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Implementation of Sustainable urban Drainage systems with a relation to Ecosystem services

A case Study of Häggenås, Sweden

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Abstract

This thesis investigates how SUDS implementation in Häggenås, Sweden, can enhance ecosystem services (ESS) compared to traditional drainage practices. As an alternative to Conventional Drainage Infrastructure, SUDS offer not just management of stormwater, but also promotes ecological functions such as infiltration, habitat provision and recreation. The study uses a mixed-method approach, combining spatial analysis using GIS and Scalgo live with a conceptual ecosystem services evaluation- framework. Six different layout scenarios were simulated and compared. The study involved 1. Modelling runoff and infiltration behaviour under these different land use scenarios and 2. evaluating the potential delivery of provisioning, regulating, supporting, and cultural ecosystem services. Spatial overlays of land use, hydrological flow paths, and terrain were used to identify locations where SUDS could effectively address both drainage challenges and ecological opportunities, resulting in layouts including a fully sealed, vegetated, wetland-oriented, recreational and Hybrid configurations. The results show that SUDS, when placed in high-runoff and low-infiltration zones, can significantly reduce surface water volumes and improve local ecological functions. For example, wetland dominated, and vegetation-based designs significantly improve regulating and supporting services. These layouts are particularly effective in supporting biodiversity and water retention services. However, trade-offs were observed between infiltration and rapid runoff control, as well as between spatial land availability and ecosystem service multifunctionality. The study concludes that SUDS can be a valuable strategy for enhancing ecosystem services in rural settlements like Häggenås. However, successful implementation depends on planning capacity, site-specifics such as soil type and topography, policy integration, and long-term stakeholder engagement. The study highlights the importance of including ESS- thinking in early-stage spatial planning through accessible geospatial tools.

1 Introduction

1.1 Stormwater treatment throughout time

The management of wastewater from settlements is not a concern that has risen recently. Since the beginning of human civilisation, it is understood that the stormwater from inhabited areas needs to be managed in a way (Barbosa et al., 2012). Therefore, stormwater treatment is an ancient concern; some of the most advanced drainage systems at the time were constructed by Romans and existed even before, in Ancient Greece, Crete and in the Mesopotamian Empire. In these times, the practice of stormwater treatment was executed with a primary focus on conveyance of water away from urban areas (Fletcher et al., 2015).

Today´s perception of wastewater management differs from the old approach, the earliest adoptions of modern urban planning date back to the Garden City movement in the beginning of the 20th century (Home, 1990), which was one of the first examples of implementing green belts to provide food, amenity, recreation and leisure spaces within developed cities. In London, the parks movement in the 1870s and 1880s viewed urban green spaces as places of health (Loughran, 2020). Not only in London, but in several countries, green spaces- and Infrastructure has often been implemented before modern times, as part of planning measures that are designed to improve the urban ecosystem and human living conditions at the city scale (Tang et al., 2018). But it is a challenging task to maintain natural processes of previous ecosystems on a long-term basis, without the influence of human urbanisation (Alberti, 2005). Especially in modern times with growing population throughout the years, in which more infrastructure has been built, at the cost of natural vegetation (Khan et al., 2022). This is because Global urbanization trends are leading to widespread impermeable surface development and installation of complex infrastructure (Willems et al., 2012). Reckless urbanisation nowadays can be easily observed all around the globe, it´s an easy way to deal with stormwater; in some cases, these conventional "grey" solutions rapidly channel stormwater away from the source to prevent flooding in public spaces (Johnson & Geisendorf, 2019; Narasimhan et al., 2023). Temporarily, this approach seems problem-solving when it comes to runoff mitigation.

But at the same time, "grey" infrastructure leads to increased volume and peak flow of stormwater after rain events, resulting in floods (Biswal et al., 2022) if not managed correctly. Additionally, in the case that grey infrastructure doesn´t cause floods by increasing peak flow, there are major problems arising for receiving water bodies (Grella et al., 2016). This regards water quality, since dust and organic substances from construction and transportation are washed from streets and impervious surfaces (Johnson & Geisendorf, 2019; Kang et al., 2024). Especially through artificially inserted pipes and ageing systems that often can be hardly exchanged. More precisely, untreated runoff and stormwater contain a high amount of chemical and microbiological contaminants (e.g., heavy metals, fecal bacteria), which affect the environmental quality of water and sediments (Jarosiewicz et al., 2024). When these issues get linked to global warming mainly driven by anthropogenic activities, they pose severe impacts on ecosystem dynamic and human health (Brooks et al., 2016). This also directly impacts biodiversity and local communities (Lapointe & Matzie, 1996).

1.1.1 Sustainable urban Drainage Systems and Nature based Solutions

Urbanization in northern Sweden, especially in smaller towns is increasing (Nuur & Laestadius, 2010). As more grey infrastructure replaces green space, the need for sustainable stormwater management becomes urgent (Khan et al., 2022).

The measures to sustainably treat stormwater are variously known as Sustainable Urban Drainage Systems (SUDS) in the United Kingdom, low impact development (LID) in the United States of America, and sponge city approaches in China (Narasimhan et al., 2023). In this research, they will be addressed as SUDS. These systems are an integrated network of engineered vegetated areas and open spaces (i.e., green roofs, rain gardens, porous pavements, etc.) used to protect natural ecosystem processes and functions and to offer a wide variety of benefits to people and wildlife (Ferrans et al., 2022). More concretely, one of the main goals of SUDS is to restore the natural water balance. This is achieved by increasing infiltration and evapotranspiration processes with detention at the source and promoting rainwater harvesting and reuse (Raimondi et al., 2023). Another more concrete goal is to avoid floodings and to increase the capability of ground vegetation to reduce harmful effects of pollutants (Johnson & Geisendorf, 2019).

An important feature of SUDS are nature-based solutions (NbS), which build the fundament of the ecological processes used in urban planning (Pineda-Pinto et al., 2022). More specifically, NbS are defined as living solutions driven by natural processes and structures that are designed to mitigate different environmental challenges, while providing multiple benefits to economy, society and ecological systems at the same time (Frantzeskaki, 2019). The SUDS approach recognises three main categories of NbS;

(1) Infiltration systems, including permeable pavements, swales, rain gardens, soakaways, infiltration trenches, and infiltration basins; (2) Evapotranspiration systems, which include green roofs, retention basins, wetlands, and (3) rainwater harvesting systems (Kabisch et al., 2022). To support and facilitate the implementation of NbS- design for stormwater management, cities have developed guidelines, covering design variables, materials, construction, and maintenance of some NbS types (Orta-Ortiz & Geneletti, 2022).

1.1.2 Ecosystem Services in planning processes (problem description)

These previously explained Nature-based Solutions (NbS) offer a sustainable pathway and are useful tools for efficient planning, but their integration with existing infrastructure in urban settings remains still occasional (Jarosiewicz et al., 2024). NbS in this context are strongly linked with Ecosystem services, but even if sustainable planning approaches have increased over the years (Roggema, 2016), there's limited integration of ecosystem service evaluation in urban drainage design. Municipal designs may not fully exploit the potential of NbS to provide benefits for the environment, beyond management water quality-and quantity (Cotterill & Bracken, 2020). Stormwater systems in new residential areas are often based on engineering convenience and safety rather than optimizing ecosystem services (Cotoarba et al., 2020). For this case study, Ecosystem services will be defined according to the Millennium Ecosystem Assessment- framework, "the benefits people obtain from ecosystems, categorized into provisioning, regulating, cultural, and supporting services" (MEA, 2003).

Essentially, there is a gap in knowledge regarding the lack of ecosystem-based evaluation of SUDS in urban planning. And although SUDS have been widely studied, few studies have compared them using ecosystem- services indicators in a localized Swedish planning context. When applying this gap to Östersunds municipality, there is currently no method to compare SUDS layouts from an ESS perspective in the planning process.

1.2 Purpose of Study

The study follows the following purposes:

(1) Gain a better understanding of optimizing stormwater infrastructure by integrating ecological and hydrological performance metrics
(2) Increase the general understanding of how Ecosystem Services can be evaluated in connection to SUDS
(3) Introduce more consideration for Ecosystem Services into the planning of future projects

1.3 Research question

"How does the implementation of Sustainable Urban Drainage Systems (SUDS) in the community of Häggenås affect ecosystem services compared to conventional practices?"

2 Methodology

2.1 The chosen site

Häggenås is a semi-urban community in Östersund Municipality, Jämtland County. This location was selected for a case-study because it is currently being developed for a school, preschool, sports hall, and adjoining green space (Sigma Civil AB, 2024) which are located in the town- centre. Real design-decisions are still being made on the site, in fact the municipality has already provided a stormwater assessment plan with SUDS infrastructure details, which gives an informational background for evaluating current Ecosystem Services. Some of the most important current features of this site include: A 10-meter elevation difference with a slope that stretches from north to south. The soils mainly consist of moraine, and the estimated depth of the bedrock is 3-10 meters. The site has existing land uses such as open grasslands, paved surfaces, and woodland edges that are partial (Östersund Municipality, 2023). Häggenås' municipal plan includes basic SUDS features, but lacks a design tailored toward maximizing human enjoyment and health through ecosystem services.

2.2 Delimitations

The study is focused solely on the area outlined in the municipality development plan "Häggesta 1:59" (Sigma Civil AB, 2024), (Figure 1) approximately 25 km to the north of Östersund. This site is a pilot-project, in which new sustainable stormwater infrastructure will be implemented. Hydrological analysis is limited to surface water processes, for example surface runoff volume and infiltration capacity. Groundwater modelling and long-term water quality impacts are beyond the scope of this project. Seasonal variations are also not included in the study boundaries either. Therefore, the results of this project apply to warm seasons, in which stormwater doesn´t freeze or is being influenced by altering seasons.

Figure 1 Original Detail-plan for the site "Häggesta 1:59" (Sigma Civil AB, 2024)

2.3 Data Collection

This study used a comparative scenario analysis, based on quantitative surface water modelling and qualitative ESS assessment. The primary modelling tool used was Scalgo Live, which is a web-based surface water modelling service. The program uses high-resolution national elevation data from the Swedish mapping, cadastral, and land registration authority Lantmäteriet, with a 0.5–2-meter raster cell size that changes with local data availability (See Scalgo live sources in the Appendix nr. 2).

The platform's flash flood and flow accumulation modules were used to simulate runoff dynamics and investigate terrain sensitivity. Also, for spatial analysis, factors such as slope, land cover, drainage flow were taken into consideration.

The “Illustrationskarta” (Figure 1) and stormwater report (Sigma Civil AB, 2024), provided the baseline infrastructure, drainage intent, and technical assumptions. Drainage is presently conceived through a sequence of SUDS features such as macadam trenches, rain gardens, detention basins, and underground stone coffins (Sigma Civil AB, 2024). These were identified through the stormwater planning document of the municipal baseline and cross-referenced with the Illustrationskarta (planning map) georeferenced in QGIS, for a better and more accurate simulation of the runoff in Scalgo live. Runoff generated in this area is drained with 2 main outflow routes, both leading southwards through and beyond site limits, making slope and flow accumulation modelling necessities (Östersund Municipality, 2023). The parameters for comparison in this research are: (1) runoff volume; (2) Infiltration volume. Based on these two parameters, and variations of the models in terms of building materials and land cover, conclusions will be drawn about Ecosystem services.

2.4 Data Analysis

All designs were drawn by hand into Scalgo live, and all model variants were based on the same terrain, drainage direction and rainfall conditions (100mm), with the only difference being the configuration of the land cover and SUDS features. This was achieved by altering land use layers, infiltration rates, curve numbers (CN), and abstraction ratios (λ). The infiltration capacity was input manually in Scalgo live for all surface types, based on soil classifications and expected performance in literature (Archer et al., 2020; Kuok et al., 2023; Wang et al., 2018). For instance, rain gardens were assigned a CN of 70 and λ of 0.1. Impervious areas like roofs and pavements were given CN values close to 98 with λ = 0.05, According to (Ballard et al., 2015) as presented in Table 1. The Curve number (CN) stands for how much of the rainfall becomes runoff, depending on land cover, soil type, and surface condition (Oliveira et al., 2016). meaning that a Higher CN results in more runoff, and a lower CN in more Infiltration and less runoff. On the other hand, Lambda (λ) defines how much water is initially lost before runoff even starts. For example, through Evaporation, direct Infiltration into dry soil or depression storages in form puddles or detention tanks. The smaller λ is, the faster the runoff starts (Ballard et al., 2015).

Table 1: Values for Curve Number and Lambda for most notable SUDS-features (based on standard tables from CIRIA SUDS Manual by Ballard et al., 2015)

Surface Type	Curve Number (CN)	Lambda (λ)	Types of Vegetation
Impervious surfaces	98	0.05	Concrete, Rooftops
Rain gardens	70	0.10	Designed infiltration with vegetation

Pervious pavement	75–85	0.07–0.10	Gravel-filled or porous surfaces
Natural forest areas	60–70	0.20	Soil with high retention
Vegetated open space	75–80	0.10	Grass or lawns
Wetland zones	50-55	0.15–0.20	Modelled with high storage capacity
Macadam ditches/trenches	60–70	0.10–0.15	Subsurface gravel-filled infiltration ditches

In this investigation, six different layouts were compared. The first layout is the originally proposed layout by the municipality of Östersund. The comparison to this layout is firstly a variation of "Extreme scenarios":

(1) The site being completely covered in concrete; This scenario represents a model for reckless urbanisation and the effects on wastewater runoff, infiltration and Ecosystem services. This layout serves as a contrasting option when comparing it to the others. This scenario helped identify the magnitude of runoff increases when green infrastructure is absent.

(2) The site containing an excessive amount of natural vegetation and landcover; This scenario opposes the first layout by representing a model for natural habitats which were not influenced by human urbanisation. This site is focused on representing the high permeability of well-structured forest soils.

(3) This model doesn´t differ from the municipality´s proposed layout in terms of Sustainable urban drainage. Instead, it solves the issue of runoff volume; The runoff was channelled into a single large wetland located at the bottom of the slope. Storage depth was modelled at 50 cm across 5,000 m², resulting in an expected full retention of stormwater. This layout is heavily focused on Water retention and infiltration.

After the "extreme" scenarios,

(4) the proposed model is being compared to the recreational Layout: Designed to enhance human-centred ecosystem services. This scenario included permeable pavements for pathways, tree clusters, low-density recreational lawns, blue-green spaces and more. An

open space with permeable pavements and stairs in the middle of the site; On the south side of the layout opportunities for open-air recreational activities. Combining detention ponds into walkable pathways and rather spreading out the water stored at the surface (instead of channelling it all into one big detention system). The layout had similar total green space as the municipal plan but focused more on aesthetic and functional design rather than including “wild zones” for recreation.

(5) Ecological Engineering layout: which contains a high number of features that resemble the implementation and functions of ecological engineering. This layout uses evapotranspiration, infiltration, and detention at the source. Detention ponds, infiltration trenches and gravel beds were included. The overall amount of vegetation present in this layout exceeds the previous one by a lot, since infiltration is not simulated artificially in this case. Rather, it keeps water at the surface to increase the recreational function and increase natural processes at the same time. This layout focuses heavily on restoring the natural water balance. Therefore, it aligns with the main goal of sustainable urban drainage systems (Fletcher et al., 2015).

Runoff and infiltration outputs were extracted for each scenario and compared to the baseline. Outputs included total runoff volume (m^3), infiltration volume (m^3), and flow accumulation maps. For a visual representation of the infiltration rates of different land covers used, check Appendix nr. 3&4.

2.4.1 Method for the evaluation of Ecosystem services

To translate ecosystem services (ESS) into measurable indicators, this study used a simplified quantification approach using hydrological outputs as proxies for specific services. Surface runoff volume was used as a proxy for flood regulation (a regulating service), while infiltration capacity served as a proxy for groundwater recharge and purification functions, which can be counted as a regulating service as well. The higher the infiltration rates and the decrease in runoff volume, the higher the provision of regulating ESS respectively. Each SUDS layout's performance was evaluated by comparing modelled runoff and infiltration volumes against the baseline (municipal) scenario. The relative changes were interpreted as improvements or reductions in the associated ecosystem services. While this approach focuses on quantifiable hydrological outputs, it also reflects provisioning and supporting services like biodiversity through land cover types (such as forest or wetland) and cultural services (via recreational land uses). Regulating Ecosystem services will be presented in the Results, whereas the other Types of Ecosystem Services (Provisioning, supporting and Cultural) will be evaluated further on in the Discussion. This is because Runoff-and Infiltration are clear and numerical measures for Regulating services, and biodiversity and recreational land uses are quantitative measures for Provisioning, supporting and cultural services. The distinction here is that Quantitative measures are part of the Results, and Qualitative measures part of the Discussion.

3 Results

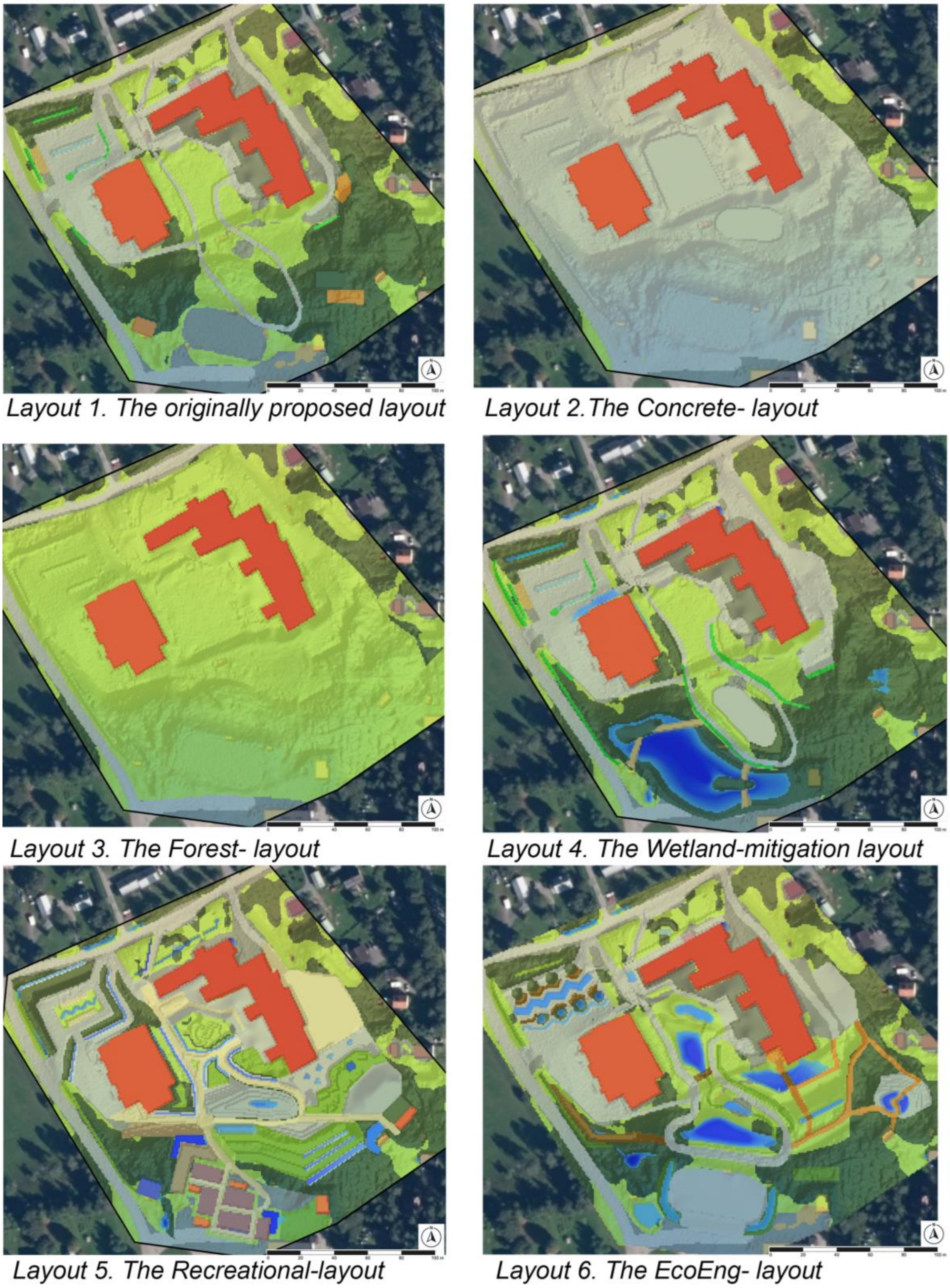

Figure 2 Layout variations 1-6. (For explanation of landcover-colors, check Appendix 4)

As visible in Table 2, the original Runoff volume from the proposed plan is 919,05 m³ and the Infiltration volume is 1.883,94 m³. In comparison, when looking at the "All Concrete" Model which simulates reckless urbanization, the completely impervious surface coverage generates 264.56% higher runoff (3,350.45 m³ compared to the baseline 919.05 m³). This results to 3.6x more stormwater entering site-specific drainage systems during precipitation events. Since the site is covered in concrete, the natural water infiltration sinks down to 329.81 m³ – an 82.49% reduction from the baseline 1,883.94 m³.

On the other hand, the natural vegetation cover of the "All forest" layout reduces runoff by 36.51% (583.55 m³ compared to 919.05 m³). This layout also achieves 59.75% greater infiltration (3,009.58 m³ compared to 1,883.94 m³)

The "Wetland mitigation" model reports 0 m³ runoff volume – a complete 100% reduction from baseline, while Infiltration increases by 24.31% (2,341.9 m³ vs. 1,883.94 m³), though less intensively than the forest scenario.

The Recreational approach decreases runoff by 32.23% (622.88 m³ compared to 919.05 m³), while having a Neutral Infiltration Impact, since it remains nearly identical to baseline (+0.25% at 1,888.7 m³).

The ecological engineering- model cuts runoff by 60.34% (364.49 m³ compared to 919.05 m³). At the same time, infiltration increases by 19,8% (2256,88 m³ compared to 1,883.94 m³).

Table 2 Runoff and infiltration volume values and percentage difference from proposed plan

Version of Plan	Municipality proposal	All Concrete	All Forest	Wetland mitigation	Recreational	Eco-Engineering
Runoff Volume	919,05	3.350,45	583,55	0	622,88	364,49
Percentage difference	0%	264,56%	-36,51%	-100%	-32,23%	-60,34%
Infiltrated	1.883,94	329,81	3.009,58	2.341,90	1.888,70	2256,88
Percentage difference	0%	-82,49%	59,75%	24,31%	0,25%	19,8%

Figure 3 is a visual representation of the previously mentioned data values, in which the “all concrete” and the “all forest” layouts have the highest values in Runoff volume and Infiltrated volume respectively. It is visible that the wetland-layout in this figure completely cuts the runoff flowing out of the site compared to the other Layout configurations.

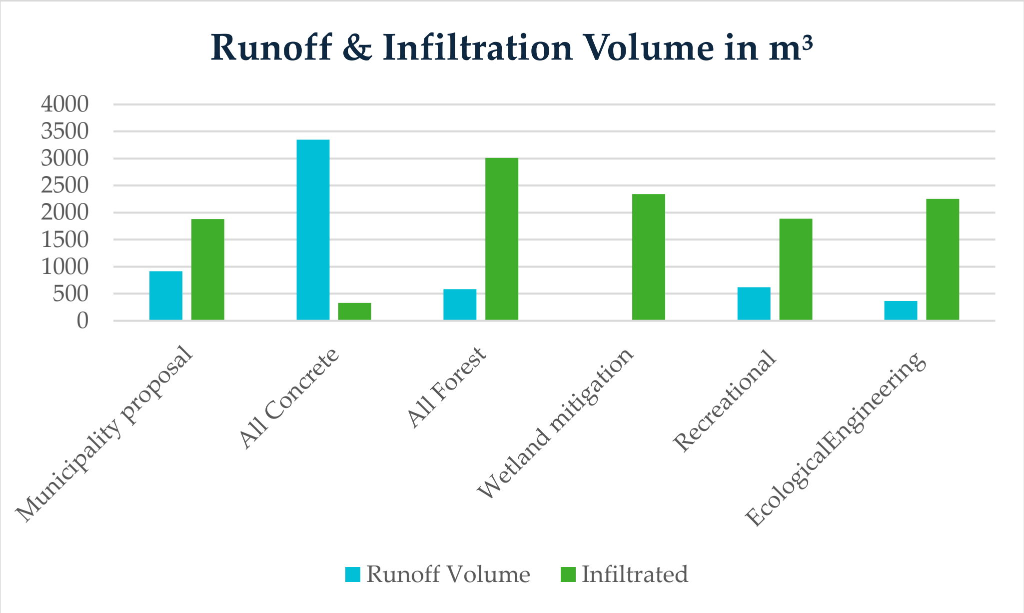

Figure 3: Runoff- and infiltration volume comparison in column diagram

4 Discussion

4.1 Ecosystem Services and SUDS Reflections by Layout

4.1.1 All Concrete Layout

The Runoff in this layout is excessive (since it increased over 2.5x), meaning that this scenario demonstrates a near- total loss of regulating services, especially regarding flood mitigation. With little to none- infiltration and no vegetation, provisioning and supporting services are absent (Alberti, 2005). Recreational services are arguably present to some extent, if the assumption is made that sports-fields or other (impermeable) cultural structures have been built in this layout. This layout creates a hydrological model dependent on engineered-drainage due to the loss of permeable surfaces (in form of vegetation in this case) and therefore reduced capability of groundwater restock. While this layout may reduce short-term planning costs, it leads to higher long-term expenses (e.g., flood mitigation, infrastructure repair, degraded water quality) (Khan et al., 2022). One of the strengths of this layout is the maximized buildable space and potential for recreational buildings. The cultural aspect of Ecosystem services will only be neglected, if the site will be completely covered concrete (e.g. a big parking lot). Since for this site, the intention was to reduce infiltration as much as possible, the ground cover is not limited to be concrete. Sports fields or running tracks have the same outcome as concrete (when only considered the runoff coefficient). This is observable, because the drainage of sports fields demands much greater planning and considerations to the redirection of rainfall to the underdrain system, than is normally necessary in agricultural drainage (Adams, 1986). Another benefit for this layout is the low maintenance infrastructure.

4.1.2 All Forest Layout

The forest layout, which was supposed to mimic a natural ecosystem-environment, nearly maximizes regulating services through flood control in this case, demonstrating forests' capacity to intercept rainfall through detention storage and enhanced infiltration (Wang et al., 2018). It also shows signs of strong supporting services and Biodiversity enhancement by simulating a natural habitat area. The soil show casts a forests' ability to maintain soil porosity while supporting carbon sequestration through the soil (Verma & Ghosh, 2024). This facilitates vertical water movement even during intense storms. This layout lacks recreational services, in the sense that the services are somewhat subjective. Hiking in nature can be considered as a cultural service, but in this case the assumption exists that the children belonging to the school- and preschool area don´t find a cultural service in a forest.

4.1.3 Wetland layout

The aim of this layout was to reduce runoff to zero and therefore providing exceptional regulating service**.** This performance stems from a wetlands' dual capacity for (1) surface water storage and (2) gradual release through evaporation. This system prioritizes holding water rather than rapid percolation. Wetlands provide one of the most multifunctional SUDS types (García & Santamarta, 2022). Beyond only reducing runoff, they offer supporting (habitat creation), regulating (water purification), and cultural (landscape value) services.

4.1.4 Recreational Layout

This layout illustrates how permeable recreation areas (e.g., sports fields with drainage systems) can mitigate stormwater flows compared to dense urbanization. This recreational layout shows trade-offs between hydrological performance and human well-being. They may not maximize infiltration, but offer cultural services like increased mental health, aesthetics and moderate (compared to baseline) regulating services. Since the Infiltration remains nearly identical to baseline, this suggests that careful landscape design can maintain natural hydrology, while accommodating public amenities (Hellmers et al., 2018). Figure 4 reflects a visual representation of the ambience in the “main square” of the recreational layout. For a complete visualisation of this layout in the style of the proposed municipal baseline, check Appendix Nr. 1.

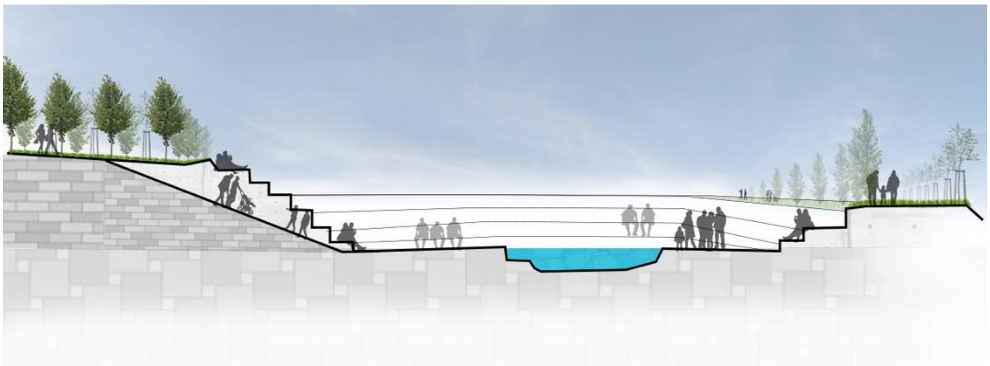

Figure 4 Conceptual side-view of Open space for recreation

4.1.5 Ecological Engineering Layout

This layout shows strong runoff control through technical solutions while simultaneously increasing infiltration. The achievement of runoff reduction outperforms pure conservation approaches through integrated green infrastructure and controlled drainage systems (Biswal et al., 2022). It provides targeted regulating services but risks compromising natural supporting services. Apart from its runoff benefits, infiltration increases as well, which highlights the potential for mitigating both evaluation-parameters (runoff and infiltration) at the same time and therefore resulting in the best performing layout out of the Six modelled ones, in terms of overall Ecosystem Services- evaluation (Appendix Nr. 7). As seen in figure 5, water is kept at the top of the soil to increase evapotranspiration and restore the natural water cycle while increasing recreational value.

Figure 5 Conceptual side-view of slope- usage and restoration of natural water balance

Table 3: Legend for Table 4

--	**No potential**
-	Not supportive
+/-	Dependent on Variables
+	Supportive
++	Very supportive

Table 4: Evaluation of Ecosystem Servies in connection to the Layouts

	Original	Concrete	Forest	Wetland	Recreational	EcoEng
(Biodiversity)	-	--	++	+	-	+
Supporting	+/-	-	+	+	-	+
Recreational	+	+	+/-	+	++	+/-
Provisioning	-	-	+/-	-	+	+
Regulating	+	-	+	++	+	++

For a more detailed explanation of Ecosystem services and the connection to the layouts, check Appendix nr. 5

4.2 Trade-offs in SUDS Planning

It has to be noted, that one layout can't fully optimize all Ecosystem services at once (Cai et al., 2020). For example, biodiversity-rich designs (like the "All forest", "Wetland mitigation" and the "EcoEng" layouts) may reduce developable land which can be used for recreational purposes (Gret-Regamey et al., 2020). The layouts which are dependent on Infiltration, in this case the "EcoEng" and "Wetland mitigation" may struggle in clay-rich soils, which limits the application and implementation of these features to some extent. On the other hand, engineered SUDS may outperform nature-based designs in runoff, but miss recreational or aesthetic value (Ashley et al., 2015). So, the key takeaway is ecosystem services must be balanced based on the goals of the project. For a spider diagram comparing layouts across ESS categories, check Appendix. Nr. 6.

4.3 Comparison with Literature

In this section, each ecosystem service that was analysed (regulating, supporting, provisioning, cultural) will be compared with similar case studies, or theoretical expectations.

Regulating Services (runoff reduction, infiltration)

The findings for the optimized layouts validate similar research, which cites the potential for SUDS in enhancing regulating services, particularly by reducing floods and infiltration. Ashley et al., 2015 for example, emphasizes that the use of permeable surfaces and the implementation of planted drainage systems (such as swales and wetlands) significantly reduce surface runoff. Similarly in the present study, the "Ecological Engineering" and "Wetland" layouts led to a decreased runoff by 60-100 %, supporting the regulatory function identified in previous studies. In this rural illustration, however, there is a second observation: while runoff was regulated, infiltration depended on soil and layout composition, an issue identified by (Archer et al., 2020) who argues that SUDS is dependent on local geohydrological contexts The results therefore confirm the importance of site-specific adaptation in SUDS design.

Supporting Services (biodiversity, habitat provision)

The potential for SUDS to support ecosystems, for example habitat creation and local biodiversity gain, has been well-established in existing literature (Briers, 2014). Findings from this study confirm that intensely vegetated designs, especially the "All Forest" and "Wetland" (in terms of blue-green infrastructure) cases, theoretically offer greater local biodiversity support by mimicking natural ecosystems and promoting species diversification. The findings support the hypotheses proffered by (Gómez-Baggethun & Barton, 2013), who argue that urban green infrastructure can serve as substitutional ecosystems in developed environments. Although from an ecological perspective these advantages were evident, general interviews with stakeholders indicate a lack of local perception concerning biodiversity as an objective for planning, mentioned by research carried out by (Johnson & Geisendorf, 2019). Since Stakeholder input was outside of the delimitation range, it is difficult to predict the outcomes of stakeholder inputs specifically for these layouts.

Cultural Services (e.g. recreation, aesthetic value)

Cultural Ecosystem services, such as recreational sites, were more subtle in the results. Whereas the "Recreational" design tried to increase cultural value, its hydrological function was still the same as the baseline (increase by 0.25%), which suggests trade-offs. This repeats (Cai et al., 2020) findings, in which they speak about how green infrastructure with multifunctional aims must sometimes compromise ecological performance for human advantages. It must be noted that Recreationally- focused layouts may still outperform "natural" layouts, if carefully designed with permeable pavements that in this case, simulate ecological processes. This doesn´t mean that Natural vegetation should be replaced by artificial mimics but suggest that recreational value can still be achieved in sites sustainably.

Trade-offs and multifunctionality

One of the central themes of the literature is that no single design of SUDS will achieve maximum function of all ecosystem services simultaneously. This study supports this assertion, as all design scenarios involved trade-offs. The "All concrete" design optimized buildable space but reduced infiltration through rapid diversion on the surface—a conflict also noted in the study of (Fletcher et al., 2015). Similarly, the "All-Forest" configuration recorded high supporting and regulating services but minimal cultural or provisioning benefit, repeating the SUDS manual (Ballard et al., 2015), which highlights the tension between biodiversity-convivial land uses and urban development potential at the spatial scale. Such parallels indicate that while the specific SUDS layouts in Häggenås are unique, the same planning issues are found in many global contexts.

4.4 Reflections on Methods and Limitations

Reflecting on the methodological approach used in this thesis, several strengths and limitations emerge. Using Scalgo Live as the main software for modelling is suitable for quantifying runoff and infiltration and comparing spatial layouts. It was possible to rapidly model compared to other softwares, and spatial clarity was easily obtainable (Warzecha & Dudek-Klimiuk, 2023a). Scalgo live is a tool suitable for strategic and planning work in more efficient urban and water management, since basic data on the amount and direction of surface runoff can be estimated with this tool (Warzecha & Dudek-Klimiuk, 2023b). It can convert areas into catchments, establishing flow paths, introducing features like ditches, culverts, and reservoirs, and analysing land cover (Wałęga et al., 2024).

On the other hand, relying on default assumptions within Scalgo live (surface runoff calculations, absence of subsurface modelling) posed some limitations. If Scalgo live was to be applied on bigger projects, a primary limitation lies in the necessity for high-quality digital terrain elevation (Wałęga et al., 2024). For groundwater modelling and detailed pipe-drainage engineering, other softwares need to be used. Additionally, the version of Scalgo live used for this research does not allow to include the time-variable in the rainfall conditions. This study used a 100mm rainfall parameter, which is assumed to be falling all at once onto the site. In real life scenarios, this amount of rain would fall over a certain period of time. By not including the time-factor in Scalgo live, metrics like infiltration will be limited severely. If the soil had more time to infiltrate the rainwater, less runoff would be resulting in the outcomes of the layouts. On the other hand, the fact that these layouts are able to withstand 100mm of sudden rainfall (and still reduce runoff from the municipal baseline) show the potential of these configurations in real-life storm events.

Apart from the technical aspects, Scalgo live is limited for measuring biodiversity or long-term ecosystem resilience. These assumptions may simplify or overlook important localized hydrological dynamics, such as infiltration capacity or seasonal variability in precipitation and snowmelt — a relevant factor in Häggenås due to its northern climate. Other methods that can be included in the research for future studies are ground-truthing, biodiversity field surveys, or life-cycle cost assessments to increase the accuracy of results. In this research, these methods are outside of the delimitation range, and therefore not of significant relevance.

Overall, the methodology was sufficient to meet the study’s aims, especially as a scoping and planning tool. The approach provided a holistic overview of both the ecological and infrastructural landscape, which is valuable for early-stage planning and decision-making. Since groundwater modelling or water quality were outside of the delimitation-range of this project, Scalgo Live was suitable for this investigation.

4.5 Reflection on method to evaluate ESS performance

A reflection needs to concern the subjectivity in evaluating and assigning scores to ecosystem services based on land use or location it´s a method that, while practical, poses risks of overgeneralization. The grading criteria for the different ecosystems was based on a qualitative comparison between the amount of present SUDS features in a layout. For example, the more Recreational features a layout contains, the higher the recreational value of it (See Appendix Nr. 5). Ecosystem service mapping used categorizations, and the accessibility data (recreational potential) lacked detailed validation, or public perception input. These limitations restrict the study's ability to assess cultural services with precision. Integrating stakeholder input or ecological field surveys could have improved the robustness of this part of the analysis. In this case, the method used for evaluating Recreational services is not quantitative, there´s no numerical value to it. This also is reflected in the spider diagrams of the Appendix Nr. 6. These diagrams serve as a visual representation of strength and weaknesses and are not based on calculations. They were compared between themselves in performance compared to the municipal baseline, and according to the rating they were assigned different values. The best performing layout (or the one with the most potential) got the best score, and the worst performing (least potential) the lowest score.

It needs to be noted that the TEEB- framework (Buckley, 2011) has been taken into consideration while evaluating Ecosystem Services, although not explicitly mentioned in the methodology of this research. The Study uses a functional classification of Ecosystem Servies, similar to TEEB´s categories (provisioning, regulating, supporting, and cultural services) to evaluate the performance of different SUDS layouts. This approach is in line with the framework to use quantifiable hydrological outputs (infiltration and runoff volume) as proxies for ecosystem service delivery. TEEB recommends integrating ecological and economic reasoning into urban infrastructure design. This scenario-based comparison of SUDS layouts can therefore be seen as a simplified- and localized application of the TEEB framework.

About the SUDS- features and spatial distribution, the layouts themselves would doubtlessly appear different if a different author would have designed them; the decision for designing the layouts are based on the author´s own perception of what a layout about a type of ecosystem services should look like and what SUDS features it should include.

4.6 Conclusion

This study aimed to examine the effects of application of Sustainable Urban Drainage Systems (SUDS) within the Häggenås community on ecosystem services as compared to conventional stormwater management. From the results, SUDS were found to improve quite significantly through various ecosystem services, ranging from regulating ecosystem services such as flood management to supporting services like biodiversity. An increase in multifunctionality was observed where SUDS overlaps with natural covers, and this indicates that these measures can provide co-benefits beyond water management. Therefore, SUDS are not only infrastructure works but also nature improvers and can improve the provision of Ecosystem services more in a sustainable manner.

The evidence aligns with the assumption that SUDS can be an effective way to enhance ecosystem services in small rural towns. Emulating natural functions, SUDS represent a multifaced alternative for conventional drainage systems, serving benefits of not only stormwater management, but also that of overall ecological welfare. These findings highlight the significance of integrating ESS during early urban planning and the development of stormwater strategies, especially in areas that experience infrastructural challenges.

4.7 Perspective

Follow-up research should evaluate the long-term performance of SUDS in similar environments, especially including seasonal variations in the planning process. Research on public perceptions, maintenance demands, and cost-benefit analysis would also help inform policymaking. A recommendation is to examine and overcome the limitations that have been faced in this research, for example through the limitations in Scalgo live or lack of a framework for quantitatively assessing Ecosystem services. Extending the scope to look at climate change adaptation scenarios would provide a better appreciation of the value of SUDS in building local resilience.

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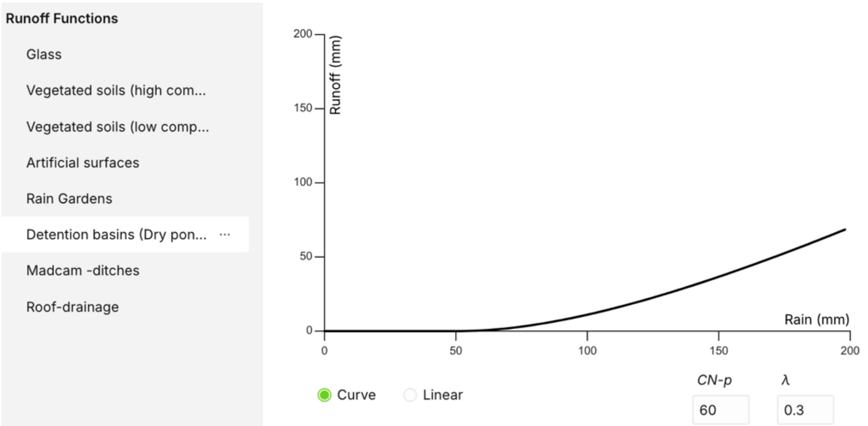
Appendices

Appendix 6 *Recreational layout from top view, in the style of the Detail-plan for the proposed layout (original boundaries in red)*

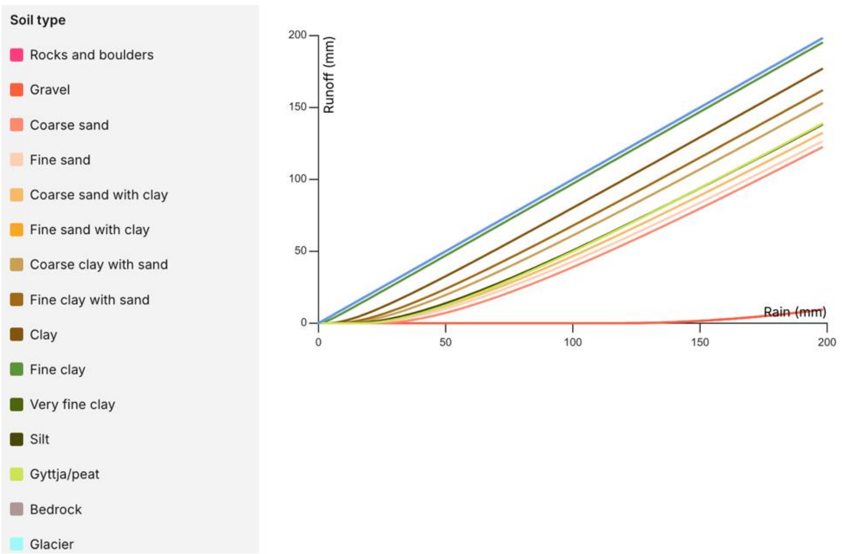
Appendix 2 *Sources for elevation- and for Flash flood mapping- dataset in SCALGO live (Swedish)*

Organization	Data set	Date acquired
Lantmäteriet	Markhöjdmodell, grid 1+	2024-08-20
Lantmäteriverket (FI)	Höjdmodell 2 m	2024-07-15
Lantmäteriverket (FI)	Höjdmodell 10 m	2017-10-04
Kartverket (NO)	NDH DTM1	2024-05-14

Kartverket (NO)	DTM 10	2013-07-30
Lantmäteriet	Hydrografi, Shoreline	2023-11-28
Lantmäteriet	Byggnad Nedladdning	2024-03-11



Appendix 3 *CN-p and λ for different SUDS features used in Layouts*



Appendix 4 *Presets for runoff functions in Scalgo live based on different land cover types*

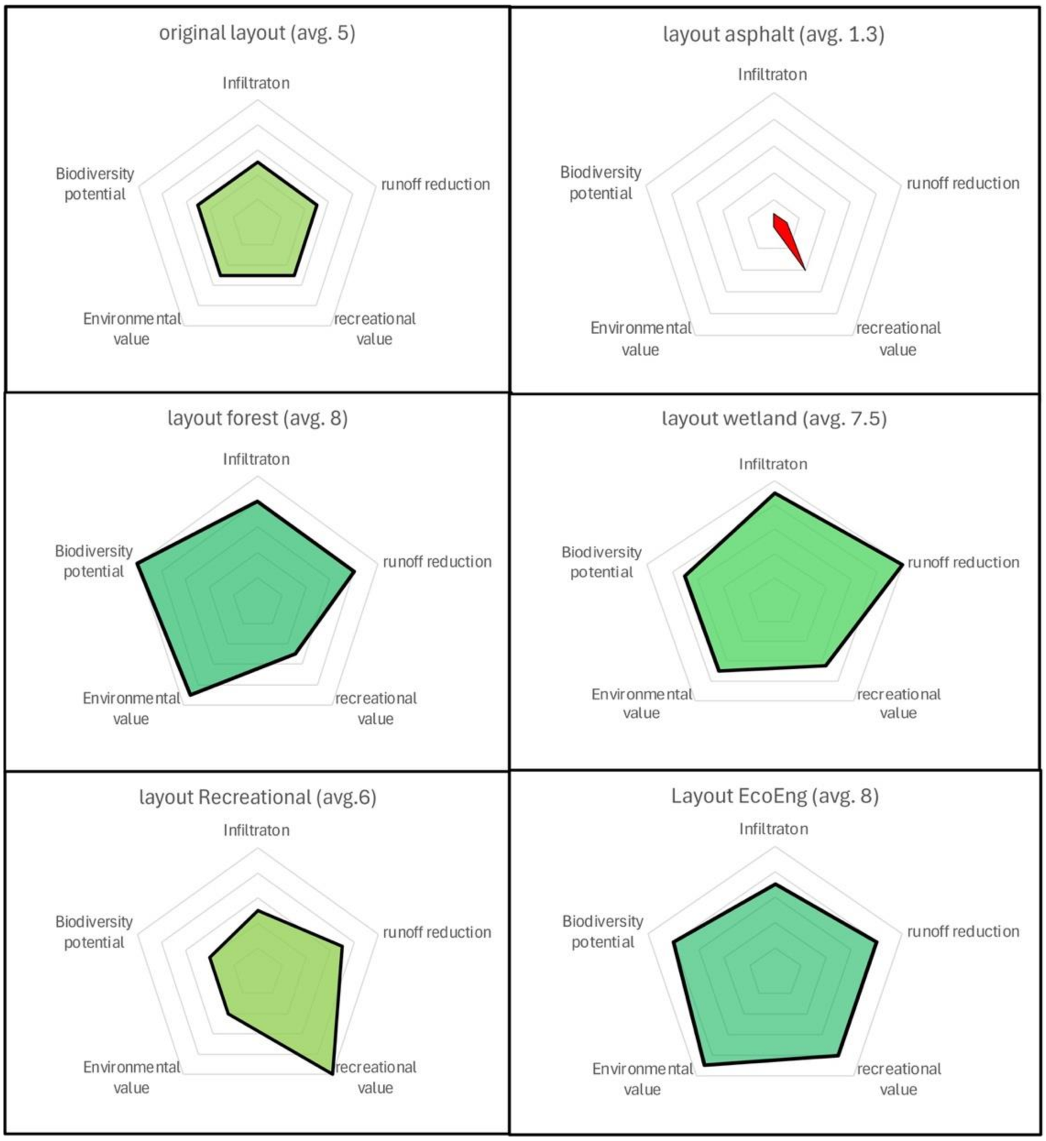
Note to Appendix 4: In the layout-configurations of the results, Light green landcover stands for peat, and dark green landcover stands for Silt. Silt results in less runoff and peat in more runoff from the site. Therefore, it can be assumed that Silt took the function of a forest-soil, even though normal forest soils don´t solely consist of silt, but rather a mixture of sand, silt, and clay, which contribute to their overall texture and properties.

Appendix 5 *Ecosystem Services linked to nature-based solutions appearing in the different layouts*

Nature based solution	Function/ ESS	Layout	Reference
Pervious Pavement	-Allows growth of plants in its vicinity/*Biodiversity* - Lower surface temperature compared to regular concrete/ *Regulating service* -Increased infiltration/ *Regulating service*	1/4/5/6	(García & Santamarta, 2022) (Kuok et al., 2023)
Infiltration Pond	- infiltration tank of a residential area serves as a playground for children in the dry season /*cultural services* - Infiltrated stormwater does not always reach a baseflow with high temperatures and is evapotranspirated /*supporting services*	4/5/6	(García & Santamarta, 2022) (Ballard et al., 2015) (Orta-Ortiz & Geneletti, 2022)
Bioretention System	- leaf colour for aesthetic services and maximum plant height for sense of place /*cultural service* - sequester and store carbon throughout the ponding area /*supporting service*	5/6	(García & Santamarta, 2022) (Ballard et al., 2015)

	- increases in native flora and wildlife habitat in the neighbourhood /*Biodiversity* - discharge quality of the catchments with bioretention ponds is better than those without them /*Regulating services*		(Gómez-Baggethun & Barton, 2013)
Green Swale	-soils used in bioswales can serve as effective reservoirs of functional microbial communities /*biodiversity* - act as temperature regulators because they can provide a higher surface temperature than air temperature in winter and the opposite in summer, providing a lower temperature than air /*Regulating service*	1/4/5/6	(García & Santamarta, 2022) (Ballard et al., 2015)
Filter Strip	- capacity to sequester carbon /*supporting service*	6	(Ballard et al., 2015) (Gómez-Baggethun & Barton, 2013)
Infiltration Trench	- improve the quality of infiltrated water/*Regulating services*	1/5/6	(García & Santamarta, 2022)

From report: “The grading criteria for the different ecosystems was based on a qualitative comparison between the amount of present SUDS features in a layout. For example, the more Recreational features a layout contains, the higher the recreational value of it.” SUDS features and the corresponding Ecosystem services are visible in Table 4 And are therefore comparable to one another. The legend of the assessment-table for ecosystem services serves as a visualisation of the distinction between (-) (--) and (+) (++). The more Ecosystem services a layout supports, the higher the rating (++). If a layout doesn´t allow a certain type of ESS to be included, a (--) is given. For example, the Concrete layout completely removes the potential for Biodiversity (--), or the Wetland layout provides exceptional Regulating services (++). Double digits are given to layouts with heavy focus on a certain type of ESS, normal (+) and (–) are for layouts with support, or not support for the certain ESS respectively.



Appendix 6 *Spider diagrams of Ecosystem service- evaluation for the layouts*

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