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Green Lanes for stormwater management in Glasgow

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Title

Green Lanes for Stormwater Management in Glasgow

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Abstract The urban water management in Glasgow faces challenges due several reasons. The average annual rainfall of 1500 millimetres along with retro grey infrastructure contributes to the challenges. The proliferation of impermeable surfaces in urban areas worsens the problem of stormwater runoff. This paper examines the capacity of green lanes as nature-based strategies for achieving sustainable stormwater management in Glasgow. Green lanes, implemented through the use of soil and water bioengineering techniques, have a vital function in reducing flood hazards, preserving water resources, retaining soil nutrients, and purifying stormwater. The study is in line with broader initiatives such as the Urban Water Agenda and the European Green Deal, which highlight the importance of sustainable management of water in urban areas. Stakeholders and city councils in Scotland prioritize sustainable water management, biodiversity conservation, carbon emission reduction, and urban environment enhancement by implementing green lanes and other nature-based solutions. Although there is growing interest in green infrastructure, there is a significant gap between policy and implementation, especially in post-industrial cities such as Glasgow, where the drainage infrastructure has demonstrated weaknesses. This paper presents a three-tiered methodology for identifying flood-prone areas in Glasgow and simulating stormwater runoff to evaluate the efficacy of green lanes. The research seeks to offer theoretical perspectives and practical remedies for the environmental management and disaster resilience of urban areas.

Keywords Sustainable water management, Nature based solutions, Green Lanes, blue-green infrastructure, best management practices, Stormwater management, Low-impact development,

Originality statement. I hereby declare that this Master's dissertation is my own original work, does not contain other people's work without this being stated, cited and referenced, has not been submitted elsewhere in fulfilment of the requirements of this

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DEDICATION

God, whose wisdom and mercy have sustained me throughout this ordeal, has my undying gratitude for all of this journey. I attribute the insight and tenacity I needed to finish this work to Him because I have felt His presence through every difficulty and success. There were innumerable days when I wanted to just quit and give up. May this meager research paper serve as evidence of His Majesty's hand in my personal growth, his unwavering love radiating from the depths of my being. No foreign god was accompanying Derartu; She was led solely by the LORD.

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1. INTRODUCTION

1.1. Rationale

Scotland receives an average annual rainfall of approximately 1500 millimeters (Statista), leading to intense rainfalls that can overwhelm drainage systems and elevate stormwater runoff. The situation is worsened by the increase in impermeable surfaces in cities, which obstruct water penetration. Efficient stormwater management is essential and includes implementing best management practices (BMP) such as rain gardens and permeable pavement, and incorporating green stormwater infrastructure (GSI) like green roofs and bioswales. (Ashish, Taha, 2021)

Green lanes play a crucial role in nature-based solutions for managing water quality, particularly in supporting the natural water cycle and easing the pressure on the traditional grey infrastructure. . They aid in mitigating flood risks, efficiently conserving water, retaining nutrients in the soil, and purifying stormwater. Green lanes apply soil and water bioengineering, which involves creating synergies between human activities on landscapes and natural factors and processes. (EFIB)

This is in line with larger projects such as the Urban Water Agenda, the European Green Deal, and the New European Bauhaus, which seek to revolutionize the EU's economy through sustainable methods, especially in urban water management by promoting green infrastructure and environmentally friendly practices.

Stakeholders, governments, and city councils in Scotland are implementing nature-based solutions such as rain gardens, sustainable drainage systems (SuDs) like constructed wetlands, and retrofitting permeable spaces with permeable pavers to prioritize sustainable water management. Green lanes, with their vegetated pathways, provide various advantages for stormwater management, such as absorption, filtration, and pollutant prevention.

Green lanes offer advantages that extend beyond urban stormwater management. They help sustain urban environments by preserving biodiversity and lowering carbon emissions. They provide environmental, social, and policy solutions. Green lanes have a

positive effect on green infrastructure, encourage active mobility, and improve walkability and connectivity.
Although there is increasing interest in green infrastructure throughout Europe, there remains a discrepancy between policy goals promoting green infrastructure and the actual implementation on the ground, leading to challenges in realizing sustainable urban water management practices. In Glasgow in particular, as a post-industrial city, the drainage infrastructure has shown a notable lack since heavy rainfall in 2002.

Studying the effectiveness of green lanes in managing stormwater in Glasgow offers a timely chance to enhance both theoretical understanding and practical solutions in environmental management and disaster resilience.

This paper uses three different layers of data to identify flood-prone areas in Glasgow and study the impact of green lanes. A generated model of stormwater runoff will simulate the runoff coefficient, followed by design guidelines for possible green lane applications.

1.2. Background

Currently, the management of water in urban areas, specifically the management of stormwater, is a significant and pressing challenge. In urban areas, a large portion of the ground surface is impermeable, leading to significant changes in the water cycle and the overall quality of urban life. Urban environments differ from natural ecosystems by displaying increased surface runoff, decreased groundwater replenishment, and lower rates of evaporation. Adverse events such as heavy rainfall, sudden downpours, or unexpected natural events frequently cause sewer overflows and deficiencies in drainage systems. Urban areas disrupt the natural cyclical pattern of water, which includes precipitation, infiltration, surface runoff, and evaporation, thereby impeding its normal progression.

The importance of urban stormwater management (USM) has become increasingly apparent, especially in terms of its ability to regulate stormwater flow, enhance water quality, and enhance the visual attractiveness of urban landscapes. The acknowledgment of this phenomenon is amplified as urban areas confront the worldwide difficulties presented by climate change and increasing threats of inundation. The high relevance is attributed to the escalating extremes resulting from climate change and the wide expanse of vulnerable coastlines. Green-lanes as a nature-based solutions, are one element of USM that could be maximized.

An in-depth analysis of relevant factors is necessary to investigate the local and regional factors that influence stormwater flow patterns and determine the appropriateness of the sustainable urban drainage system. Urban drainage and hydrological dynamics are the main factors that significantly affect the movement and spread of stormwater in urban areas. Furthermore, the structure and characteristics of soil types in a specific area significantly impact the processes of water infiltration, retention, and conveyance. Furthermore, climatic factors, including patterns of rainfall and temperature changes, have a significant impact on the occurrence and strength of storm events, which in turn influence the movement of stormwater. Through a comprehensive analysis of these factors, urban planners and hydrologists can obtain a more profound understanding of the feasibility and effectiveness of incorporating SUDS methodologies for stormwater management in urban and regional areas.

1.3. Aim and Objectives

1.3.1. Aim

The purpose of this research is to examine the efficacy and viability of incorporating green lanes into stormwater management strategies. The objective of this study is to evaluate the effectiveness of green lanes in managing stormwater runoff, minimizing flood hazards, and enhancing water quality. Its goal is to offer evidence-based recommendations that can improve resilience, sustainability, and safety in terms of stormwater management.

1.3.2. Objectives

I. Identify the stormwater runoff-prone areas with fewer mitigation plans.
II. Performance assessment of Selected sites (using Storm water management model SWMM)
III. Proposing SUDS designs and guidelines for the identified areas

1.4. Scope

The study focuses on the City of Glasgow. The application of Green Lanes is being examined in three distinct areas within Glasgow.

1.5. Research gap

In the field of stormwater management, it is crucial to comprehend the present effectiveness of the existing systems in order to suggest enhancements or evaluate the current situation. Although the significance of evaluating green infrastructure, particularly Green Lanes, in Glasgow, is acknowledged, there is still a notable deficiency in the capacity to assess their efficiency and sustainability. The challenge stems from the absence of quantifiable data required to assess the effects of blue-green infrastructures. This research aims to fill this gap by creating techniques to evaluate and control stormwater using Green Lanes. The purpose is to improve the comprehension and implementation of different nature-based solutions for managing stormwater.

2. LITERATURE REVIEW

2.1. Important Terms,

Sustainable water management (SWM), Nature-Based solutions (NBS), green lanes, Blue-green infrastructure (BGI), Best Management Practices (BMP), Green stormwater infrastructure (GSI), Urban stormwater management (USM), Stormwater management model (SWMM), Combined sewer overflow (CSO), Low Impact development (LID), Water Sensitive Urban Design (WSUD), Sustainable (Urban) Drainage Systems (SUDS), **SIMD, SEPA, SIMD (Scottish index of multiple deprivation) SuDS (Sudden discharge systems), WSUD (water sensitive urban drainage system), EFIB (European federation of soil and water Bioengineering)**

2.1.1. Urban water management trends

The traditional urban stormwater management or grey infrastructure approaches involve making changes or additions to conventional sewerage networks. This encompasses the creation of interceptor tunnels specifically engineered to intercept combined sewer overflow (CSO) discharges, thus averting the direct release of polluted water into the surrounding ecosystem. (Dolowitz et al., 2017) This system is mostly based on constructing more drainage lines and enlarging the capacity of the conventional line.

The impacts of traditional grey infrastructure are diverse, including the introduction of different pollutants such as nitrogen, phosphorus, suspended solids, pathogens, and heavy metals into water bodies. (De La Crétaz & Barten, 2007)

These contaminants greatly diminish the quality of water and present dangers to aquatic ecosystems. Furthermore, the appearance of waterways is frequently compromised by the existence of grey infrastructure. In addition, the presence of grey infrastructure can cause thermal pollution, which can lead to changes in biodiversity in aquatic environments. Moreover, the effectiveness of conventional grey infrastructure for stormwater management is anticipated to face growing challenges due to the effects of climate change and the rise in severe weather events.

Dolowitz argues Various policies and techniques for managing stormwater at its source are commonly referred to as Best Management Practices (BMPs), Low Impact Development (LID) practices, Water Sensitive Urban Design (WSUD), Sustainable (Urban) Drainage Systems (SUDS), and Green Infrastructure.

Contrary to the traditional methods green infrastructure is often depicted as a progressive and environmentally sustainable option, while grey infrastructure represents a persistent continuation of conventional sewerage design and management practices.

Brown et. Al (2008) explains it as an increment and update from water supply city which is more concerned about access and security to the future water sensitive self-sufficient plan.

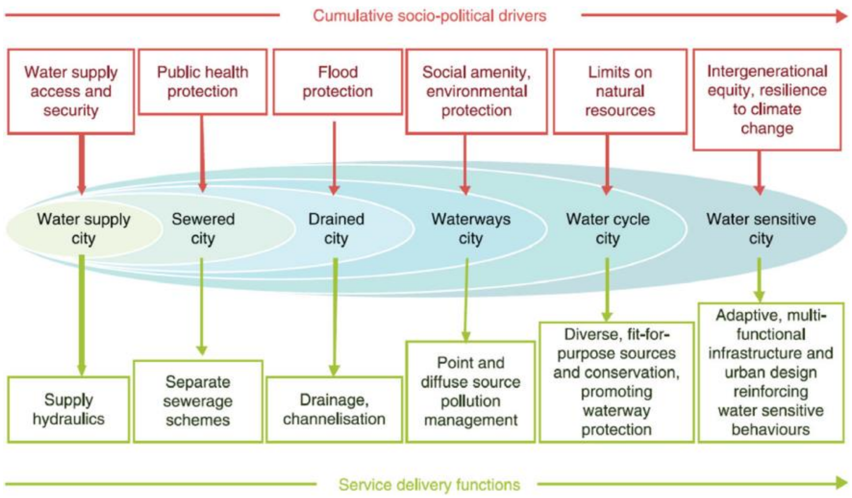


Figure 1Water management trends over time Browm et al. (2008)

Green infrastructure strategies focus on implementing techniques that aim to reduce the impact of surface water by using source control methods. These methods involve using environmentally friendly practices. The main goal is to prevent or reduce the amount of runoff that goes into municipal sewer systems. (Dolowitz et al., 2017) That gives an implication of a progressive and environmentally sustainable option.

Blue-green infrastructure provides numerous advantages, one of which is its capacity to postpone or substitute expensive grey infrastructure. Blue-green infrastructure, in contrast to traditional grey infrastructure, typically involves lower initial investment and ongoing maintenance costs. Therefore, municipalities can attain substantial financial savings by choosing blue-green solutions. Additionally, the adoption of blue-green infrastructure can result in decreased water treatment expenditures and reduced costs for maintaining the landscape, thereby enhancing financial savings.

Aside from its cost-effectiveness, blue-green infrastructure offers a variety of environmental benefits. Blue-green solutions support sustainable water management practices by improving groundwater resources and reducing the need for water imports and the associated energy costs. In addition, they provide ecosystem service values such as enhanced flood risk management and decreased stormwater runoff volumes, thus alleviating the effects of urbanisation on waterways and surrounding landscapes.

Moreover, blue-green infrastructure is essential in mitigating stormwater pollution by decreasing instances of sewer overflow and improving the quality of waterways. These measures enhance water conservation and promote the replenishment of groundwater, while simultaneously fostering improved air quality and reducing greenhouse gas emissions. In addition, blue-green infrastructure mitigates the impacts of urban heat islands and provides habitats for a wide range of plant and animal species, thus fostering biodiversity and carbon storage.

In addition to the environmental benefits, blue-green infrastructure provides substantial social advantages. It has a beneficial effect on public health by enhancing life expectancy, diminishing health disparities, and promoting physical activity and mental well-being. Furthermore, it promotes social engagement, inclusivity, and unity, resulting in more secure communities and improved public safety. Integrating blue-green features in urban environments not only improves the aesthetic appeal but also enhances climate resilience, leading to an overall improvement in the quality of life and well-being of the community.

Furthermore, blue-green infrastructure not only promotes food production and offers recreational opportunities, but also improves the overall water quality, thereby reinforcing its significance in establishing sustainable and resilient urban landscapes.

2.1.2. Blue-Green Infrastructure (BGI)

A carefully designed system that includes natural and semi-natural areas, as well as other environmental features, that are planned and maintained to provide a wide range of ecosystem services. (Brears, 2018)

Green streets are a crucial part of green infrastructures, which are a connected network of green areas that can preserve and provide important functions of natural ecosystems, along with their associated benefits. (Benedict and McMahon, 2012).

2.1.3. Types of blue-green infrastructures

Different forms of Blue-Green Infrastructure (BGI) function as efficient mechanisms for sustainable stormwater management. One example of this type is vegetated and bioretention swales, which are constructed channels containing vegetation that promote the filtration and absorption of stormwater runoff. Riparian buffers, restored waterways, and constructed wetlands are examples of Best Management Practices (BGI) that enhance water quality and restore habitats. Constructed wetlands serve as natural filtration systems, efficiently eliminating pollutants from stormwater prior to its entry into water bodies.

Green streets are a type of BGI that involves designing roadways to include natural features like bioswales and permeable pavements. These features help to manage stormwater directly on the site. Green street designs often incorporate specific features such as buffer vegetation and lawns, stormwater planters, bump-outs, and tree trenches. These components function together to collect and penetrate stormwater, decreasing the amount of runoff and relieving stress on traditional drainage systems.

Pervious pavement and repaving initiatives are additional Best Management Practices (BGI) strategies that have the goal of reducing impervious surfaces and encouraging natural infiltration. Porous pavements, composed of pervious materials, facilitate the infiltration of rainwater into the ground, thereby replenishing underground water sources and reducing the impact of flooding. Depaving initiatives entail the removal of current pavement to restore surfaces that allow water to pass through, thereby improving the land's ability to absorb and purify stormwater.

Every variant of BGI provides distinct advantages and uses, which contribute to the development of urban environments that are more resistant and environmentally friendly. Municipalities can achieve effective stormwater management and improve ecological integrity and community well-being by implementing a combination of these strategies.

Green streets are a crucial part of green infrastructures, which are a connected network of green areas that can preserve and provide important functions of natural ecosystems, along with their associated benefits. (Benedict and McMahon, 2012).

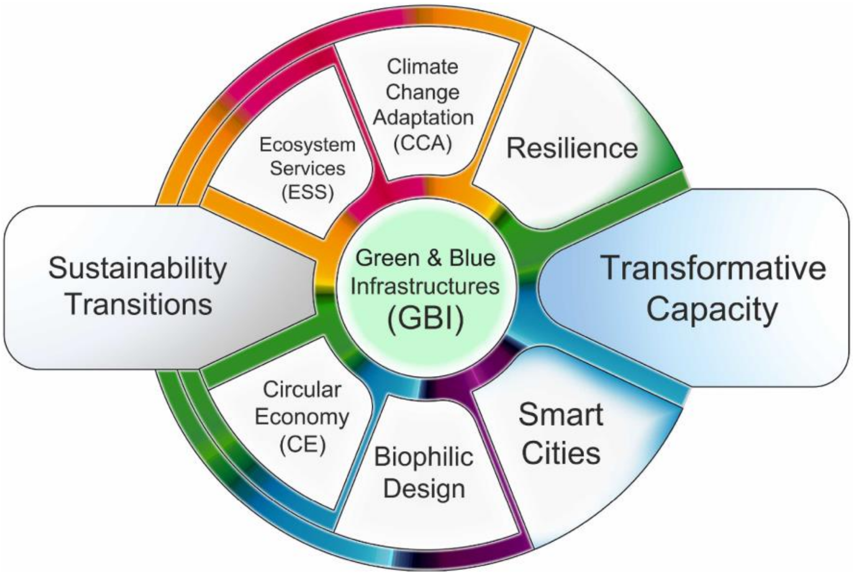


Figure 2 Green and blue Infrastructure GBI transitional ideas (Puppim de Oliveira et al., 2022)

Green and Blue Infrastructure (GBIs) and related transitional ideas play important roles in creating environments that can change for the better in cities. (Puppim de Oliveira et al., 2022)

In terms of measuring the benefits, Blue-Green Infrastructure (BGI) solutions may require a longer period of time for establishment in comparison to traditional grey solutions. Furthermore, it is recognised that it may require a significant amount of time for BGI solutions to fully achieve the wide range of advantages they are intended to provide. (Brears, 2018)

Urban Green Space (UGS) has been broadly treated as a valuable and limited resource to handle the challenges brought by high-density urban environment. Green stormwater management has been prompted around the world. To reduce the potential conflicts between stormwater management and other requirements on UGS (especially human needs), the research community and governments encourage the urban planners and designers to integrate stormwater analysis into UGS design. However, the professional term and operation of the traditional hydrological model is a huge challenge to the designers who haven't touched hydrological knowledge. This study developed a method to simulate and quantify stormwater in UGS by the particle system in the design platform- Rhinoceros +Grasshopper. (Jia et al., 2022)

This approach employed five distinct urban object categories, such as terrain and building footprint, to streamline processes and enhance efficiency. To address the issue of abstracted particle movement not accurately reflecting land cover infiltration, the researchers employed particle location categorization and the UGS retaining stormwater hypothesis. The feasibility of the integrated model was determined by testing its iteration times, rainfall depth (selected rainfall event), and particle radius. The comparison tests indicate that insufficient iteration times can result in particles halting before reaching the bottom of the terrain. Therefore, a minimum of 4000 iteration times is set for the simulation. Additionally, the sensitivity to rainfall events and particle size is minimal, with simulation results varying by only 1%. Furthermore, inadequate particle numbers can impact the accuracy of the analysis, necessitating a balance between accuracy and work efficiency. Lastly, the volume of stormwater is also a factor to consider. The experiments demonstrate that the method is capable of supporting the initial design of underground gas storage (UGS) facilities. (Jia et al., 2022)

2.2. Green Lanes

A built system consisting of permeable surfaces, soil, and plants, designed to directly reduce and treat stormwater runoff at its source. (Tompson and Sorvig, 2007)

2.3. Efficiency

In stormwater management refers to a system or strategy's capacity to handle stormwater runoff effectively and optimally, while reducing adverse effects on the environment, infrastructure, and communities. It could be influenced by the ability to capture, treat, and safely transport runoff, the implementation of sustainable and cost-effective methods, and the capacity to adjust to evolving climatic conditions and land use patterns.

2.4. Viability

Refers to the feasibility, practicality, and effectiveness of implementing a specific approach, technology, or strategy to tackle stormwater-related issues

2.5. Stormwater

A rainwater that has fallen onto roads or roofs and often contains chemicals or pollutants. (Greene, 1999)

2.6. Glasgow City

As a pre-industrial city has gone through different urban fabrics and population dynamics. In highly populated urban areas, the rise in intense local rainfall events results in the overwhelming of sewage systems and subsequent flooding like storm Isha in late January of 2024.

The primary factor driving the increased use of Sustainable Drainage Systems (SuDS) in Glasgow is the notable lack of capacity within the drainage infrastructure, which was highlighted by a storm event and subsequent localized flooding in the eastern area of the city on July 30, 2002. As a result of this event, a working group was formed to create the Glasgow Strategic Drainage Plan (GSDP). (Macdonald & Jones, 2006)

The plan acknowledged that Sustainable Drainage Systems (SuDS) was a crucial strategic solution for dealing with capacity limitations. Implementing Sustainable Drainage Systems (SuDS) in pre-existing urban areas presents more significant obstacles in comparison to undeveloped land, but it has been given higher importance in urban revitalization initiatives based on the suggestions of the Rogers Report. (Fenner, 1999)

In terms of guide lines and regulations Scottish water has a collective guideline that is Sewers for Scotland 4.0 and SUDS for roads. Presently Glasgow uses a combined sewer system for stormwater management and green infrastructure is an element of Glasgow's storm water plan.

In research conducted by (Macdonald & Jones, 2006) Representatives from the main institutions involved in the GSDP working group were interviewed. Although there were differences in institutional agendas, a notable degree of consensus emerged. The implementation of conventional drainage methods, such as the installation of additional main sewer lines and the investigation of cross-catchment transfer alternatives to relieve pressure on susceptible parts of the drainage system, was acknowledged. One of the interviewees emphasised that Sustainable Drainage Systems (SuDS) are an important strategy for reducing peak flows in the city's drainage infrastructure.

“. . . I mean call me a fool, but I've noticed that if it doesn't rain then everything

works fine, so therefore it follows that it's the *rain* that's the problem”

(Iain McNab, Glasgow City Council, 4 August 2005).

Even though there are promising indications for wide acceptance of SUDS in Glasgow,

There also are parallel constructions going on to support the current drainage system. The 4.8-kilometer (3.1-mile) Shieldhall Tunnel, which runs from Craigton to Queen's, shows how committed Scottish Water is to improving water quality and reducing flooding in terms of improving the existing grey infrastructure.

3. MATERIALS AND METHODS

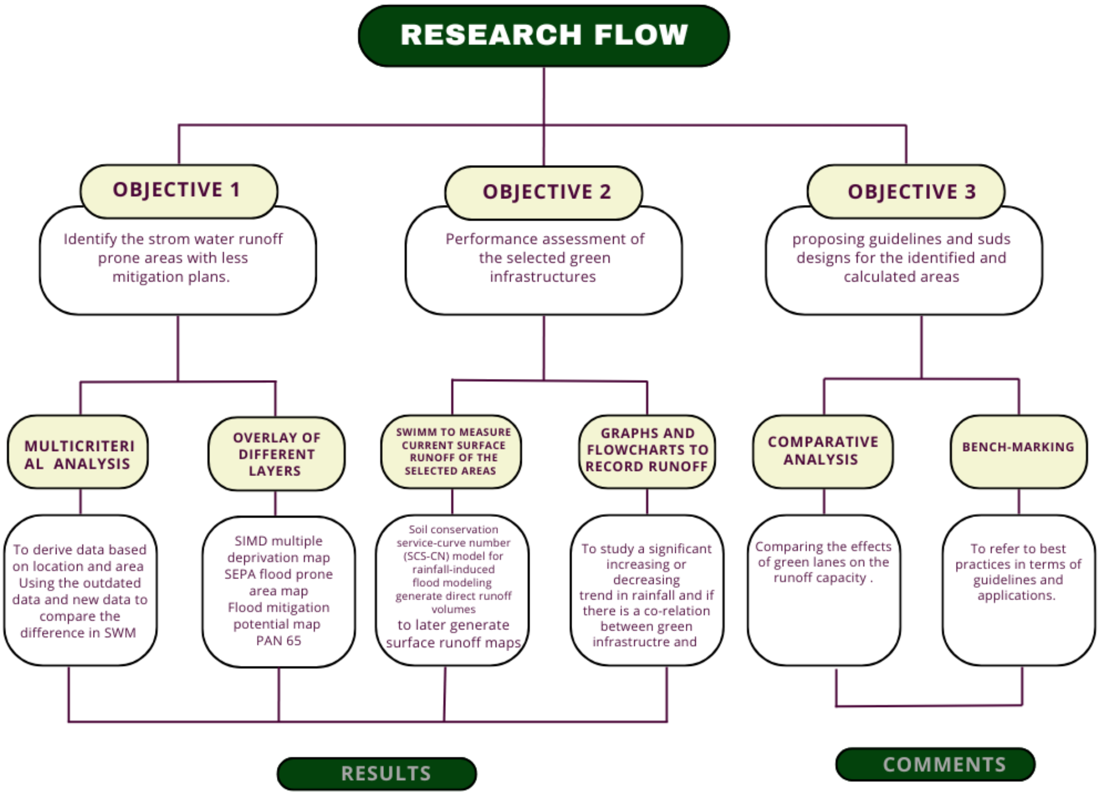


Figure 3 Research flow

This paper employed various methodologies to accomplish the three objectives of the research process. Three layers of data were employed to identify locations that are susceptible to stormwater and flooding. The primary means of accomplishing the initial goal is through the utilization of spatial data. To accomplish the second goal, the Environmental Protection Agency utilized SWIMM, a stormwater modelling software. The third objective design proposal and guidelines were developed using a combination of literature review and illustrating software.

3.1 Methodology

Overall spatial and figurative analysis is applied throughout this research. Multiple software uses facilitated the analysis Supplemented with literature studies and benchmarking. The last part also includes design guidelines.

3.2 Site selection

This paper took into account deprivation, which encompasses factors such as income and access to resources when determining the site selection. The study aimed to examine environmental equity for individuals who are susceptible to harm. The second layer pertains to the underlying cause of flooding, which is crucial for comprehending the issue and formulating an effective management strategy. The third layer involves assessing the potential for mitigating flooding and determining the necessary level of preparedness for such events. The greater the vulnerability of an area in these three categories, the more likely it requires a more immediate management plan.

3.2.1. Multicriterial analysis

To select highly flood-prone areas to identify and quantify the effects of green lanes, and propose prototypes, multicriterial analysis has been synthesized. SIMD has identified deprived areas in multiple deprivation maps and this research has used the 20% deprived (most deprived of the category) to overlay along with two other layers. The Scottish Index of Multiple Deprivation is a comparative indicator of the level of deprivation in 6,976 small areas known as data zones. If an area is classified as 'deprived', it can indicate that the residents have a low income and limited access to resources or opportunities. The SIMD examines the level of deprivation in a region across seven domains: income, employment, education, health, access to services, crime, and housing. (SIMD)

The second criterion is flood-prone areas identified by SEPA categorizes this in three main domains; surface water, coastal flooding and river caused flood prone areas. The Third criterion is, a flood mitigation plan determining factors of flooding and likelihood.

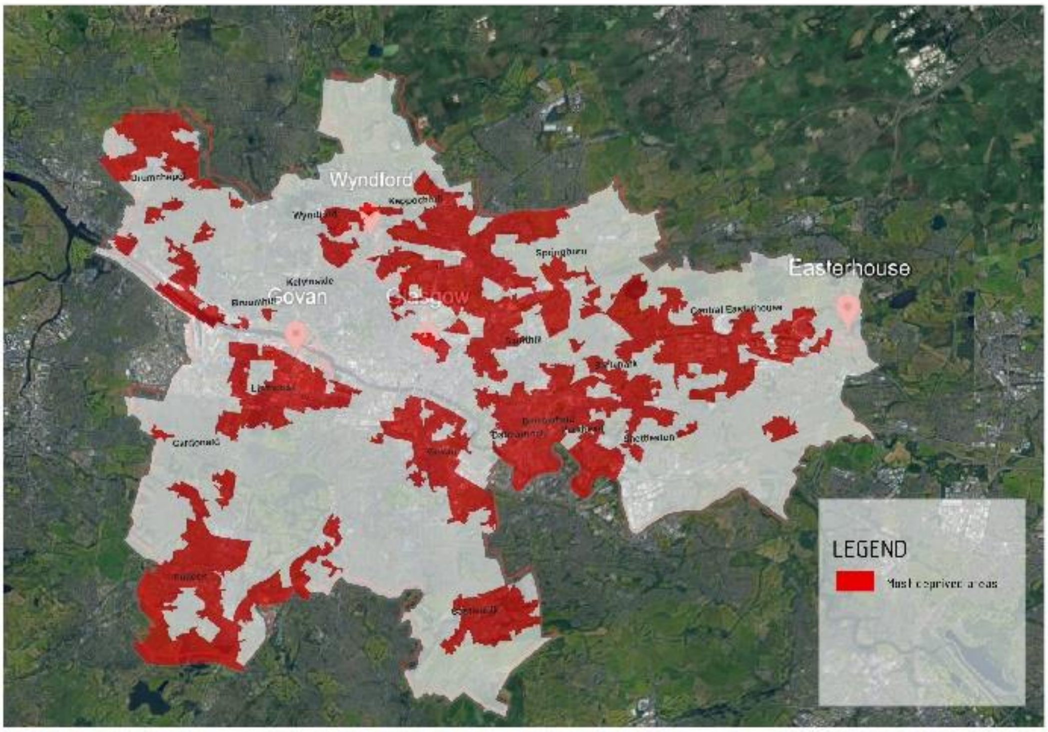


Figure 4 SIMD Most deprived on multiple deprivation maps of 20%

Source: Majekodunmi et al. (2020) Scottish Govt., 2020.

This Map identifies 20 % most deprived areas in Glasgow. According to SIMD, it's the most deprived area in Glasgow city.

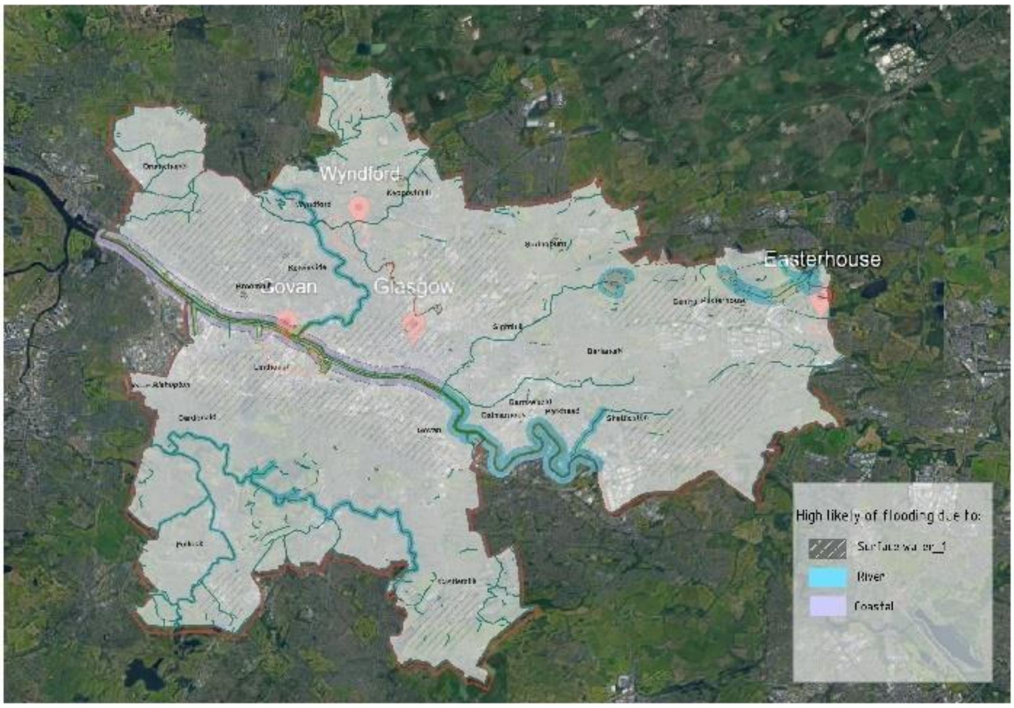


Figure 5 SEPA Map of causes of flooding

Source: Redrawn from Majekodunmi et al. (2020) SEPA data available at (http://map.sepa.org.uk/floodmap/map.htm).

In this map, three different causes of flooding are identified and sites with more than one cause are selected for this research.

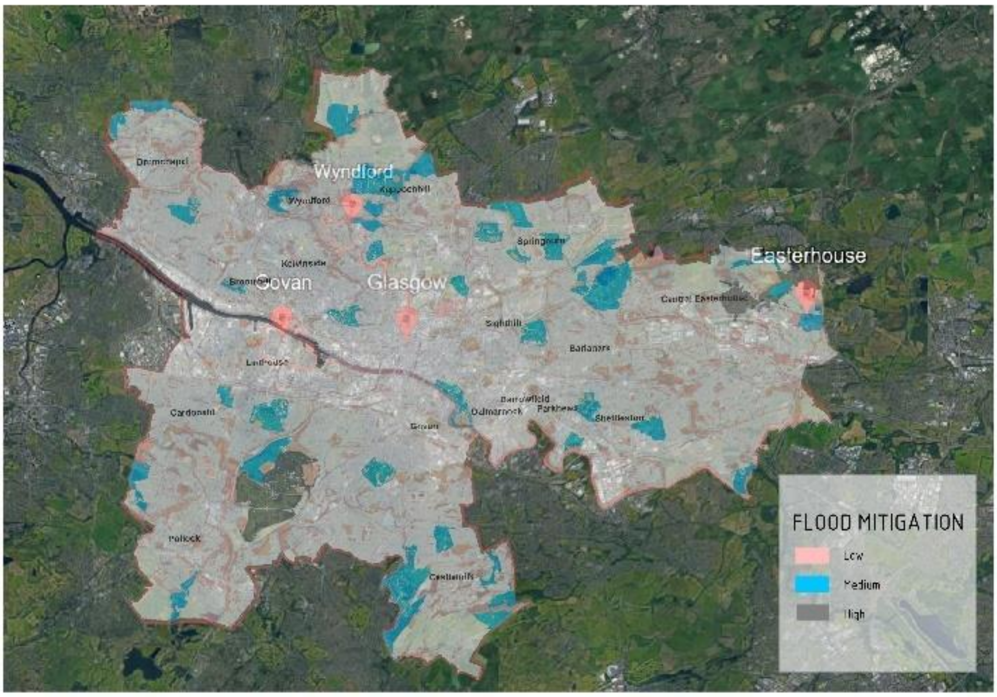


Figure 6 Flood Mitigation potential for the most deprived areas of Glasgow City.

Source: Redrawn from Majekodunmi et al. (2020)

The sites chosen based on this map are those with low flood mitigation plans, as it is these areas at risk that require mitigation.

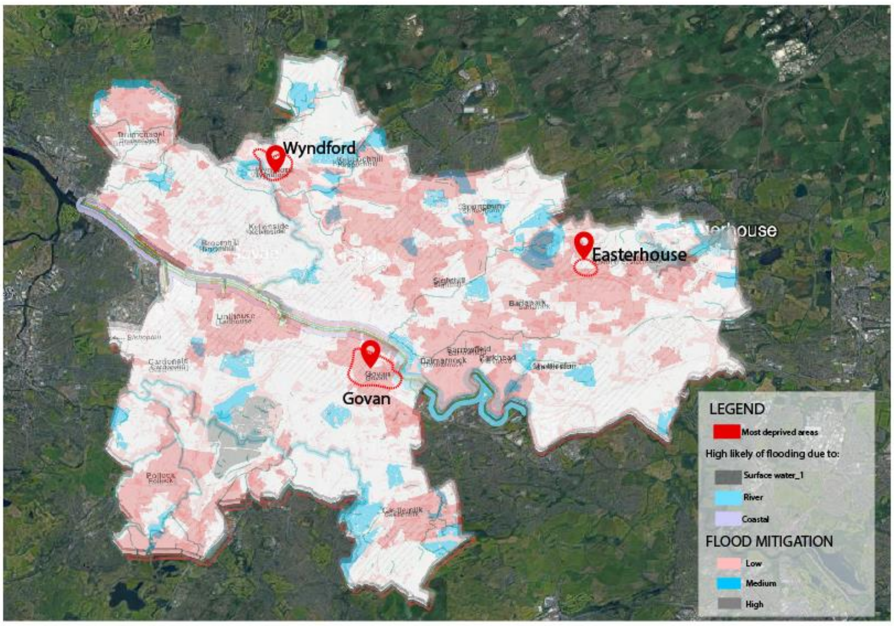
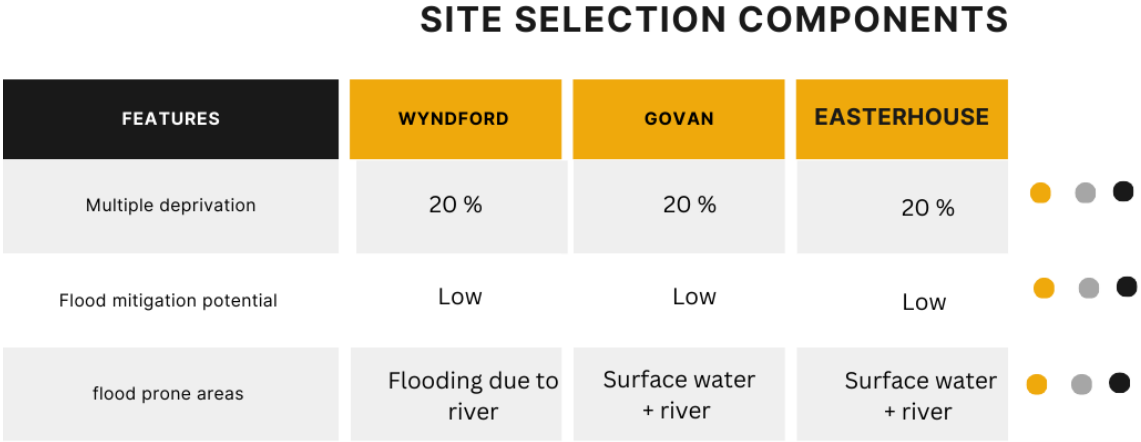


Figure 7Overlay of the three layers to identify appropriate site

Source: Redrawn from Majekodunmi et al. (2020)



SITE SELECTION COMPONENTS

FEATURES	WYNDFORD	GOVAN	EASTERHOUSE	
Multiple deprivation	20 %	20 %	20 %	● ● ●
Flood mitigation potential	Low	Low	Low	● ● ●
flood prone areas	Flooding due to river	Surface water + river	Surface water + river	● ● ●

Figure 8 site selection components

Upon evaluating the three criteria, it was determined that the overlapping locations exhibited potential areas for intervention. Among these options, the three chosen ones exhibit varying levels of risk, distinct urban configurations, diverse run-off and drainage conditions, and varying opportunities for implementing Green Lane components. Each set of questions pertains to a distinct aspect of flood risk management. Wyndford is a vintage residential neighborhood located close to the city centre. The buildings were constructed in the 1960s and their grey infrastructure has deteriorated. The allocation of space is crucial when designing an environmentally friendly pathway for the region. Govan is a waterfront region characterized by limited social welfare support. The area is facing a significant challenge of imperviousness, compounded by the presence of a crucial existing infrastructure line. Easter House is facing groundwater issues, however, there is no need to worry about space constraints when it comes to planning for mitigation, as there is plenty of available space in the area.

3.2.2. Flow calculation

The SWMM software is used in this paper to calculate the stormwater runoff.

For this study, the SWMM model was ideally constructed based on the following assumptions. Using the areal map, sub-catchments were considered to calculate the stormwater runoff.

Assumptions given to calculate this scenario are,

1. Different sub-catchments that cover blocks in the area,
2. Junction nodes linked to catchment outfalls and rain gauge.
3. A rain gauge connected to all the catchments
4. Different percentages of imperviousness,
5. At the junctions, inverted elevations of different meters were assumed to get to the calculation acquired.
6. For the outlet, links were created between catchments that lead to junctions.
7. The links are conduits with a circular shape pipeline and the maximum depth for the conduit is 1.5 meters.

This study only needed the flow rate and intensity to be set on the settings for the rain gauge. The rain format was set on volume and the calculation is done with a time interval of 1 hr, snow catch factor 1.0, and data source time series. Within a return period of a 4-hr rainfall event with an interval of hourly rain data was given every four hrs. see Appendix A

3.3. Sponge equivalent

The term "sponge equivalent" is used to describe a measurement used in different green stormwater infrastructure systems. It compares the effectiveness of a specific number of facilities in controlling factors such as runoff volume, peak runoff, and runoff pollution. Ou et al. (2023) This paper has referred to the sponge equivalent technique to quantify results.

For the betterment of the simulated runoff coefficient of the simulated sites, we can relate it to volume control mechanisms. According to Ou et al. (2023), conversion relationships between typical infiltration techniques can be utilized the following table explains the relationships.

Individual Facility	**Typical Structure**	**Area Required per Unit Volume of Runoff (m2/m3)**	**Runoff Volume Control per Unit Area (m3/m2)**	**Runoff Volume Control Equivalent**
Sunken green space	Water retention layer: 200 mm Planting soil: 250 mm Native soil	3.64	0.28	0.44
Bioretention	Water retention layer:200 mm Bark mulch layer: 50 mm Fill layer: 600 mm Permeable geotextile/sand layer: 100 mm	1.61	0.62	0.62

	Gravel layer: 300 mm Permeable geotextile			
Percolation pond	Sedimentation tank and forebay Slope ratio 1:3, water depth: 0.6 m Top layer of planting soil: 250 mm Filtration medium layer: 400 mm Drainage time: 24 h	1.67	0.60	0.97
Percolation well	Well diameter: 1.5 m Well depth: 3 m Drainage pipe diameter: 0.15 m Drainage pipe length: 3 m Gravel porosity: 35% Gravel thickness: 0.5 m	0.33	3.00	4.84

Table 1 Sponge equivalent coefficient

Source Ou. et.al (2023)

Conversion relationships for equivalent runoff volume control are provided for four storage techniques and bioretention facilities.

By utilizing these conversion metrics, it is possible to estimate the potential improvement that can be achieved through the implementation of green lanes.

. The precise numerical values and formulas may vary due to factors such as fluctuations in rainfall intensity, climate change, and changes in the quality and quantity of surface runoff. The presence of these variations poses a challenge in formulating a formula that can be universally applied.

4. ANALYSIS AND RESULTS

4.1. Area description

Based on the results of the multicriterial analysis the three areas selected are closely similar in terms of runoff vulnerability.

Easterhouse is a residential sub-urb located in the east end of the city. Has elements and services for a suburb including shopping centres. Another top ranker in the Scottish multiple deprivation model of the 20% most deprived. Flood mitigation plan identifies it as a low mitigation. The cause for flooding and surface water runoff is surface water and its proximity to river Clyde and river Kelvin. On the SEPA map this area has a 10% probability of flooding.

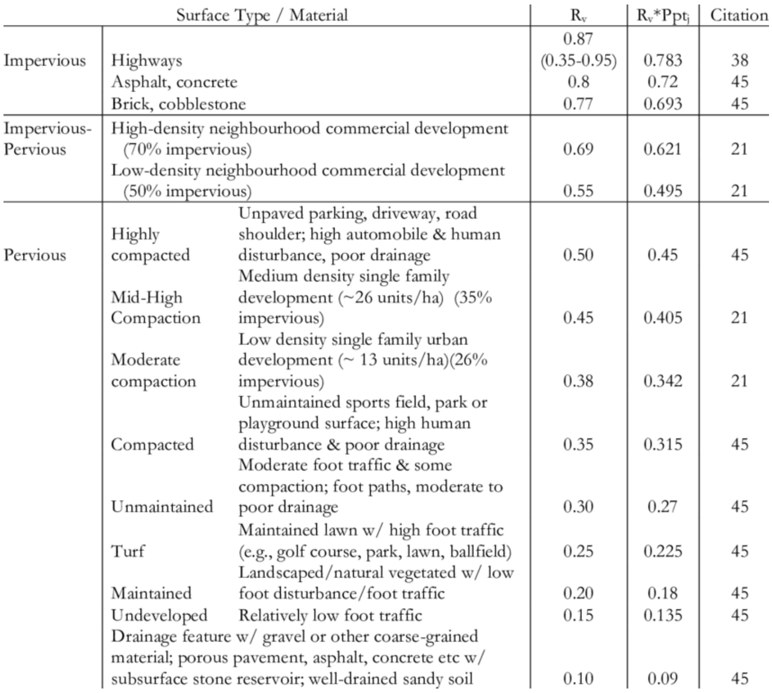
Govan is a riverside district primarily consisting of residential areas, along with a combination of shopping centres, warehouses, and transportation stations. According to the Scottish index of multiple deprivation model, it is ranked first in the category of 20% deprivation. Govan has been categorised as having a low level of flood mitigation plans. Furthermore, the reason for the occurrence of flooding and surface water in the area can be attributed to its close proximity to the river Clyde and the presence of ground water. SIPA reports that the area has a 10% annual probability of flooding in all three categories: river flooding, coastal flooding, and surface water flooding. All three categories have the highest probability of occurring.
The simulation was applied at a shopping centre located adjacent to a bus and subway stations. The area is completely covered with asphalt and a 70% imperviousness factor is used to calculate the overall drainage simulation.

Wyndford is a residential area with a retro council house of 1960s and 1970s. In about two miles proximity to the city centre, the Scottish index of multiple deprivation model identifies it among the 20% most deprived. Flood mitigation plan located the area among the low zone. Cause for flooding and surface water runoff is caused by the areas proximity to river Kelvin and ground water levels. According to SEPA this area has a 10% probability of flooding each year.

4.2. Comparison of results

Comparisons of results is based on attributes taken to simulate the model. The table below shows the imperviousness of different surface materials. Yang, Wenyu et al l's runoff coefficient table is referred to for simulation environment assumption. To show the differences in surface water runoff and flow routing. Using the table below the software SWMM modelled a runoff simulation with different imperviousness rates.

The common motivating element to assess advantages of green lanes in stormwater management is if its possible to quantify the viability and efficiency of the application in improving the natural water cycle. The assumption in this case is to showcase the positive impacts if possible.



Surface Type / Material			R_v	R_v*Ppt_j	Citation
Impervious	Highways		0.87 (0.35-0.95)	0.783	38
	Asphalt, concrete		0.8	0.72	45
	Brick, cobblestone		0.77	0.693	45
Impervious-Pervious	High-density neighbourhood commercial development (70% impervious)		0.69	0.621	21
	Low-density neighbourhood commercial development (50% impervious)		0.55	0.495	21
Pervious	Highly compacted	Unpaved parking, driveway, road shoulder; high automobile & human disturbance, poor drainage	0.50	0.45	45
	Mid-High Compaction	Medium density single family development (~26 units/ha) (35% impervious)	0.45	0.405	21
	Moderate compaction	Low density single family urban development (~ 13 units/ha)(26% impervious)	0.38	0.342	21
	Compacted	Unmaintained sports field, park or playground surface; high human disturbance & poor drainage	0.35	0.315	45
	Unmaintained	Moderate foot traffic & some compaction; foot paths, moderate to poor drainage	0.30	0.27	45
	Turf	Maintained lawn w/ high foot traffic (e.g., golf course, park, lawn, ballfield)	0.25	0.225	45
	Maintained	Landscaped/natural vegetated w/ low foot disturbance/foot traffic	0.20	0.18	45
	Undeveloped	Relatively low foot traffic	0.15	0.135	45
	Drainage feature w/ gravel or other coarse-grained material; porous pavement, asphalt, concrete etc w/ subsurface stone reservoir; well-drained sandy soil		0.10	0.09	45

Table 2Percentage of perviousness

Source Yang, Wenyu et al.(2020)

4.2.1. Easterhouse

As a low-density neighbourhood, the percentage of imperviousness according to Yang and Wenyu, is 50 %. For a maintained well-vegetated neighbourhood the imperviousness is 20 %

The initial background for calculating the stormwater runoff is set to the imperviousness of 50% with a time series rainfall event of four hrs and hourly rainfall rate. For the comparison, we will look at the same attributes only with a difference in the imperviousness of the surface area. See Appendix for details

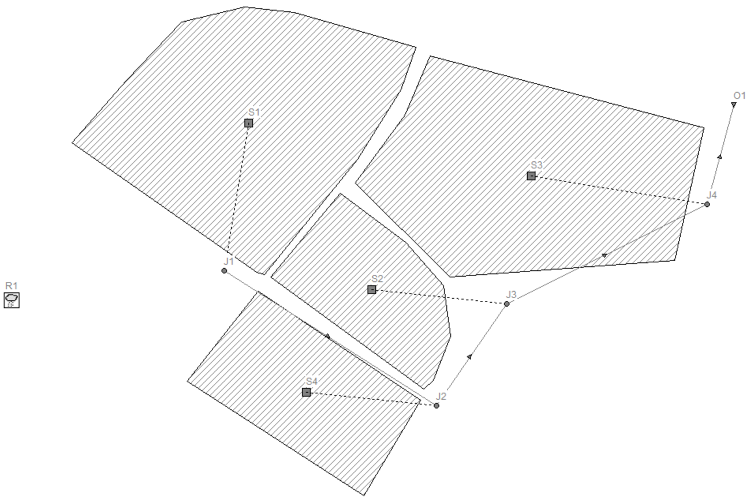
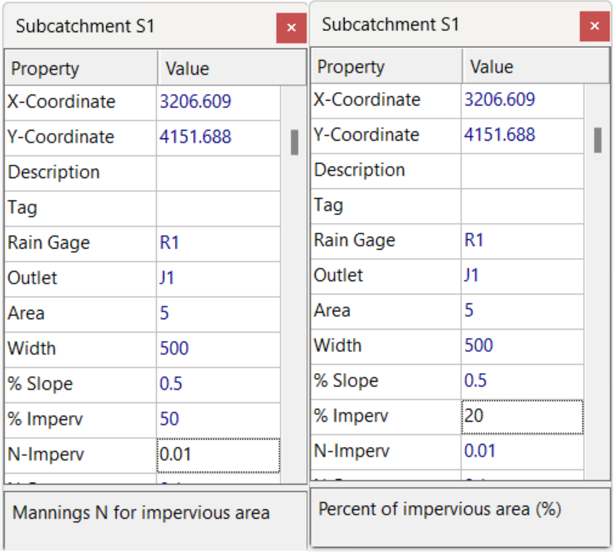


Figure 9 Easterhouse simulation sub-catchments



Subcatchment S1

Property	Value
X-Coordinate	3206.609
Y-Coordinate	4151.688
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	50
N-Imperv	0.01

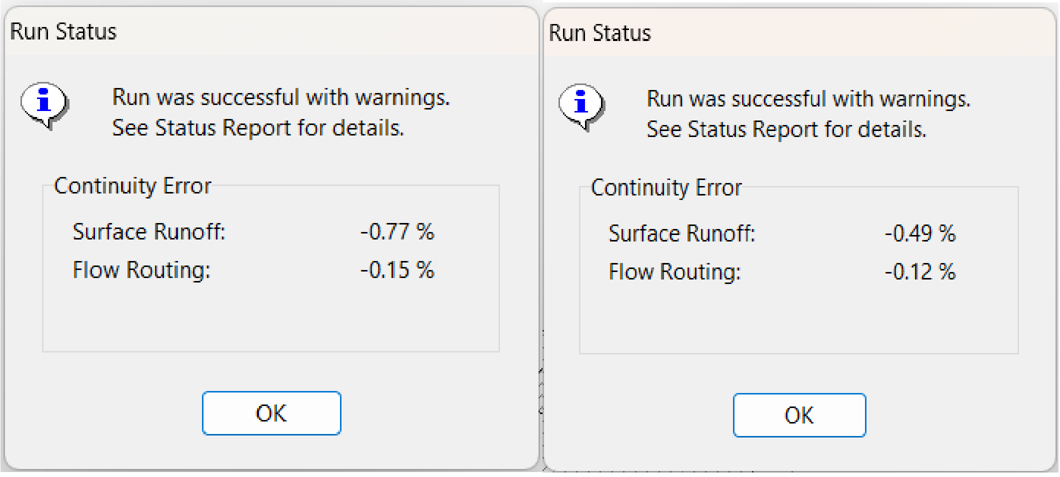
Mannings N for impervious area

Subcatchment S1

Property	Value
X-Coordinate	3206.609
Y-Coordinate	4151.688
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	20
N-Imperv	0.01

Percent of impervious area (%)

Figure 10 Easterhouse Sub - catchment properties of different perviousness percentages



Run was successful with warnings.
See Status Report for details.

Continuity Error

Surface Runoff: -0.77 %
Flow Routing: -0.15 %

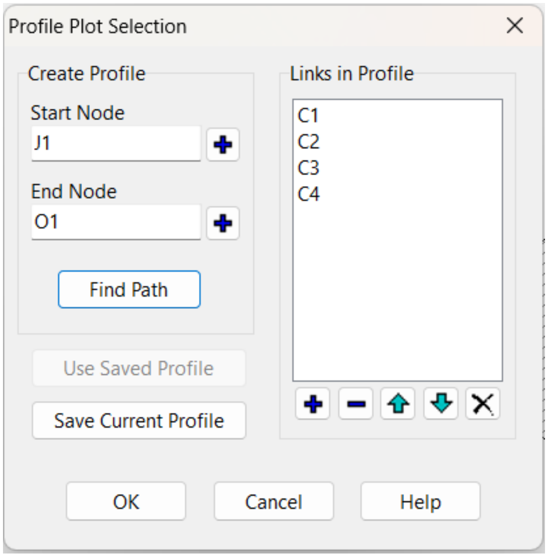
Run was successful with warnings.
See Status Report for details.

Continuity Error

Surface Runoff: -0.49 %
Flow Routing: -0.12 %

Figure 11 Easterhouse surface runoff comparison

The simulation run resulted in a -0.77 % surface runoff and flow routing of 0.15 %with 50% imperviousness. The negative amount implies a possible current direction alteration. Comparing percentage imperviousness, when the model is run with 20% imperviousness surface runoff increases to -0.49. Generally surface runoff under 1 % is tolerable, yet since this simulation was taken to compare different imperviousness percentages affecting surface runoff, we can conclude from the above result that more perviousness reduces surface runoff.



Start Node: J1

End Node: O1

Links in Profile:
C1
C2
C3
C4

Figure 12 Easterhouse Path of conduit links for profile plot

Here we have a path linking all four catchment areas to the outfall.

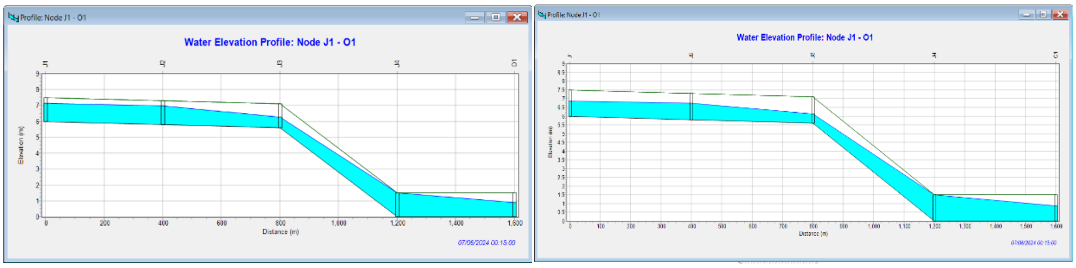


Figure 13 Easterhouse water elevation profile comparison

The elevation profile plot shows that more perviousness reduces water runoff. In this case with the elevation of 7 meters surface runoff will happen with perviousness rate of 50%. In the case of the 20 % perviousness the water fills up only 6.7meters and surface water runoff does not happen at the original elevation of 7meters, using the same rainfall event.

4.2.2. Govan

As a commercial development, and transport hub, the percentage of imperviousness at the simulation area of Govan cross shopping centre according to Yang and Wenyu, is 70 %. For a maintained well vegetated neighbourhood the imperviousness is 20 %. The environment set on modelling these two comparative simulations is the imperviousness change in the above two magnitudes.

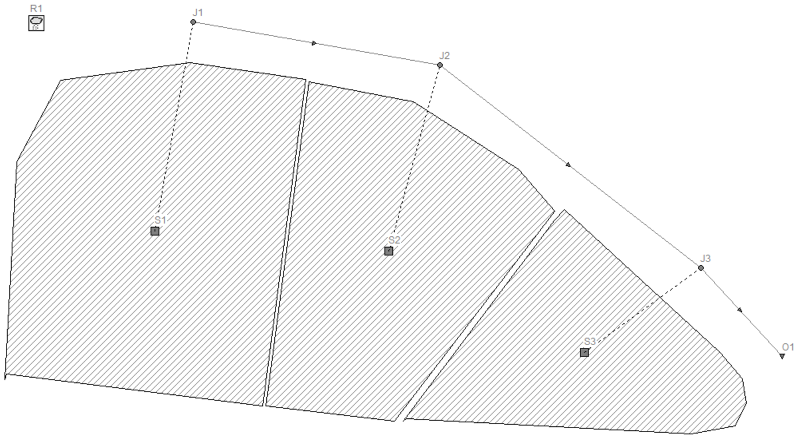
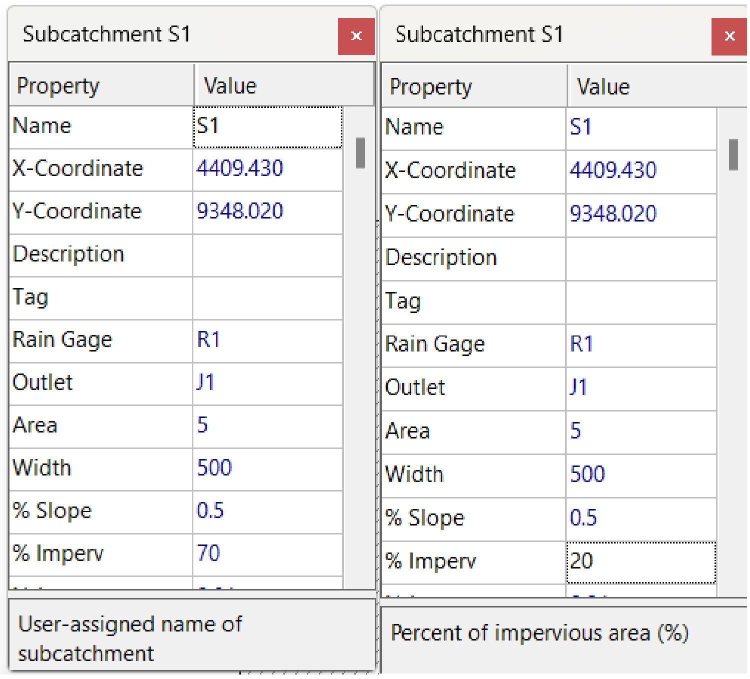


Figure 14 Govan simulation sub-catchments



Subcatchment S1

Property	Value
Name	S1
X-Coordinate	4409.430
Y-Coordinate	9348.020
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	70

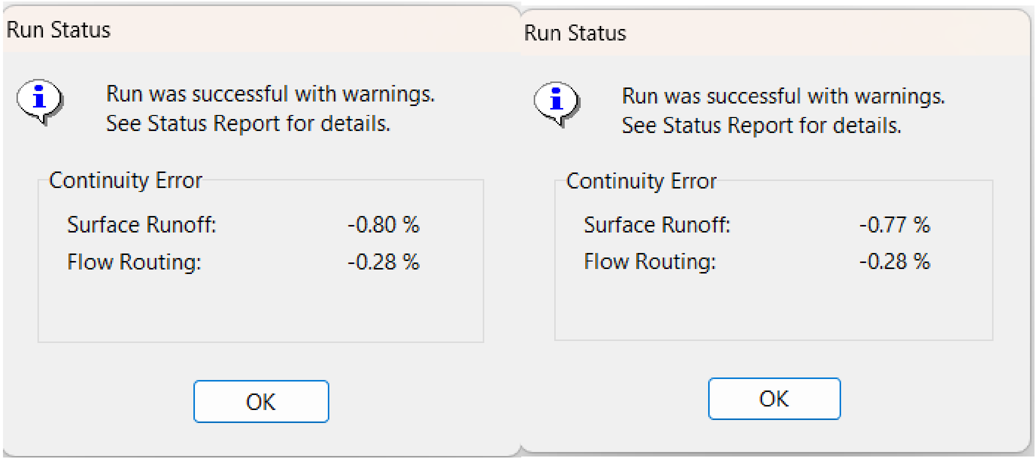
User-assigned name of subcatchment

Subcatchment S1

Property	Value
Name	S1
X-Coordinate	4409.430
Y-Coordinate	9348.020
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	20

Percent of impervious area (%)

Figure 15 Govan catchment properties of different perviousness percentages



Run Status

Run was successful with warnings.
See Status Report for details.

Continuity Error

Surface Runoff: -0.80 %
Flow Routing: -0.28 %

Run Status

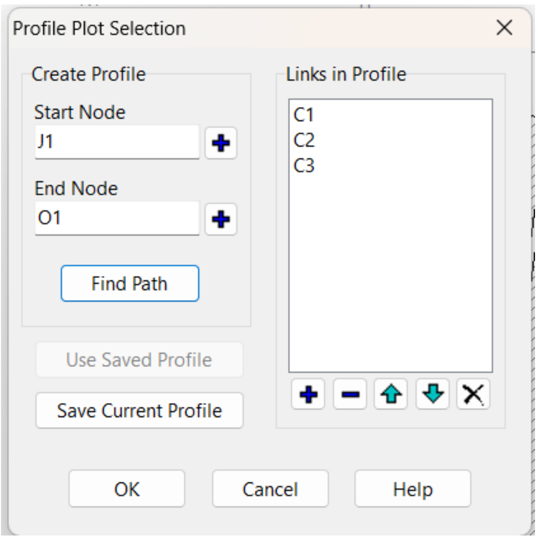
Run was successful with warnings.
See Status Report for details.

Continuity Error

Surface Runoff: -0.77 %
Flow Routing: -0.28 %

Figure 16 Govan surface runoff comparison

The simulation run resulted in a -0.80 % surface runoff and flow routing of -0.28 %with 70 % imperviousness. The negative amount implies a possible current direction alteration. Comparing percentage imperviousness, when the model is run with 20% imperviousness surface runoff increases to -0.77%. Generally surface runoff under 1 % is tolerable, yet since this simulation was taken to compare different imperviousness percentage affecting surface runoff, we can conclude from the above result that more perviousness reduces surface runoff.



Start Node: J1

End Node: O1

Links in Profile: C1, C2, C3

Figure 17 Govan Path of conduit links for profile plot

Looking at the water elevation profile taking the same measurements i.e Links are created between the junction nodes and the outfall. The links are conduits with a circular shape pipeline and maximum depth for conduit is given to be 1.5. (Similar for all the three simulations)

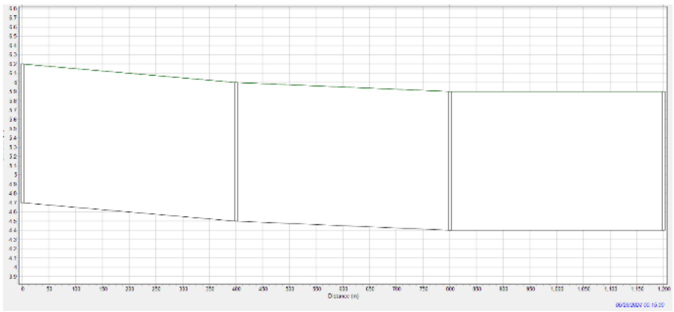


Figure 18 Govan water elevation profile

In the case of Govan there will be no overflow in the drain based on the simulation results.

4.2.3. Wyndford

As a high to mid-density neighbourhood, the percentage of imperviousness according to Yang and Wenyu, is 45 %. For a maintained well vegetated neighbourhood the imperviousness is 20 %

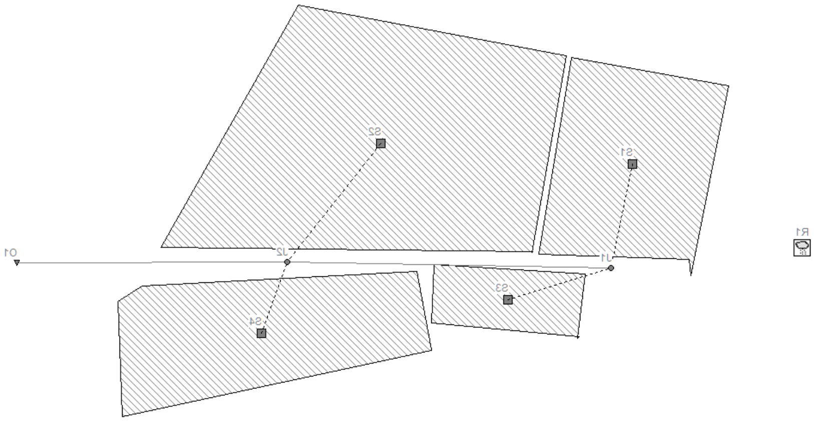
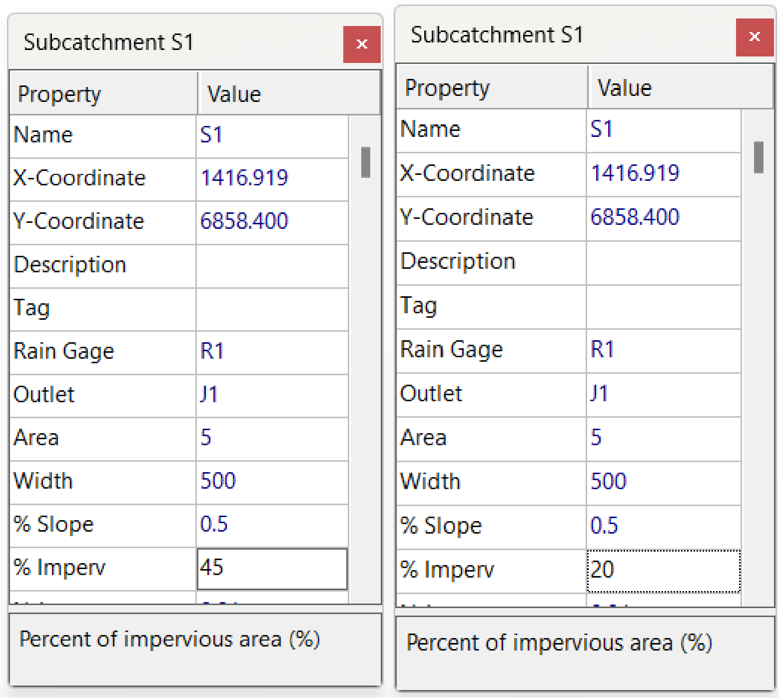


Figure 19 Easterhouse simulation sub-catchments



Subcatchment S1

Property	Value
Name	S1
X-Coordinate	1416.919
Y-Coordinate	6858.400
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	45

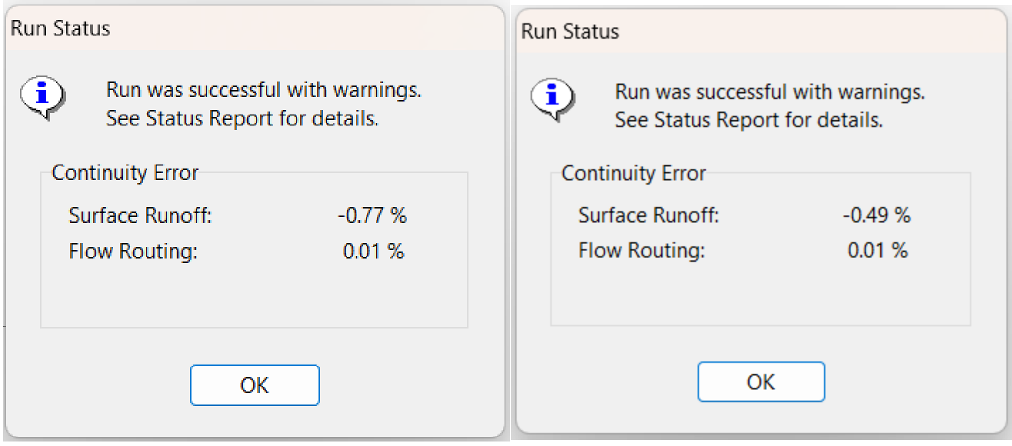
Percent of impervious area (%)

Subcatchment S1

Property	Value
Name	S1
X-Coordinate	1416.919
Y-Coordinate	6858.400
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	20

Percent of impervious area (%)

Figure 20 Wyndford catchment properties of different perviousness percentages



Run Status

Run was successful with warnings.
See Status Report for details.

Continuity Error
Surface Runoff: -0.77 %
Flow Routing: 0.01 %

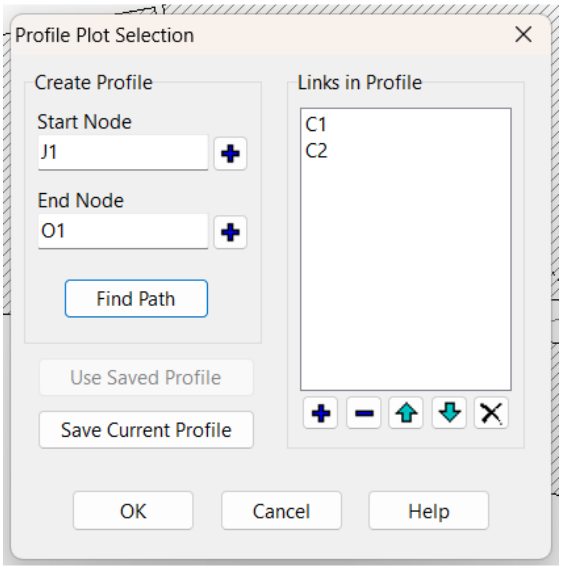
Run Status

Run was successful with warnings.
See Status Report for details.

Continuity Error
Surface Runoff: -0.49 %
Flow Routing: 0.01 %

Figure 21 Wyndford surface runoff comparison

The simulation run resulted in a -0.77 % surface runoff and flow routing of 0.01 %with 45% imperviousness. The negative amount implies a possible current direction alteration. Comparing percentage imperviousness, when the model is run with 20% imperviousness surface runoff increases to -0.49. Generally surface runoff under 1 % is tolerable, yet since this simulation was taken to compare different imperviousness percentage affecting surface runoff, we can conclude from the above result that more perviousness reduces surface runoff.



Profile Plot Selection

Create Profile
Start Node: J1
End Node: O1

Links in Profile
C1
C2

Figure 22 Wyndford Path of conduit links for profile plot

The water profile plot indicates that the path to the outfall consists of Node junctions 1 and 2. This is because both junction nodes were common to four catchment areas and connected to the outfall.

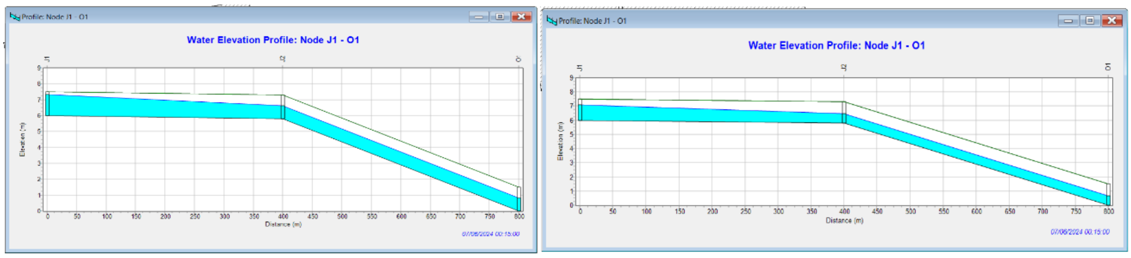


Figure 23 Wyndford water elevation profile comparison

The elevation profile plot shows that more perviousness reduces water runoff. In this case with the elevation of 7.5 meters surface runoff will happen with perviousness rate of 45%. In the case of the 20 % perviousness the water fills up only 6.8 meters and surface water runoff does not happen at the original elevation of 7.5 meters, using the same rainfall event.

5. BENCHMARKING, AND GUIDELINES

5.1. Benchmarking and Discussion

5.1.1. Imagery for mapping and monitoring imperviousness (Warsaw, Poland)

The density of impermeable surfaces like roofs and pavements is crucial to assessing hydrologic processes and surface runoff in urban catchments. This density is crucial to understanding urban water cycles. Hydrological models benefit from satellite imagery, especially in urban development studies. The Copernicus SENTINEL constellation provides free, high-quality satellite images for estimating urban structure and imperviousness. Multitemporal Sentinel-2 data is extensively used to calculate urban sprawl indices. NDBI and NDVI measure the urban heat island effect. They help track urban impervious surface percentage changes.

This study In Warsaw combined SENTINEL-2 MSI data from different time periods and resolutions to develop a new local water management method for urban catchments. The results were quantitatively compared to Copernicus' Imperviousness High Resolution Layer (HRL), visually with OpenStreetMap data, and qualitatively with Planet's high-resolution imagery. The study area included Warsaw, Poland's capital and most populous city with 1.78 million people. The study used 2015 Sentinel-2, Planet Scope, and Copernicus HRL imperviousness data.

The European mission SENTINEL-2 uses two satellites to take high-resolution, multi-spectral images. Two satellites in the same orbit are 180° apart. The mission seeks global, high-resolution multispectral images. Additionally, it seeks to maintain SPOT satellite multispectral imagery. For future operational products like land-cover maps, land-change detection maps, and geophysical variables, it will collect observation data.

Pan-European High-Resolution Layers (HRL) provide accurate land cover attributes and enhance land cover/land use mapping. The imperviousness products show soil sealing percentage and change. The HRL measures man-made sealed areas' spatial arrangement and soil sealing per unit area.

Planet Scope satellite imagery is a continuous sequence of frame images called "scenes." This product contains orthorectified, multispectral satellite data. The processed data allows researchers to create data science and other information products. The imagery has been processed to remove terrain distortions and can be used for data science and analysis.

Calculate the NDVI ratio by combining visible and near-infrared wavelengths. The Normalised Difference Build-up Index (NDBI) identifies urban areas with higher SWIR reflectivity. Final resolution will be 20 metres.

The Planet Scope Analytic Ortho Scene produces 4-band multispectral images with NDVI. This study categorises urban land covers as impervious surface and others. The spatial assessment of impervious surface classification showed that NDVI and NDBI indices are reliable urban surface imperviousness indicators.

The median NDVI value was better for urban areas and bare soil than Planet Scope high-resolution satellite imagery. However, impermeable surfaces were misclassified, especially in regions with fewer buildings and more green spaces. However, regions with many buildings and impermeable surfaces were properly classified.

NDVI and Copernicus High-Resolution Layers were compared for impervious surface mapping. From SENTINEL-2 imagery, NDVI was calculated. The visual comparison showed that satellite-identified impervious surfaces were more complex than Copernicus products.

This study showed that SENTINEL data can identify urban development. It also showed that calculated indicators and SENTINEL-1 imagery can be used to analyze impervious surfaces in rapidly growing cities. SENTINEL and other satellite data will be used to improve impermeable surface identification and categorization in future research. The results will also be compared to high-resolution UAV data. (G. Kuc 1 , J. Chormański, 2019)

5.1.2. Green infrastructure drainage of a commercial plaza (Sweden)

A study in northern Sweden evaluated the hydrological performance of two commercial areas with Green Infrastructure (GI) storm drainage and a conventional storm sewer system. The GI catchment avoided directly connected impervious areas by diverting runoff from a parking lot to a cascade of three infiltration features, a fractured rock strip draining onto a sloping infiltration area, followed by a collector swale. Both catchments were monitored over four years by measuring rainfall, runoff, soil water content, and groundwater levels near the swale.

The study partnered with a municipality in Northern Sweden to examine the hydrological performance of a 0.75 ha extension of an existing suburban commercial plaza with drainage designed according to GI principles. This was achieved by reducing the total catchment imperviousness (TCI) of the plaza extension catchment to zero, by diverting runoff from the asphalt parking lot onto a pervious strip, followed by a sloping infiltration area, and collecting residual runoff in a swale, which eventually drains into a local storm sewer system.

The conventional drainage catchment, with a runoff contributing area of 2.54 ha, is located 300 meters away from the GI site. The catchment is 96% impervious and comprises two asphalt parking lots and roofs of several large commercial buildings. The catchment is drained by conventional curb and gutter drainage into a storm sewer system. Rujner, Hendrik et al

Hydrological factors and response variables studied included rainfall depth, duration, rainfall intensity, antecedent dry days, initial groundwater level, initial soil water content, temperature, and relative humidity. The study aimed to understand the impact of hydrological factors on groundwater and runoff conditions.

The study also explored the interdependence of hydrological factors controlling the runoff response at the GI site, testing correlations between parameters using the Spearman Rho test with a significance threshold of $p < 0.05$. The relationships between hydrological performance indicators and likely influential factors at the GI site were also explored using scatter plots of each hydrological factor versus the performance indicators with 60 recorded rainfall events. (Rujner et al., 2022)

5.1.3. Measuring performance of Low-impact development practices for surface water runoff (Dresden)

This case study aims to assess the effectiveness of Low Impact Development (LID) techniques in managing stormwater runoff in an urban catchment area in Dresden, Germany. The study area, encompassing a 0.85 km2 campus with a variety of land cover types such as roads, buildings, parking lots, squares, and green areas, was chosen based on the data and financial limitations that were present.

Approach

The U.S. Environmental Protection Agency Storm Water Management Model (SWMM) was utilized to conduct hydrological simulations. The model used data provided by local authorities, including information on the piping network, terrain conditions, satellite images, and historical rainfall events. The study examines the process of calibrating and validating a model, as well as the selection of parameters that have a significant impact on the model's performance.

Discoveries

The study assesses the technical and economic efficacy of multiple Low Impact Development (LID) practices, including Infiltration Trench (IT), Permeable Pavement (PP), Rain Barrel (RB), and their different combinations. The results suggest that the performance of LID practices is affected by the duration of precipitation scenarios and the particular implementation strategies. Additionally, the cost-effectiveness of the LID practices is examined, emphasizing the economic and technical performance of the various options.

Consequences

This case study offers valuable insights into the technical and cost-effectiveness aspects of Low Impact Development (LID) practices, contributing to the comprehension of stormwater management measures. The article also examines possible constraints and proposes areas for future research, such as conducting uncertainty analysis on influential factors and conducting a comprehensive evaluation of LID performance across various scenarios.

In conclusion,

The study's findings enhance the comprehension of LID practices for stormwater management and offer guidance for decision-making processes regarding their implementation.

5.2. Designing for quantity

In designing for quantity Sustainable Urban Drainage Systems (SuDS), CIRIA recommends checking the following factors

1. Manage runoff from developed areas to regulate water use.
2. Attenuation slows and retains runoff on the premises before releasing it into the

receiving watercourse at a maximum rate.
3. Consider the impact of all development in the catchment area and climate change effects.
4. Plan to reduce water runoff and utilize surface water as a resource by integrating water cycle management with the built environment.
Rainwater can be used for irrigation and other purposes, reducing water use.
When managing water quantity, consider design objectives for water quality, amenity, and biodiversity.
7. Prioritise surface water runoff release, regulate its amount and rate and consider downstream limitations and storage loss.
8. Check that the drainage system's flood risk level is acceptable for the site and mitigate external flooding risks.
9. Surface SuDS components should show rising water levels, to indicate quick action.
10. Consider climate change risks and service level demand, components with adaptability to meet future capacity needs.
11. Peak flow rates, discharge volume control, return periods, and critical rainfall duration determine water quantity design standards.
12. Capture, absorb, and collect rainwater to reduce water runoff during heavy rainstorms.
Try to achieve the desired runoff behaviour for all events, especially flood-reducing ones.
14. Reduce water runoff on developed sites by 30% to match natural, undeveloped sites.
15. Check that the drainage system can prevent on-site flooding and consider a design that exceeds its capacity to mitigate risks from events that exceed it.
Enable emergency vehicles to reach affected areas during intense runoff and reduce flooding risks.

5.3. Guidelines

Blue-green elements will be crucial in the future for planning climate-optimized streets in neighbourhoods that are at risk of flooding, to create liveable environments. Blue-green elements are becoming more prevalent in areas where there is a need to alleviate water bodies and sewers, while also improving water supply to plants.

The blue-green street toolbox EFIB acknowledges the different looks and presentations of blue-green streets. It also classifies the elements into six groups

- Vital tree locations,
- Elements of evaporation,
- Elements of infiltration,
- Elements of heavy rain prevention,
- Elements of water purification and
- Elements of water use

These elements support the natural water cycle which makes them suitable for applications in already developed areas.

SIRIA manual for sustainable drainage also gives priority to seven elements in designing SUDS.

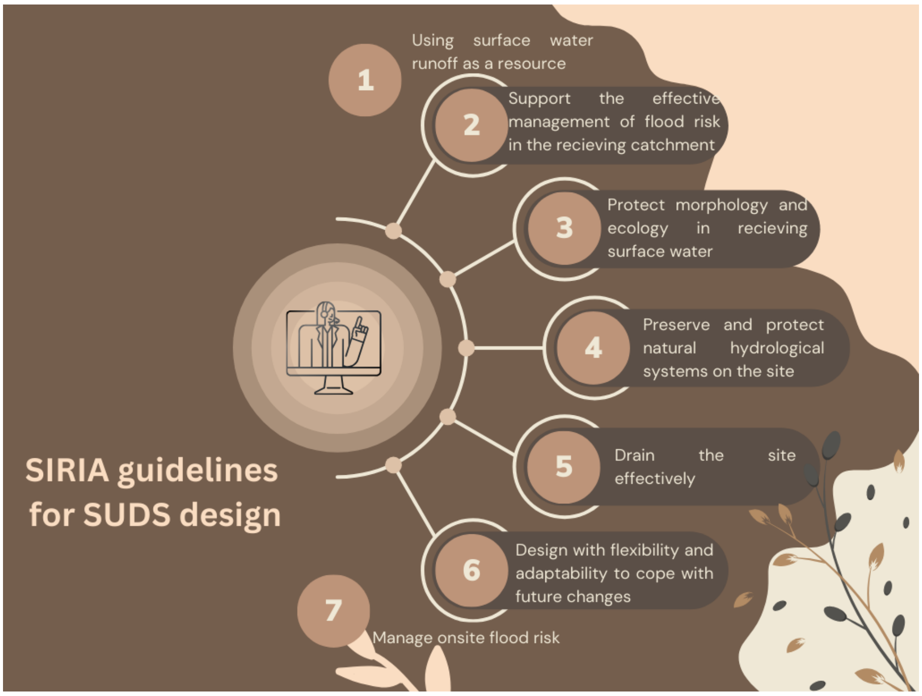


Figure 24 Guidelines for designing sustainable drainage

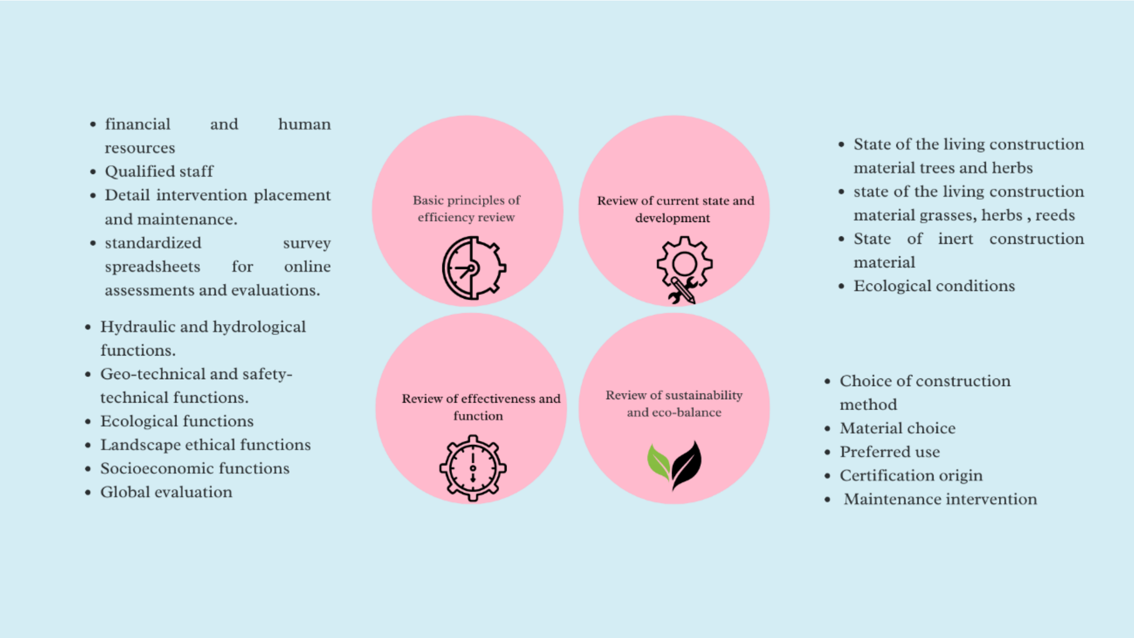
Source CIRIA

5.3.1. Efficiency guidelines for Bluegreen infrastructure

EFIB has efficiency checkpoints applicable to any Bluegreen infrastructure specifically for soil and bioengineering methods. It includes the basic principles, a review of the current and developed state of the living construction material, a review of effectiveness and function hydraulic and hydrological functions, and a review of sustainability and eco-balance.

Monitoring is an essential requirement for the continuous development of specialized knowledge on soil and water bio-engineering, as well as for ensuring the quality and safety of its interventions. Both the financial and personnel aspects of the monitoring process must be adequately insured.

The following table is a summary of the checkpoints in measuring efficiency for blue-green infrastructures.



- financial and human resources
- Qualified staff
- Detail intervention placement and maintenance.
- standardized survey spreadsheets for online assessments and evaluations.

- State of the living construction material trees and herbs
- state of the living construction material grasses, herbs , reeds
- State of inert construction material
- Ecological conditions

- Hydraulic and hydrological functions.
- Geo-technical and safety-technical functions.
- Ecological functions
- Landscape ethical functions
- Socioeconomic functions
- Global evaluation

- Choice of construction method
- Material choice
- Preferred use
- Certification origin
- Maintenance intervention

Figure 25 EFIB Efficiency guidelines summary

5.4. Applicable Green Lane elements

5.4.1. Pervious pavements

Pervious pavements allow rainwater to permeate the surface and structural layers while accommodating pedestrian and vehicular traffic. Before use, the water is stored beneath the surface until it is absorbed into the ground or released downstream in a controlled manner.

Pervious surfaces and substructures manage surface water runoff near its source. They catch runoff, reduce its amount and frequency, and provide a treatment medium. Filtration, adsorption, biodegradation, and sedimentation occur in the surface structure, subsurface matrix (including soil layers where infiltration is allowed), and geotextile layers.

Pervious pavements are divided by surfacing material into two categories. Reinforced grass or gravel surfaces, resin-bound gravel, porous concrete, and porous asphalt allow water to permeate their surfaces.

Water-impermeable surfaces make up permeable pavements. The materials are arranged to leave space between the surface and sub-base. Standard concrete block paving is designed to let rainwater or runoff seep through the gaps between the blocks and into the pavement structure.

The main surface options for pervious pavement are modular permeable paving, porous asphalt, grass reinforcement, resin bound gravel, and porous concrete.

5.4.2. Green roofs

Green roofs improve aesthetics, ecology, building performance, and surface water runoff. Intensive green roofs exist. Large roofs with shallow substrates reduce building structure loadings. Despite easy planting and maintenance, they are rarely accessible. Roof gardens, or intensive roofs, have deeper substrates and higher building loads. Many plantings are possible but needed.

Blue roofs store water. Storage allows controlled water release as attenuation. It can irrigate nearby green roofs or cool the roof on hot days. Recreation and non-potable building use are also possible. Blue roofs can have exposed water, storage under a permeable material or modular surface, or an elevated deck or impermeable covering. Green "blue roofs" have reservoir storage zones below the growing medium. Blue roofs are similar to other manual components, so the chapter does not analyse them. To protect the building, the roof design must consider weight and waterproofing. Green roofs are more expensive to install and maintain but have long-term benefits. Vegetated cover must safeguard roof waterproofing. Protecting roof waterproofing from physical damage, UV radiation, and extreme temperatures extends its lifespan. In summer, green roofs save energy by cooling through evapotranspiration from plants and substrate. Winter roof insulation is affected by water. Wet winters in the UK reduce insulation gains. With many green roofs, urban heat islands can be reduced. They capture dust, improving air quality. Green roofs efficiently retain and filter rainwater and circulate water to support the natural water system. This paper emphasises ground water, so green roofs are only recommended on one site.

5.4.3. Bioretention

Rain gardens and other bioretention systems use specially designed-soils and plants to slow runoff and purify contaminants. They excel at Interception and can also provide: attractive landscape elements that are self-sufficient in irrigation and fertilisation habitat and biodiversity support local microclimate cooling through evapotranspiration. Surface water management components can be easily integrated into diverse development landscapes using different shapes, materials, planting, and dimensions. A low-density development may have gradual boundaries and gentle inclines, while a high-density application would have distinct boundaries and steep vertical sides. They usually manage and treat runoff from frequent rainfall. Consider how design velocities will affect the system for larger events. An overflow or bypass is often better for diverting excess water from intense events to downstream drainage elements. Before passing through vegetation and soils, runoff is stored in the system's ponds. Engineered soil mixes can be chosen as filter media to improve bioretention. To remove nutrients, designs can include submerged anaerobic zones.
The filtered runoff is either collected using an underdrain system or infiltrated into the surrounding soil, depending on site conditions. Evaporation and plant transpiration reduce runoff volume. The main hydraulic benefit of bioretention systems is

interception. However, attenuation storage on the surface or in the drainage layer can regulate runoff. Check dams or weirs can slow water movement across the system. CIRIA

5.4.4. Ponds and wetlands

Ponds and wetlands are permanent bodies of water that reduce and purify surface runoff. Emergent and submerged aquatic vegetation along lake shorelines and in shallow, marshy zones improves treatment and provides amenity and biodiversity. Thick clusters of plants help attach pollutants to plants, break them down with oxygen, and stabilise settled sediment to prevent stirring. A large portion of wetlands is covered in aquatic vegetation. They also vary in depth and may include shallow land masses. However, this document considers ponds and wetlands synonymous. Attenuation storage is above the permanent pool and wetland. The outfall's flow control system adjusts discharge rates based on water levels. This fills the pond during storms. Rainfall runoff is collected and treated in the pool. The size of the pool affects its ability to remove solid pollutants because larger volumes allow for longer sedimentation and more biodegradation and biological uptake.

When designing ponds and wetlands, upstream pre-treatment systems or sediment forebays are essential. This prevents open water features from looking bad and smelling bad. It also reduces rapid sediment build-up, which is expensive and difficult to remove and dispose of. Ponds and wetlands remove fine silts and refine surface water runoff before release.

Well-designed and maintained permanent bodies of water provide aesthetic, amenity, and wildlife benefits to developed sites. Ponds can be built with grassy sides or hard materials to enhance densely populated urban areas. Efficiently managed ponds and wetlands can boost property values and attract business and tourism. Ponds' visual appeal, seamless integration into the environment, and communal value influence public opinion. Thus, landscape architects should design and specify pond form, layout, and vegetation. Design should not be done by engineers without landscape architecture experience.

5.4.5. Swales

Swales are vegetated channels with a shallow, flat bottom that are used to convey, treat, and reduce the flow of surface water runoff. When employed in the design of SuDS they have the ability to enhance both biodiversity and aesthetics. These drainage systems are utilised to remove water from roads, paths, and car parks by collecting and redirecting the dispersed runoff. They can also be employed to transport runoff on the surface while simultaneously enhancing access corridors or other open areas. Swales may exhibit either uniform or non-uniform profiles and employ various planting strategies based on the specific characteristics of the site and the desired outcomes of the system. Swales have the ability to carry away excess water instead of using pipes, while nearby filter strips and flow spreaders can remove the need for curbs and drains.

A typical swale channel is characterised by its wide and shallow structure, which is covered in grass. This design serves the purpose of reducing the speed of water flow and enabling processes such as sedimentation, filtration through the root zone and soil matrix, evapotranspiration, and soil infiltration. Check dams or berms are structures that can be used to temporarily store runoff in a swale. This helps to increase the amount of pollutants that are captured and absorbed, while also reducing the speed at which the water flows, particularly on steep slopes.

There are three different kinds of swale; Conveyance and attenuation swale, dry swale and wet swale. CIRIA

5.4.6. Channel/ detention basins

Topographical depressions called detention basins are usually dry except during and after precipitation. Online components direct regular event surface runoff through a basin. When flow increases, the restricted outlet fills the basin, storing runoff and reducing flow.

As offline components, they can redirect runoff after a threshold.

Vegetated depressions can treat regular flows, but hard landscaped storage areas do not and are designed as off-line components.

During small rainfall events, vegetated basin soil can absorb some runoff, preventing runoff from the site. However, caution must be taken to protect groundwater from the limited infiltration. Water quality is improved by sediment and buoyant material removal in vegetated detention basins. They can also significantly reduce nutrients, heavy metals, toxic substances, and oxygen-demanding materials. Extending water detention for an event improves water quality in a vegetated detention basin. The basin area can be a recreational or amenity facility if designed properly. CIRIA

6. FINDINGS, RECOMMENDATIONS (PROPOSAL), AND LIMITATIONS

6.1. Summary

According to the previous model, there is a direct relationship between surface perviousness and stormwater runoff control. From the results above we can conclude that surface water runoff and perviousness are directly related. Although to measure directly the impact of blue-green infrastructures in terms of identifying the quantified amount of Relationship between green lanes and managing stormwater wasn't practical in this research, direct relationship indications are present.

In conclusion, the idea of measuring the efficiency and viability of green lanes in Glasgow showed challenges. This study tried to Identify the existing green lane elements in developments in Glasgow city and quantify the differences blue-green infrastructure makes in urban stormwater management from a planner's point of view. The findings lead to conclusions indicating limits on quantifying the impacts.

Even though quantification was a challenge for this research, the study has found a direct relationship between the effects of green lanes (in terms of surface perviousness) and volume control mechanisms.

With the help of Sponge equivalent conversion metrics, It was possible to estimate the potential improvements that could be achieved through the implementation of green lanes. On the other hand, the actual numerical values and formulas might be quite different from one another. The intensity of rainfall, changes in climate, and variations in the quality and quantity of surface runoff are some of the factors that contribute to this variability. Because of these factors, it is difficult to come up with a single formula that can be used for estimation or measurement that works everywhere.

According to EFIB, The interventions that require monitoring must possess a documented record of their precise location as well as a detailed description of their construction and maintenance. It is necessary to have the capability to conduct an evaluation and assessment using data banks. One essential requirement is that the survey spreadsheets must be readily available in a standardised format.

This paper previously defined viability as the ability to successfully and efficiently implement a particular approach, technology, or strategy to address stormwater-related issues. Hence, assessing the feasibility of implementing green lanes was not immediately feasible due to the aforementioned reasons.

6.2. Findings and Recommendations

6.2.1. Examples

For Govan, a major problem in this particular shopping area is porosity. The shopping area has a bus terminal and train station that have completely sealed the top surface. The aim of proposing green lane infiltration leads to the top of the priority lists. Conveyance and channeling are the two consecutive aims. Guided drains, curb and channel drains, permeable asphalt for sub-surface filter, and permeable brick paving for conveyance. The wide top surface that covers the parking and bus station can be made with permeable asphalt pavement. Then A guided drain can collect the flow and circulate it around mostly open grounds, and what is left of that could be guided to drains and bioswales.

Figure 26 Govan site plan

This site could be improved by incorporating pervious materials to disrupt the surface seal. In this manner, precipitation could have a greater duration to permeate through the natural hydrological cycle rather than remaining stagnant on the surface. If the surface is permeable and green lanes are added to the car parking islands, the drains and manholes in the system will be given sufficient time to filter the surface runoff. The green lane will effectively manage surface runoff, directing any excess water into the manholes once it reaches the same level as the curb stone. Figure 26 above suggests possible elements of green lanes to be considered. The existing open space in front of the bus and train station could be a more defined green space with similar functions with a change of surface material, from concrete to permeable pavement. Figure 27 shows a pervious parking pavement. Followed by figure 28 that shows a simulation of both the pervious parking and green lanes as an island.

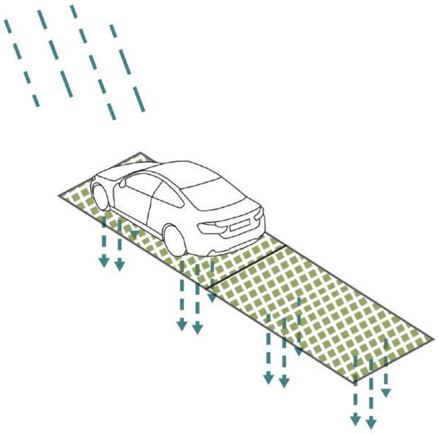


Figure 27 pervious surface material suitable for parking

Figure 28 Permeable pavement and Green lanes for parking

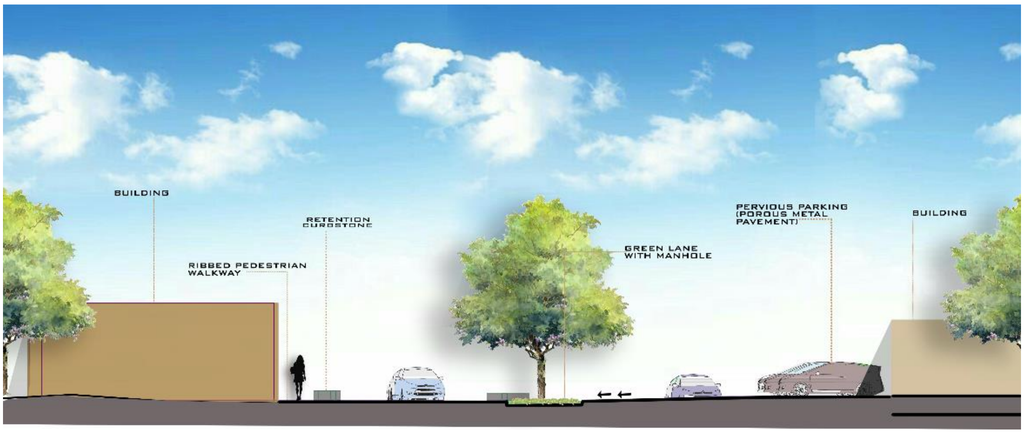


Figure 29 Cross section of Green lane elements incorporated

Figure 29 Is an illustration of the existing parking space with the proposed elements of green lanes. Buildings, pervious parking, green lane, pervious pedestrian walkway and trees in the green lane along with the grass and turfs are represented.

Figure 30 Illustration of elements of green lanes for Govan

Figure 30 gives more perspective to the proposed surrounding previous pedestrian walkways, parking spaces, and existing buildings.

Figure 31 illustration of permeable pedestrian walkways

Figure 31 illustrates the close-up look for the surface material and pervious pedestrian walkway.

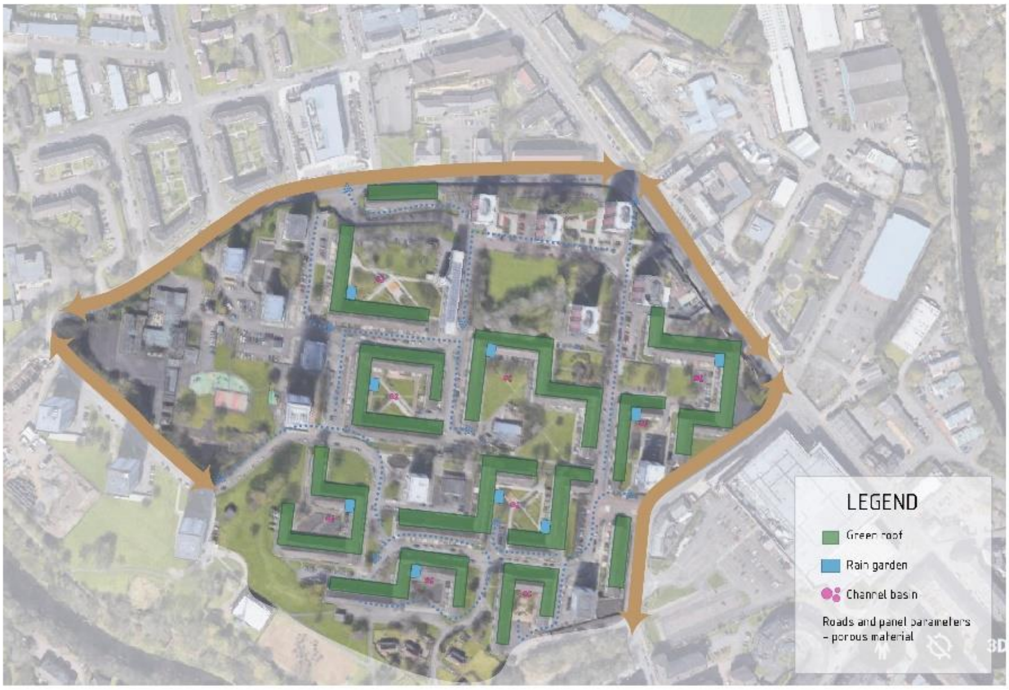


Figure 32 Wyndford site plan

In Wyndford, to propose a solution for this specific site, priorities are given to rainwater collection, conveyance, and retention. The intention is to lower hydraulic loads from the combined drains and prevent overflow. For that, we can look at bioretention solutions with vegetation varieties, percolation ponds, channel basins, green roofs, rain gardens, and permeable pavements to promote conveyance. Figure 32 illustrates the installation of green roofs, rain gardens, and connected channel basins. To keep the natural water cycle and support the existing retro drain permeable materials could be utilized in all the spaces available. Since space isn't a luxury since the area is already developed, Green roofs and rain gardens could be installed in the already existing buildings. The open spaces between the blocks could serve as connected channels complementing the open spaces. The channels could add aesthetics to the green spaces. Figure 33 illustrates the retaining properties of permeable green lanes. With a thick base and sub-base these green lane elements could be more useful in a smaller space.

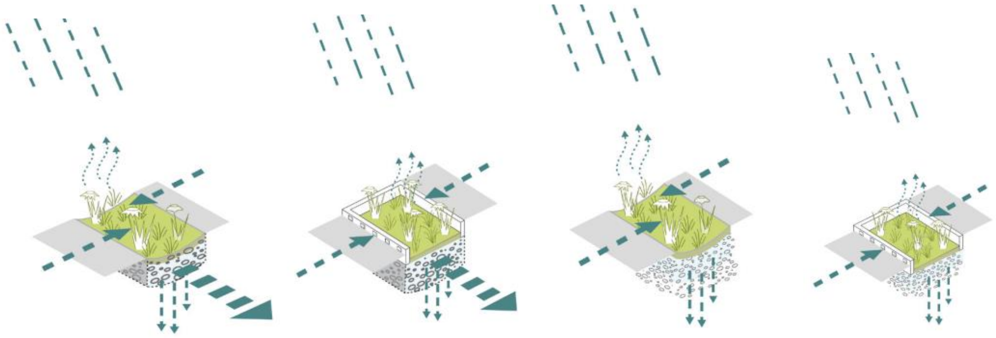


Figure 33 Water retention properties of smaller green lanes

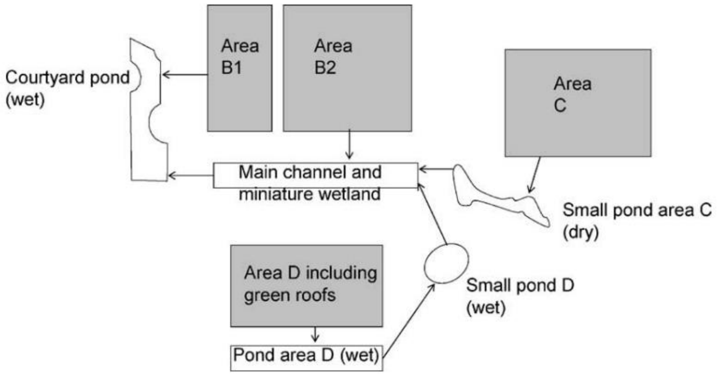


Figure 34 connected channel basins and wetlands

Source Villarreal et al.

Additionally installed to the site with suitable landscape design considerations could be a channel basin resembling Figure 34.

Generally, green lane solutions for one of the three sites could be adapted to any other site, but based on space availability, installation convenience, and impact expected, some are more suitable than others. What is common for all three is that stormwater management should be aimed toward runoff volume control (quantity).

The primary objective of sustainable management is to closely mimic the natural water balance by maximizing evaporation, optimizing infiltration, and minimizing surface runoff. To achieve the best evaporation performance of the vegetation, it is crucial to provide the street greenery with the maximum amount of water.

Figure 35 Easterhouse site plan

In the case of Easterhouse, As the area is more spacious and has a relatively moderate density, specific design guidelines could be concentrated around improving retention, detention, recharge, reuse, channeling, and infiltration. With the available open spaces and location, upcycled stormwater management could be applicable. Elements that could be incorporated to achieve these results are wastewater recycling, constructed wetlands and greenhouses, designed biodiversity, wetland ponds, stormwater wetlands, and detention basins.

The diagram in Figure 35 proposes the construction of a retaining wall along the river banks, as well as the inclusion of open swales and ponds. There is currently a pre-existing grassland with grass and turf. Due to the proximity of groundwater to the surface, ponds can collect moisture and distribute it, enhancing the aesthetic and water retention qualities of the area. The space is well-suited for expansive undulations that are linked to the surrounding vegetation. This could facilitate the drainage of the grass and turf for other athletic activities, while also allowing for the collection of water on the same site.

The guidelines for the three different sites can also be applied to other sites, taking into consideration factors such as available space, existing conditions, and the characteristics of the surrounding elements, which can be used interchangeably.

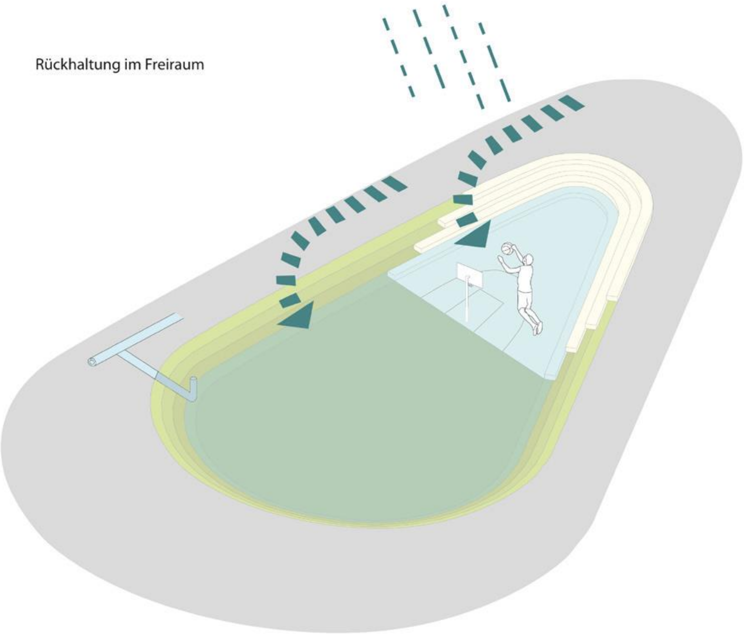


Figure 36 Open swale next to a basketball court

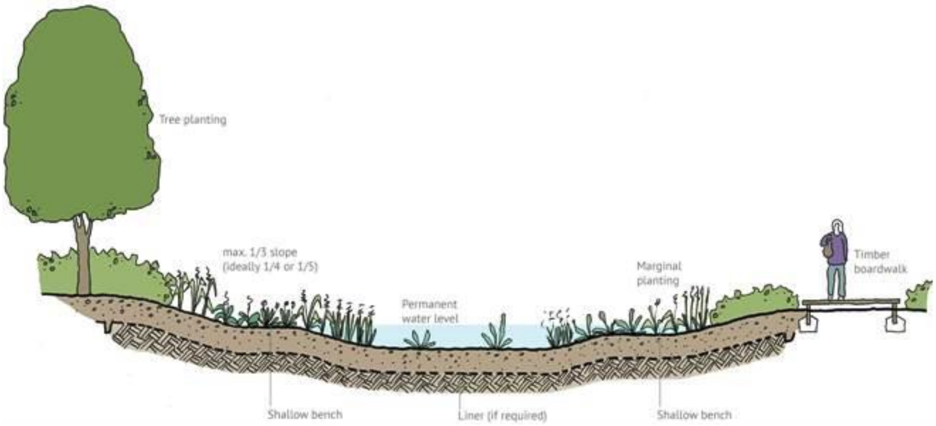


Figure 37 CIRIA Sustainable Drainage Systems (SuDS) Manual Section

6.2.2. Need for stakeholder engagement in planning, financing implementation, and management.

In the Bluegreen Streets toolbox, examples of different cities implementing the management strategy were mentioned with their exemplary results. For example, in Berlin, Berlin Waterworks and the state of Berlin signed a framework agreement in 1999 to divide street drainage duties. Berlin Waterworks plans, builds, operates, and renews troughs, trough trenches, and similar systems. The Senate Department for Environment, Mobility, Consumer, and Climate Protection finances planning and construction. The state of Berlin covers rainwater fees for public streets and squares. Property owners are responsible for paying rainwater fees for land connected to the sewer system. (BGIS toolbox A)
Another example showcasing smooth stakeholder communication and working together towards the success of blue-green infrastructure management in Hamburg. Different systems in Hamburg have different street drainage responsibilities. Troughs, ditches, and similar features can be water or street ditches, depending on their location and purpose. If they drain streets only in public paths, they are street ditches. This classification uses sections of a legal framework.

Public wastewater systems include Hamburg's gradient and pressure pipelines (collectors, sluices). These wastewater pipelines and facilities dispose of wastewater. Troughs, trough connecting lines, street drainage lines, ditches, infiltration shafts, and troughs are not public wastewater systems. The system has clear boundaries on responsibilities, which makes it easy for management and monitoring. (BGIS toolbox A)

The collaboration of different stakeholders contributes to holistic planning that could benefit the city's move towards sustainable measures regarding stormwater management.

6.2.3. Need for further research

In addition to a comprehensive planning and monitoring strategy, there is potential for additional research and development in various areas related to evaluating the effectiveness and sustainability of green lanes and other elements of green infrastructure. Further research is required to develop the methodology and conduct more detailed investigations into the performance of green lane elements in soil and vegetation. Enhanced integration of diverse scientific and professional components could be further developed to facilitate a comprehensive planning and design approach. This could assist decision-makers in gaining a broader perspective when choosing to pursue green infrastructure development. Professionals from various but related fields can also utilize shared terminology to measure and assess the impacts of blue-green infrastructure installations.

6.3. Limitations

Even though this research presented solid implications for the improvement of surface perviousness and stormwater quantity, it was unable to quantify the exact effect of green lanes and blue-green infrastructure. Among the reasons for that is the contextuality of different urban areas and their meanings in terms of surface water quantity. For example, a flood-prone area with surface water, coastal flooding hazards, and river banks is expected to have more runoff considering the runoff path to the river or the next reservoir point. What is extreme in some areas could be tolerable in others, and that needs specific studies.

As the scope of this research suggests, the major limitation is the lack of open flow records for the open stormwater system. The challenge was significant because the principle states that management cannot be achieved without measurement. Without the capacity to measure and quantify previous actions, it becomes impractical to establish a point of reference for comparison. The lack of quantification in Glasgow's current blue-green infrastructure has required several modifications in research methods and methodologies.

The other limitation connected to the previous fact of this research is that examining efficiency and viability hasn’t been quantified. It was qualified, recommended, and proved through other means of literature and benchmarking. With that, there is ample space for further research on connecting urban open and green spaces and stormwater measurement management and control mechanisms quantitatively. Engineers, planners, and environmentalists could study further to close the gap between the applicability and understanding of guidelines and management plans.

While it is true that the research may have limitations in quantifying efficiency and viability, qualitative methods can still provide valuable insights and recommendations for urban open and green spaces. Additionally, further research could explore alternative ways to measure and assess stormwater management strategies to enhance the understanding of their effectiveness.

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SP -
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VL -
ER -
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APPENDIX A

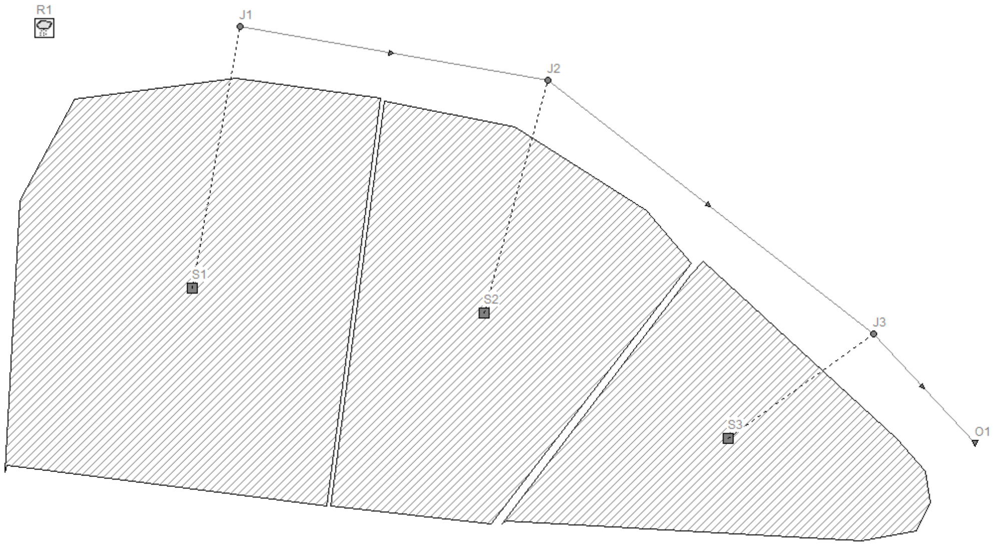
EPA SWIMM simulation for runoff volume calculation

Step 1

Downloading a georeferenced image of the site

Step 2

Tracing blocks to prepare the catchment area. In the case of Govan



This particular shopping area is subdivided into three sub-catchments. S1, S2, S3

Step 3

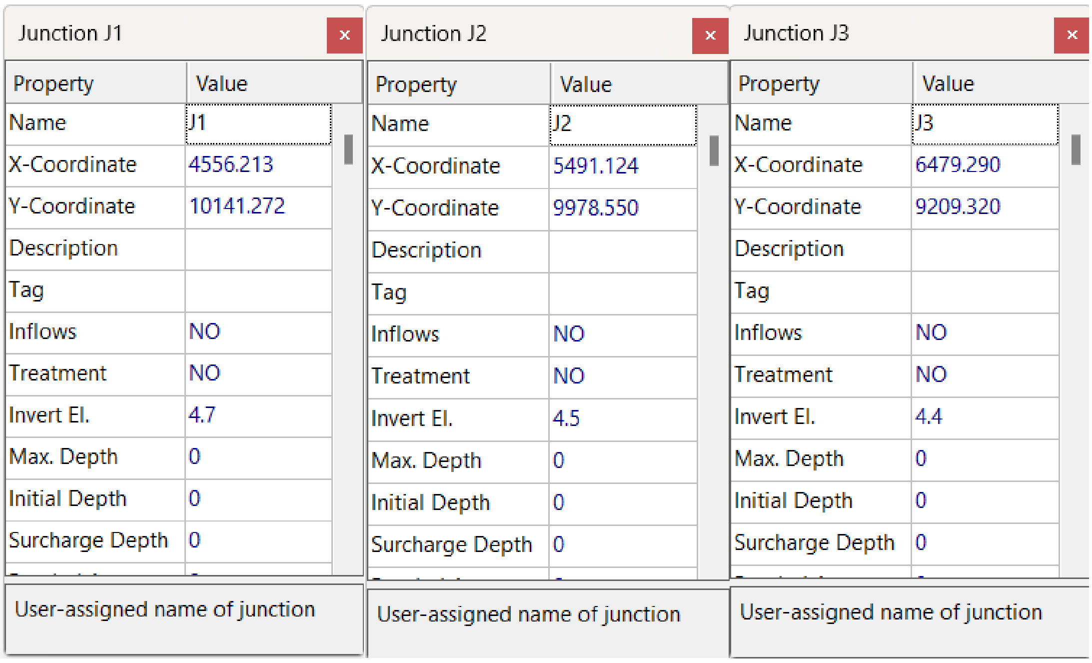
Create and connect three junction nodes to the three sub-catchments J1, J2, J3

Step 4

Add an outfall O1 and connect all the junction nodes to it.

Step 5

Connect the sub-catchments S1,S2, and S3, To junction nodes J1, J2, and J3



Junction J1

Property	Value
Name	J1
X-Coordinate	4556.213
Y-Coordinate	10141.272
Description	
Tag	
Inflows	NO
Treatment	NO
Invert El.	4.7
Max. Depth	0
Initial Depth	0
Surcharge Depth	0

User-assigned name of junction

Junction J2

Property	Value
Name	J2
X-Coordinate	5491.124
Y-Coordinate	9978.550
Description	
Tag	
Inflows	NO
Treatment	NO
Invert El.	4.5
Max. Depth	0
Initial Depth	0
Surcharge Depth	0

User-assigned name of junction

Junction J3

Property	Value
Name	J3
X-Coordinate	6479.290
Y-Coordinate	9209.320
Description	
Tag	
Inflows	NO
Treatment	NO
Invert El.	4.4
Max. Depth	0
Initial Depth	0
Surcharge Depth	0

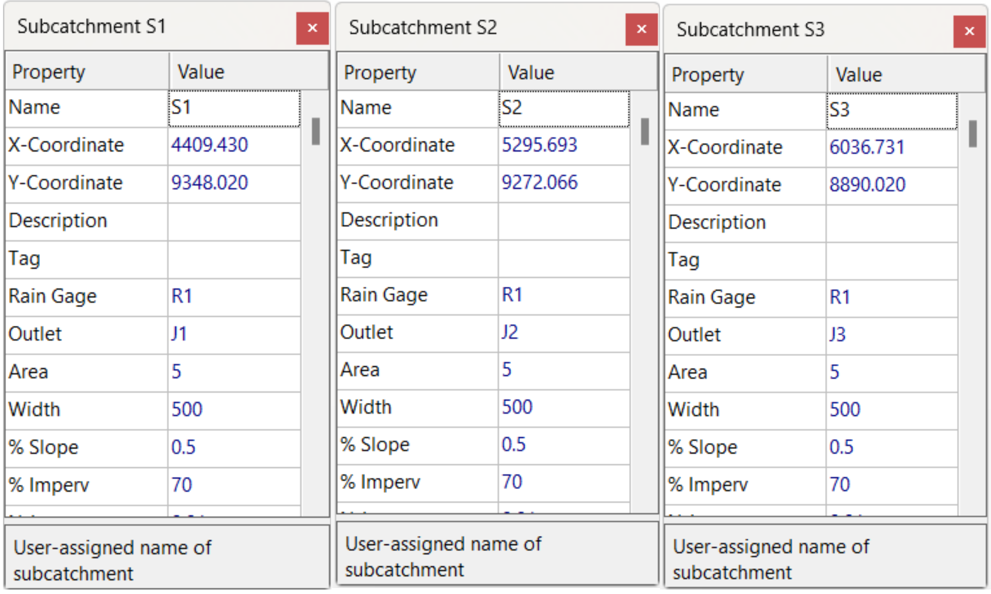
User-assigned name of junction

Step 6

Give the individual junctions inverted elevation of different values to junctions J1, J2, J3

Step 7

The slope of 0.5 % and imperviousness of the surface is 70% for the three sub-catchments S1, S2, and S3



Subcatchment S1

Property	Value
Name	S1
X-Coordinate	4409.430
Y-Coordinate	9348.020
Description	
Tag	
Rain Gage	R1
Outlet	J1
Area	5
Width	500
% Slope	0.5
% Imperv	70

User-assigned name of subcatchment

Subcatchment S2

Property	Value
Name	S2
X-Coordinate	5295.693
Y-Coordinate	9272.066
Description	
Tag	
Rain Gage	R1
Outlet	J2
Area	5
Width	500
% Slope	0.5
% Imperv	70

User-assigned name of subcatchment

Subcatchment S3

Property	Value
Name	S3
X-Coordinate	6036.731
Y-Coordinate	8890.020
Description	
Tag	
Rain Gage	R1
Outlet	J3
Area	5
Width	500
% Slope	0.5
% Imperv	70

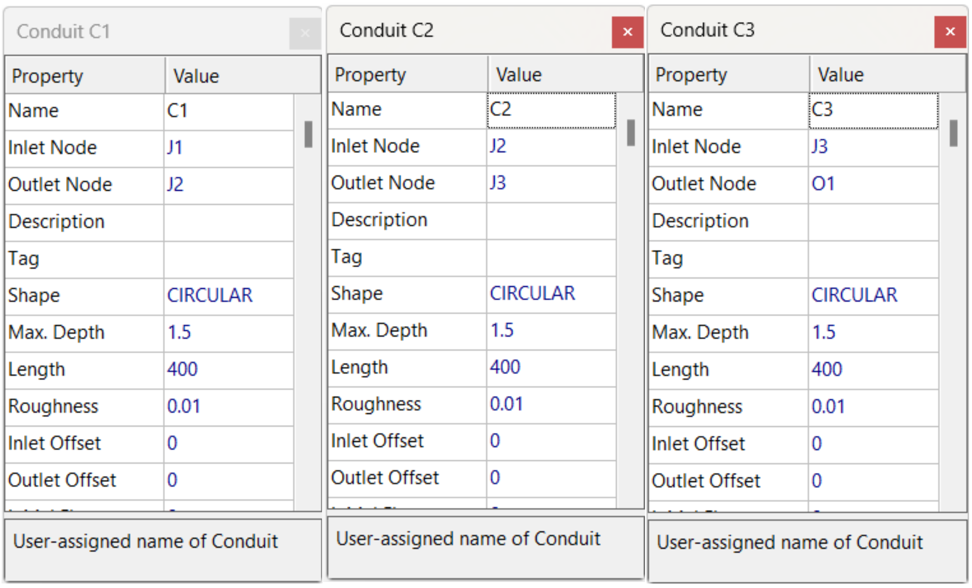
User-assigned name of subcatchment

Step 8

Create links between Junctions J1, J2, and J3 plus outfall O1 using Conduits C1, C2, and C3. C1 connects J1 to J2. C2 connects J2 to J3 and C3 connects J3 to outfall 1 O1.

Step 9

Arrange the environment for conduit links



Conduit C1

Property	Value
Name	C1
Inlet Node	J1
Outlet Node	J2
Description	
Tag	
Shape	CIRCULAR
Max. Depth	1.5
Length	400
Roughness	0.01
Inlet Offset	0
Outlet Offset	0

User-assigned name of Conduit

Conduit C2

Property	Value
Name	C2
Inlet Node	J2
Outlet Node	J3
Description	
Tag	
Shape	CIRCULAR
Max. Depth	1.5
Length	400
Roughness	0.01
Inlet Offset	0
Outlet Offset	0

User-assigned name of Conduit

Conduit C3

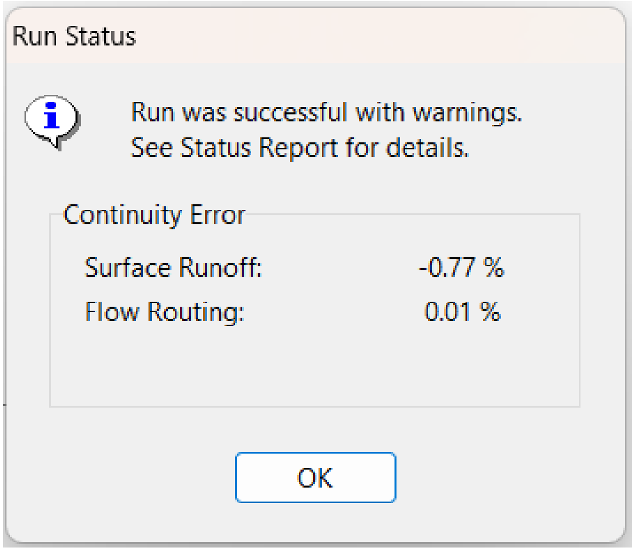
Property	Value
Name	C3
Inlet Node	J3
Outlet Node	O1
Description	
Tag	
Shape	CIRCULAR
Max. Depth	1.5
Length	400
Roughness	0.01
Inlet Offset	0
Outlet Offset	0

User-assigned name of Conduit

Circular shapes of conduit with a 1.5-meter maximum depth

Step 10

Running simulation



Run Status

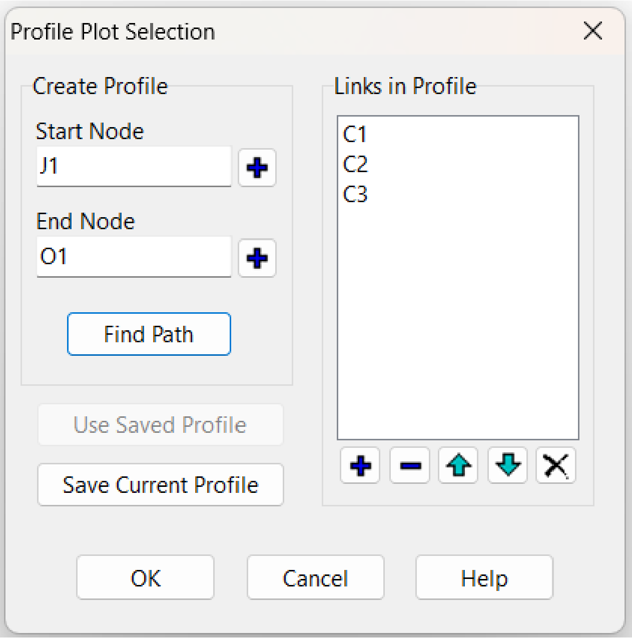
Run was successful with warnings.
See Status Report for details.

Continuity Error

Surface Runoff:	-0.77 %
Flow Routing:	0.01 %

Step 11

Elevation profile plot

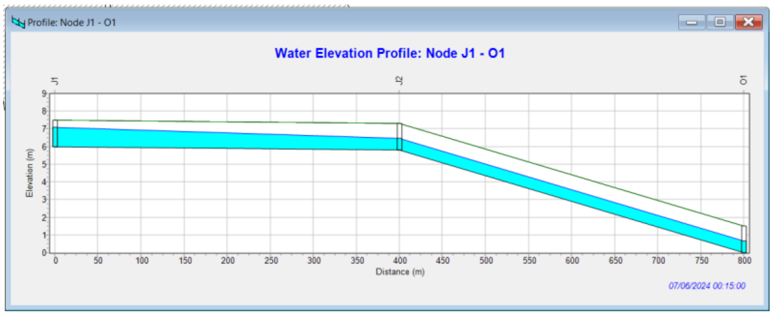


Start Node: J1

End Node: O1

C1
C2
C3

Selection of plot, starting node Junction 1 end node Outfall 1 then find the path, the links C1, C2, and C3 displayed



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