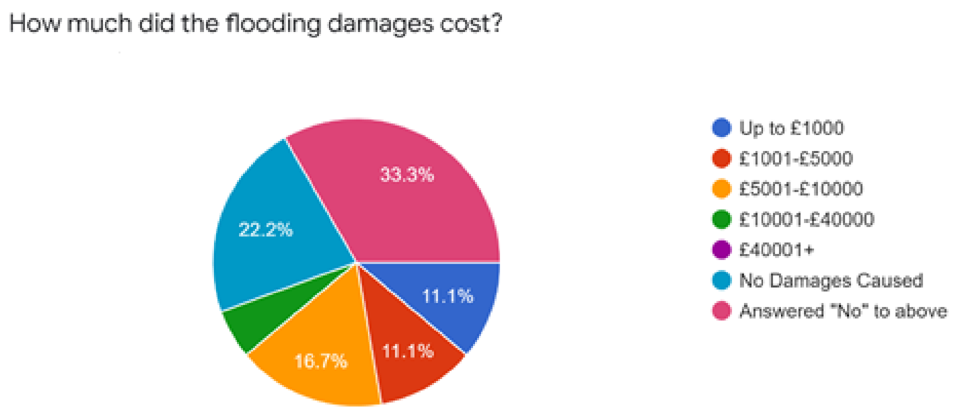

Figure 13 – Damage costs

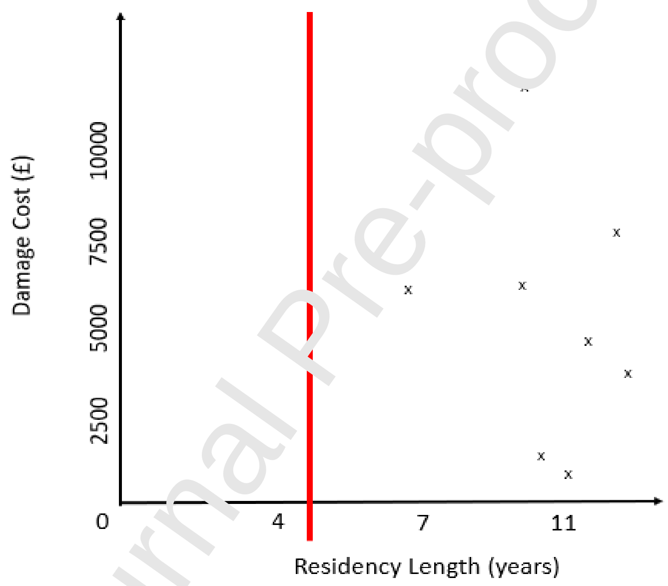

Figure 14 – Correlation Graph Contrasting Residency Length with Damage Costs

4.2.9 Question 10

As the aim and objectives do not outline whether participants are aware of what SuDS systems are, asking more SuDS based question was unwarranted. By utilising, a dichotomous question type, it was very quickly discovered that participants knew about the detention basin and drainage system that implemented into their neighbourhood to alleviate the flooding issues that once occurred in the area. As demonstrated in the pie chart Figure 15, the awareness was nearly 50:50. However, it was observed to the surprise that 55.6% of people knew what a SuDS system actually was.

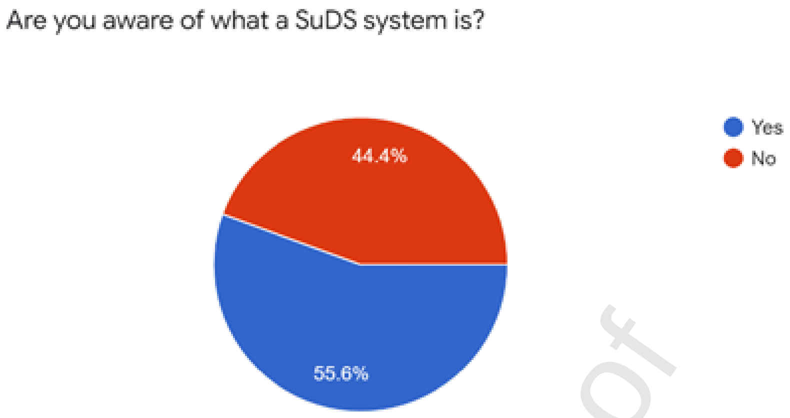

Figure 15 – SuDS system clarification

4.2.10 Question 9 and 11

To verify the effectiveness of the Detention Basin the questionnaire needed to detail some form of a scoring system before and after the installation of the SuDS device. The constant of 5 had to stay the same for both questions, so a difference could be gauged between the before and after standpoint on flooding at Gibside View. As shown in Figure 16 and Figure 17, initial impressions show that already fifty more participants answered (1) on the current flood rating scale in comparison to the before scale. In addition to this, twenty more participants answered (2) on the scale. These results blatantly suggest that the residents of Gibside completely recognise the alleviation of flooding in their area.

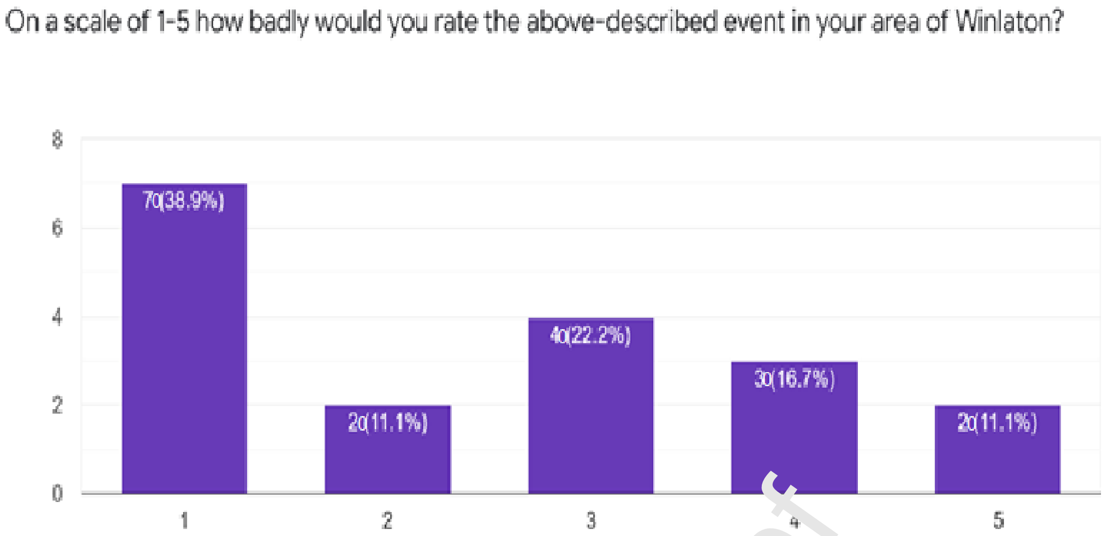

Figure 16 – Flooding ratings (before installation of Detention Basin)

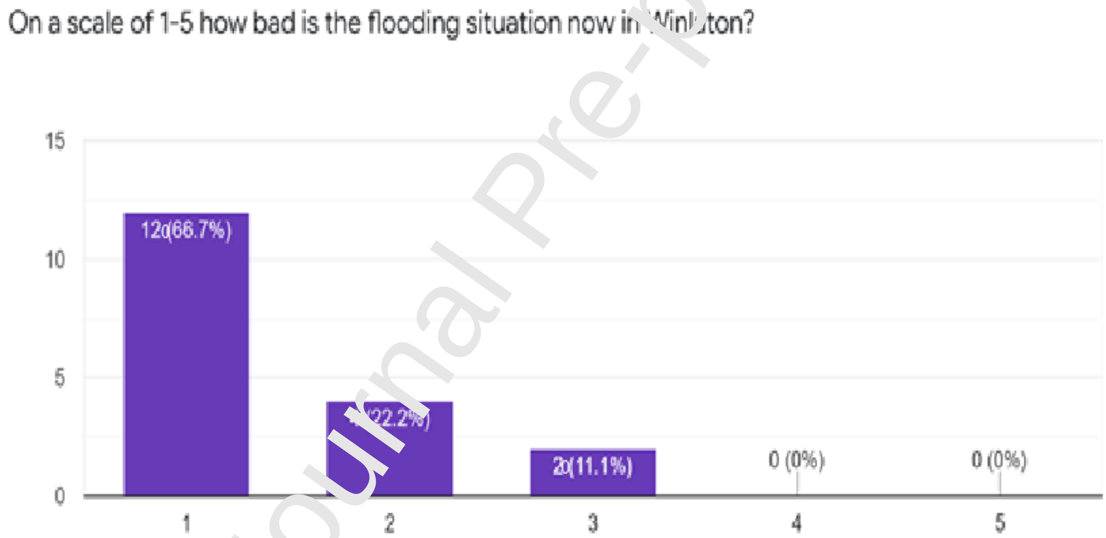

Figure 17 – Flooding ratings (after installation of Detention Basin)

This section has exhibited the findings and analysis of the data collection that was conducted. The findings proved certain predictions right, however mainly in the questionnaire, there was some surprising responses.

5.0 Conclusions, Recommendations and Further Research

Sustainable drainage systems are rapidly earning more importance due to the continuously improving success of such a system on the environment. This study performs a literature review on the philosophy behind SuDS and the reasoning behind why it is being implemented into so many UK developments. It presents the dissection of each element of a SuDS management train to discover the water quantity reduction capabilities of each device. Despite the eternal growth of the SuDS scheme, the inauguration and retrofit of sustainable drainage still remain a very complex task. Although there are many modelled methods and procedures available for SuDS that are quickly and effectively developing strongly, the system still seems to imitate the natural response of the device(s) both from water quality and quantity standpoints. There are still several underestimated cases where the SuDS installation process is challenging, as demonstrated through the Case Study completed at Gibside View, Winlaton in Gateshead. Various conventional pipe-based drainage in which already resided there had to be retrofitted, rejuvenated, and adjusted in both position & level. The collaboration between Northumbria Water and Gateshead Council ensured a thorough maintenance schedule was put in place to ensure the aesthetic appearance, Detention Basin and drainage system remains well preserved to assure efficiency and effectiveness in reducing the risk of flooding. As a way of verifying such effectiveness, a questionnaire was conducted within the site radius of the Detention Basin in the area of Winlaton. Results showed consistency of residents at Gibside View who once experienced damaged property issues related to flooding to then who apprehended a significant change in the alleviation of water quantity on days of excessive rainfall. As a result of this, it established that the Detention Basins is one SuDS system and design that resides successfully among many drainage systems throughout the United Kingdom.

As a recommendation and possibly the opportunity for further research, the potential of why stakeholders must perceive the general scope of sustainable drainage systems and how the urban water cycle could be used as an improved form of a planning & design framework could be explored. Furthermore, the process of urbanisation and climate change must also be consolidated imperatively into SuDS design to ensure the adaption to the perpetual changing circumstances. The future of sustainable drainage philosophy and design is most suitable for technical clarification on investigating the correct correlation within the investment cost and effective performance of the SuDS system. A design framework blending the social, economic, environmental, regulatory, and legislative aspects will be essential to accomplishing these intentions.

List of abbreviations

SuDS = Sustainable drainage systems

STTAT = Stormwater treatment train assessment tool

SEPA = Scottish environment protection agency

UK = United Kingdom

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Appendix A

Sustainable Drainage Systems Questionnaire

1. **How long have you resided at Gibside View?**

◯ 0-4 years

◯ 5-7 years

◯ 8-11 years

◯ 11+ years

2. **Is the property Residential or Commercial?**

◯ Residential

◯ Commercial

3. **If answered Residential to Question 2. What type of residential property?**

◯ Detached

◯ Semi-Detached

◯ Terrace

◯ Basement

◯ Other

4. **Have you ever experienced any flooding issues here at Gibside View?**

◯ Yes

◯ No

5. If answered Yes to Question 4, can you provide details of the flooding event(s)?

____

____

____

6. Are you aware of where the water came from?

◯ Drain, Gully or Sewer Cover

◯ Surface Water/Overland Flow (Rain)

◯ Other

7. What is your best estimate of the depth of the flooding?

◯ Below 1cm (10mm)

◯ 1.1cm-5cm (11mm-50mm)

◯ 5.1cm-10cm (51mm-100mm)

◯ 11cm+ (110mm+)

8. If answered Yes to Question 5, how much did the flooding damages cost?

◯ Up to £1000

◯ £1001 - £5000

◯ £5001 - £10000

◯ £10001 - £40000

◯ £40000+

9. On a scale of 1-5 how badly would you rate the above-described event in your area of Winlaton?

◯ 1

◯ 2

◯ 3

◯ 4

◯ 5

10. Are you aware of what a SuDS system is?

◯ Yes

◯ No

11. On a scale of 1-5 how bad is the flooding now?

◯ 1

◯ 2

◯ 3

◯ 4

◯ 5

Authors' contributions

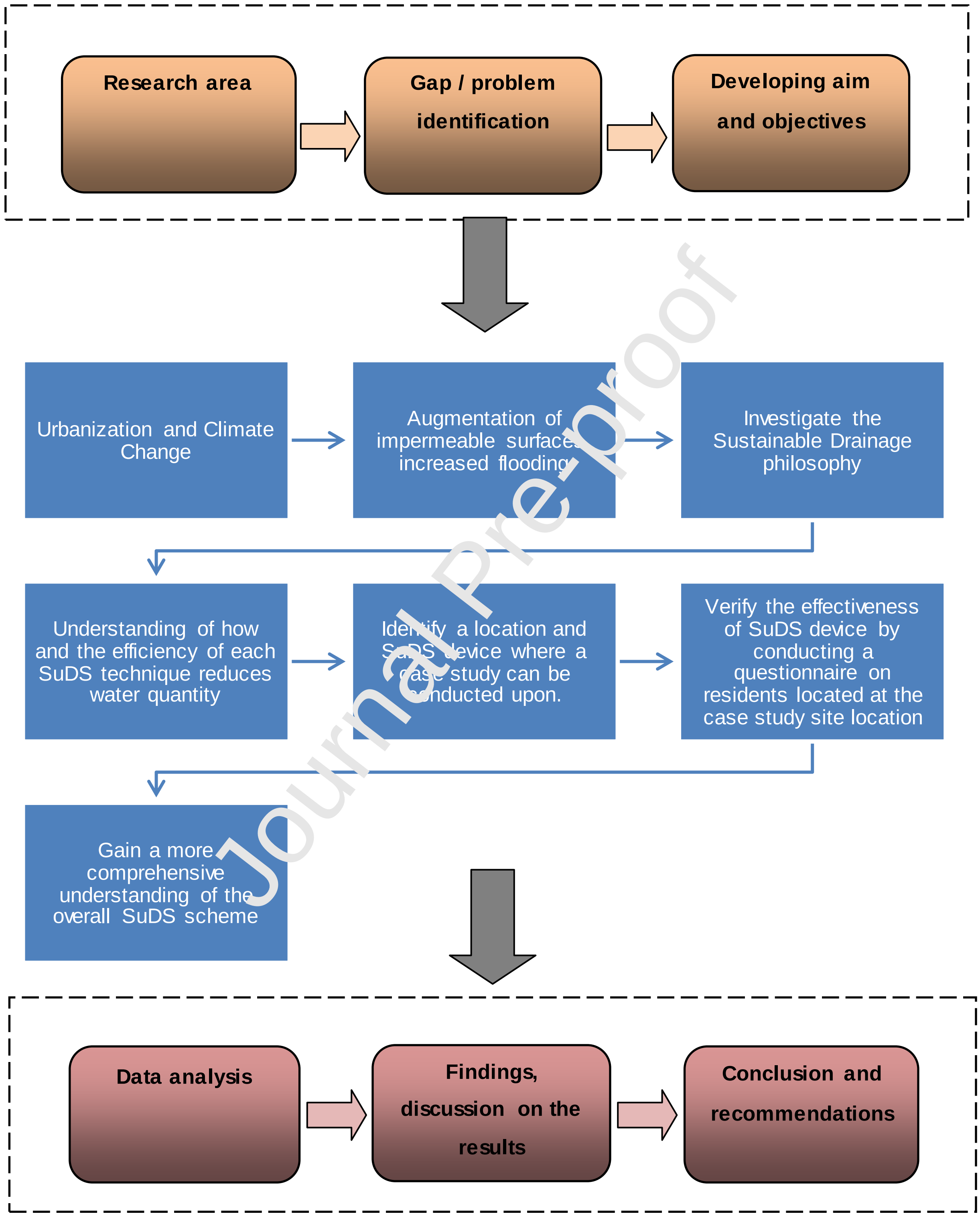
Rashid Maqbool: Supervision, Conceptualization, Methodology, Formal Analysis, Validation, Resources, Visualization, Project Administration, Writing—Review and Editing **Harry Wood:** Methodology, Data Curation, Software, Formal Analysis, Visualization, Project Administration, Writing—Original Draft

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Graphical abstract



Highlights

The paper makes some important contributions. It:

(1) investigates the reasoning that has pushed the implementation of SuDS

(2) dissects and discovers the water reduction capabilities of each SuDS management train

(3) discovers suitable devices with respect to water reduction

(4) understands why and how a particular SuDS device is implemented into site location

(5) verifies the effectiveness of a SuDS device that already resides somewhere in the UK.