Prioritisation of Nature-based Solutions in Urban Catchments

Jarrod Luxton
Abstract
Nature-based solutions (NBS) are gaining traction around the world, as cities and institutions transition towards sustainable development. NBS provide opportunities to use infrastructure based on natural processes to manage the urban water cycle, improve biodiversity and social outcomes. However, NBS are complex with multiple benefits and constraining factors to consider. Presently, there is a recognised lack of NBS planning support tools available to help institutions make strategic decisions. For public authorities, there are three key questions to answer: Which locations should be selected for NBS? Which type of NBS should be implemented? How much performance can be expected?

The objective of this study was to prioritise large-scale nature-based solutions within a case-study area in the City of Helsinki. The developed methodology built upon international research seeking to improve the systematic and holistic planning of NBS. The project used a multi-criteria assessment (MCA) framework to prioritise sub-catchments and rank identified NBS opportunities. The framework comprises of spatial data indicators for water quantity, water quality, amenity and biodiversity. A methodology for combining these indicators was developed to produce an overall NBS priority score for sub-catchments within the city. The study used spatial analysis to identify specific locations for large-scale NBS assets and rank their performance using the MCA framework. Using the sub-catchment analysis and opportunity performance scores within the MCA framework, opportunities were assessed and ranked according to their ability to respond to drivers in their catchments and deliver multi-criteria benefits.

The key results of the study are the locations, asset types and expected relative performance of nineteen large-scale NBS opportunities within the Mätäjoki case study area. These opportunities were prioritised to highlight sites with the potential to deliver the highest multi-criteria performance. The results will assist the City of Helsinki to direct investment towards those NBS opportunities that provide the largest benefits for society and avoid investment in lower performing assets.

Keywords  Nature-based solutions, stormwater management, green infrastructure, multi-criteria analysis, spatial analysis, strategic planning
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Preface

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Jarrod Luxton
1 Introduction

Urban areas are increasingly under stress from a variety of factors, many of which stem from mega-trends such as population growth, climate change and land-use transformation. Cities around the world are grappling with the impacts of legacy infrastructure in the face of a changing climate, with key challenges including flood mitigation, air and water pollution, biodiversity loss, urban heat islands and green area reduction. These challenges crosscut many traditional fields including water management, ecology, conservation, and public health, requiring solutions that are similarly integrated and multi-faceted (Raymond et. al. 2017). The recognised approach suggested by many governments and institutions around the world is apply nature-based solutions (NBS). EU Commission (2016) defined NBS as solutions that use natural processes, make effective use of resources and provide environmental, social and economic benefits.

As governments of different levels turn to NBS as an alternative approach to traditional infrastructure, frameworks and methodologies are needed to ensure strategic planning and uptake. Perhaps due to the complex characteristics of NBS, planning and execution has historically avoided consideration of the necessary multi-disciplinary factors, resulting in outcomes that do not achieve the highest environmental, social and economic benefits for society (Kuller et al. 2018). Strategic planning of NBS requires a detailed understanding of the local area, environmental, social and economic risks, up- and downstream catchment size and composition, as well as consideration of the different types of NBS available and varying benefits they deliver. The failure to strategically consider this complex equation can result in missed opportunities, reduce value in the public realm, and sally governments with NBS that do not live up to their full potential.

This study sought to develop a heuristic methodology for catchment-based identification and prioritisation of large-scale NBS opportunities related to the urban water cycle. The purpose of the method was to provide municipal authorities with the most useful tools for the planning and implementing NBS. The developed methodology should be robust to adjust to the different levels of input data that can be expected from different municipalities. More specifically, the objective was to provide indications for where NBS should be located and which type of NBS should be applied, to maximise the value and multiple benefits across the study region. Such a strategic approach seeks to systematically ensure that the limited funds for NBS are directed towards the most promising opportunities in the most critical locations. Another goal was to provide a relative performance assessment of the identified NBS opportunities, comparing the expected multi-criteria performance with the ‘needs’ of each containing catchment. The final task was to prioritise the identified opportunities and highlight those with the highest potential to deliver multi-criteria benefits.

The study was conducted within the municipal area of the City of Helsinki, Finland. The City recently indicated that NBS will form part of its response to climate resilience and adaptation policy (City of Helsinki 2019a, 2019b). Helsinki’s climate roadmap toward 2050 states the goal of Helsinki as a climate-proof city, along with increased greening, biodiversity, water management and protection against heatwaves (City of Helsinki 2019b).

Figure 1 shows the five stages that comprise the overall study process. In stage 1, a literature review was undertaken that builds upon research undertaken by Beher et al. (2016), Kuller et al. (2019), Bach et al. (2020), Kaykhosravi et al. (2019), Ariza et al. (2019). In stage 2, Sub-catchments across the City of Helsinki were identified, analysed and ranked for NBS
priority. Stage 3 involved the selection of an appropriate case-study area. In stage 4, spatial data analysis was used to identify viable opportunities for large-scale NBS, including wetlands, biofiltration systems, stream restoration, floating wetlands and multi-use detention basins. Stage 5 involved the multi-criteria performance assessment and the ranking of performance against sub-catchment ‘needs’ in order to prioritise the top opportunities.

The contention is that this process will result in priority NBS catchment maps and corresponding NBS opportunities priority list to aid the City of Helsinki’s strategic planning and decision-making process for future NBS rollout.

Figure 1 Proposed process to develop the methodology within this study.
2 Literature review

This literature review explores three main themes. The first relates to defining NBS, identifying relevant asset types and their respective benefits and performance. Secondly, the review will consider barriers to NBS and the importance of a strategic approach for NBS planning. Here previous efforts towards NBS prioritisation from published literature are explored and the implications for future methods investigated. Thirdly, the theme of catchment-based planning is covered, exploring why the catchment is a useful planning unit even beyond the field of water management. Finally, syntheses will be drawn from the three themes to inform the following components of the study and method development.

2.1 NBS: definitions, benefits and performance

The UN Climate Action Summit (2019) recognized NBS as a fundamental pathway to address climate change and biodiversity collapse. Wild et al. (2020) reviewed the state-of-the-art of NBS and noted that NBS have ‘never been more relevant, important or urgently needed than now’. In addition to international bodies, national and local governments around the world have recognised that NBS are critical to achieve the SDGs to which many are committed (Faiivre et al. 2020). Despite the near consensus on the importance of NBS, multiple definitions of the term exist that can cause confusion and dilute the core concepts.

The International Union for Conservation of Nature (IUCN) defined NBS as ‘actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits’ (Cohen-Shacham et al. 2016). The IUCN definition places an emphasis on management and restoration of ecosystems. In comparison the EU Commission (2016) defined NBS as ‘solutions that are inspired by and supported by nature, which are cost-effective, simultaneously providing environmental, social and economic benefits and helping build resilience’. The EU Commission definition places a greater emphasis on the solutions themselves. Compared to the IUCN, the EU Commission definition is broad, noting NBS can be actions ‘inspired’ and ‘supported’ by natural processes, rather than the IUCN’s emphasis on the ‘restoration’ of ecosystems. While both definitions hold merit, for the purpose of this study, the EU Commission’s definition will be adopted as it holds higher relevance within the urban context, where the protection and restoration of ecosystems are important, but not always the impetus for NBS.

Along with the mega-trends it is seeking to address, NBS is a multi-disciplinary theme that often requires expertise from a variety of professions (Raymond et al. 2017). NBS can manifest as structural and non-structural solutions. Non-structural solutions refer to policy change, adaptive planning and education (Wong et al. 2020; Lähde 2018). Structural NBS are multi-functional infrastructure assets, designed and constructed to deliver multiple benefits through their use of water management, social amenity and ecosystem services.

In the field of stormwater management, there have been several approaches to improve multi-dimensional sustainability outcomes. The naming convention for these approaches is variable, with different regions using multiple terms, often interchangeably. These terms (in no order) include; low-impact development (LID), blue-green infrastructure (BGI), green infrastructure (GI), water sensitive urban design (WSUD), sustainable urban drainage systems (SUDS), best management practices (BMP), stormwater control measures (SCM), water sensitive cities (WSC), source controls and sponge cities (Fletcher et al. 2015; Wang et al.
While there is significant overlap within many terms, there is also diversity in their primary focus and specificity. Figure 2 attempts to classify these water management approaches.

![Figure 2. Specificity and primary focus of water management terminology and NBS (modified from Fletcher et al., 2015).](image)

When considering where NBS fits within the approaches in Figure 2, it aligns with ‘green infrastructure’ as a broad, holistic approach, while adding a third dimension, incorporating other responses that may not hold water management at their core (Raymond et al. 2017). As a result, the multitude of water management terms can be viewed as a subset of NBS; they represent forms of NBS, but not the only types of NBS. In order to avoid confusion and align with the EU, City of Helsinki and other international institutions, this study will refer exclusively to NBS (EU Commission 2016; City of Helsinki 2019a; Wild et al. 2020). Operating within the NBS framing also provides the opportunity for better integration with disciplines outside the theme of stormwater management. Without recognising these types of projects as NBS, there is a risk of being overlooked by those institutions that are seeking to specifically prioritise NBS as a key pathway.

While NBS may not be defined by water management, most types of NBS tend to reduce human impact on the hydrological cycle. The hydrological cycle is a fundamental part of the climate system, and describes the movement of water and energy through spatial and temporal dimensions (Wu et al. 2013). Like other fundamental earth systems, the hydrological cycle is influenced by anthropogenic pressure in a variety of ways. Many of the dangerous effects of climate change manifest through changes to the hydrological cycle (Wu et al. 2013). Because of this, water management is a core discipline often recommended to adopt NBS
and may provide some of the best leverage points for NBS implementation in urban areas (Raymond et al. 2017; Wild et al. 2020) UnaLab (2019) highlighted constructed wetlands, biofilters, bioswales, stream restoration, multi-use detention basins and infiltration basins as techniques that synergise urban water management within the NBS approach. However, the performance of NBS asset types varies and some types of NBS perform better in certain criteria. To effectively prioritise NBS opportunities, a framework is needed to understand the multifunctional performance of NBS asset types across different criteria. CIRIA (2016) developed a framework for defining the multifunctionality of NBS that contained four criteria: water quantity, water quality, amenity and biodiversity. These criteria are interconnected and achieving success in one criteria can often cascade benefits into another (Lähde et al. 2019).

Figure 3. NBS multifunctionality framework with interconnections between criteria (adapted from CIRIA, 2016; Lähde, Khadka and Tahvonen, 2019).

Water quantity benefits can be defined as the detention and retention of runoff volumes to slow down and reduce flooding. Water quantity benefits help to revert hydrological responses of a catchment towards their pre-development conditions and protect downstream areas from damaging floods (Wong et al. 2020; CIRIA 2016). Water quality benefits help to reduce the elevated water-borne pollution loads that are associated with land use change and human activity. Pollutants and treatment processes are diverse and often supported by vegetation through the biological breakdown of pollutants (Lähde et al. 2019). Amenity provided by NBS relates to the improvement of recreation, leisure and living conditions for people living near or visiting a NBS site. These benefits are often subjective and difficult to quantify, but generally consist of improved access to nature and green space, air quality improvements, urban heat regulation, health and education outcomes (Lähde et al. 2019; Lähde & Di Marino 2019; Wong et al. 2020). The biodiversity criterion consists of benefits...
that support increases in ecological processes and species variation. Often this is achieved through habitat creation and diverse vegetation selection (Lähde et al. 2019).

Table 1 displays the anticipated relative performance of catchment-scale NBS approaches aggregated from the assessed literature. General performance comparisons are useful to enable strategic planning exercises, even though actual asset performance is expected to vary with respect to design and location (WSC National Water Initiative 2009). Each NBS asset type is briefly introduced in Section 4.5.1. Street and lot-scale NBS asset types are not the focus of this study and hence not assessed.

Table 1. Multi-criteria performance of catchment-scale NBS asset types.

<table>
<thead>
<tr>
<th>NBS type</th>
<th>Water quantity</th>
<th>Water quality</th>
<th>Amenity</th>
<th>Biodiversity</th>
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<tbody>
<tr>
<td>Biofilter</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>M</td>
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<tr>
<td>Constructed wetland</td>
<td>M</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Floating wetland</td>
<td>N</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Multi-use detention basin</td>
<td>H</td>
<td>N</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Stream restoration</td>
<td>L</td>
<td>M</td>
<td>H</td>
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2.2 NBS planning: overcoming barriers with a strategic approach

NBS can be applied across a variety of scales, from the single private lot to the streetscape to the catchment scale. While small-scale NBS (such as raingardens, infiltration trees, green roofs and walls etc.) can often be incorporated to reduce the footprint of new developments, many opportunities exist outside the scope of new development. These opportunities are located within existing urban areas and most often fall under the responsibility of local government. Many cities around the world have begun to implement NBS, but due to their complex characteristics and lack of adequate planning tools, much NBS implementation has been ad-hoc and opportunistic resulting in less than optimal outcomes (Lähde 2018; Kuller et al. 2018). In the case area of Southern Finland, research indicates that a strategic catchment-based approach is lacking and NBS considerations have been left out of high-level master planning until later design phases (Lähde 2018).

To address the identified knowledge and tool gaps in NBS implementation, many researchers have been investigating how to optimise the planning of NBS to maximise social, environmental and economic benefits and develop subsequent tools to aid public authorities (Lerer et al. 2015; Martin-Mikle et al. 2015; Kaykhosravi et al. 2019; Kuller et al. 2018; Ariza et al. 2019; Bach et al. 2020). Lerer et al. (2015) developed a framework that characterised NBS planning tools using key questions for NBS decision-makers: ‘where, which and how much’. ‘Where’ referred to the location of proposed NBS, ‘which’ referred to the type of NBS to be applied and ‘how much’ referred to quantification of the anticipated benefits of NBS.

Martin-Mikle et al. (2015) defined hydrologic-sensitive areas (HSAs) for a case-study catchment in Oklahoma, USA using topography, upstream area and soil properties as input variables. These variables were then factored with local land use and permeability to prioritise locations for NBS intervention. Their study concluded that the processing of common spatial datasets can provide communities and their public servants an affordable way to evaluate important decisions. NBS optimisation research has been striving to account for
additional benefits that may have been previously overlooked by a focusing on a single outcome (e.g. flood mitigation). In addition, the ‘demand’ for the various benefits of NBS is not spatially homogenous. Kuller et al. (2018) found that regions without access to green space derive significantly higher benefits from the introduction of NBS, while high-value waterways benefit more from pollution protection than low-value waterways.

In Canada, Kaykhosravi et al. (2019) developed a NBS ‘demand map’, an indicator that comprises of three indices; an environmental index, a hydrological-hydraulic index and a socioeconomic index. Each index subsequently comprised of a range of variables that described various biophysical and demographic features within the study area. This resulted in a raster-based NBS suitability map across the case area of Toronto, highlighting areas with a high demand for NBS intervention.

Kuller et al. (2019) introduced an NBS planning support tool known as SSANTO (Spatial Suitability Analysis Tool), which utilised GIS-based (graphical information system), multi-criteria analysis to map suitability for NBS sites within urban areas. This tool sought to spatially identify the ‘needs’ and ‘opportunities’ for NBS across a range of biophysical and social factors. These factors were scaled, weighted and combined to create a raster based NBS suitability map across the case-study area in Melbourne, Australia. The three approaches applied by researchers in Oklahoma, Toronto and Melbourne represent attempts to provide indications for optimum NBS locations, each using MCA techniques to combine relevant local spatial datasets and create an index implying the optimum locations for NBS.

Ariza et al. (2019) introduced a method to provide recommendations for NBS location and asset type. The study defined areas of need and opportunities and applied environmental, hydrologic and social indices, similar to Kuller et al. (2019) and Kaykhosravi et al. (2019) respectively. However, the approach by Ariza et al. (2019) differed in the adoption of sub-catchments as the unit of analysis and in the identification of appropriate NBS types. The developed process used sub-catchments on the citywide scale, before defining appropriate locations and types of NBS at a finer scale within these prioritised catchments. This allowed the catchment-based analysis to consider municipal interests and strategies, while the finer-scale identification stage considered the detailed spatial datasets and suitability for NBS. The study noted multi-scale analysis and the development of prioritised catchments as fundamental for NBS implementation.

With the development of UrbanBEATS (Urban Biophysical Environments and Technologies Simulator) Bach et al. (2020) attempted to deliver answers to the location, type and performance questions with regard to NBS. The model delineated a study area into a grid and created an abstracted model of the urban form using biophysical datasets. Types and locations for NBS were then simulated through a Monte Carlo approach to generate many layouts that can be filtered and evaluated against user defined preferences. The model objectives were runoff reduction, pollution management and potable supply substitution. The model used a single citywide scale in its approach, resulting in general indications for NBS opportunities, compared to the specific locations for NBS generated from by Ariza et al., 2019. UrbanBEATS Bach et al., (2020) also contains significantly more complex analytical processes than other methodologies but is also more restricted in its applicability due rigid requirements for detailed data, user knowledge and skill. This is important to consider, because the complexity of a model or methodology reduces accessibility and ultimately the likelihood of use by practitioners. Methodologies that can be rapidly applied, balancing appropriate detail with convenience are likely to be the most effective tools for tackling large-scale, multi-dimensional problems (Dargin et al. 2019).
2.3 NBS planning: managing scale with a catchment-based approach

A catchment-based approach in NBS refers to the use of natural catchments as the basic unit for planning and natural resource management (Nachtnebel & Faber 2009). A catchment (also known as watershed or basin) is an area where precipitation collects and drains to a common outlet point (USGS 2020). Catchments can exist at a variety of scales, defined by large river systems to small streams and lot-scale. Catchments that make up parts of other catchments can be referred to as sub-catchments.

Spatial disconnects between environmental resources and the scope of institutions responsible for their management has been identified as an issue that affect many earth systems (Moss 2012). Historically institutions have been allocated resource management areas that correspond to social demographics but are arbitrarily related to natural and environmental systems (van Roon 2011). A transition towards a catchment-based approach can present a challenge as the established management units of institutions often do not align with natural catchments (Seher & Löschner 2018). Much of the established literature on catchment-based planning focuses specifically on flood management (Nachtnebel & Faber 2009; Seher & Löschner 2018), but the integration of a catchment-based approach into the EU Water Framework Directive highlighted other important objectives, such as the ecological status of surface waters (EU Commission 2000). The Water Framework Directive notes that ‘the best model for a single system of water management is management-by-basin (catchment)’. The motivation behind catchment-based management is that it provides evidence for upstream actions that are often more effective than actions lower in the catchment. The catchment-based approach allows municipal authorities to justify valuable project opportunities that may otherwise seem obscure and unrelated to critical issues (Hewett et al. 2020).

While some engineers, ecologists, hydrologists and conservationists have adapted to the use of a catchment-based approach; planning and urban design often remain with the basic unit of the neighbourhood (van Roon 2011). Lähde (2018) identified that catchment considerations in Finnish urban planning were often left until the detailed design phase, where it was too late to achieve optimum outcomes. Some of the largest barriers to NBS implementation have been identified in the lack of strategic tools and approaches for high-level planning (Kuller et al. 2018; Lähde 2018). For the multidisciplinary implementation of NBS to succeed, a common management unit for all professions is needed (van Roon 2011).

A catchment-based approach benefits the NBS prioritisation process, as it results in the use of multiple scales during analysis. The method proposed by Ariza et al. (2019) made use of a multi-scale catchment-based approach by firstly identifying priority catchments within the case study area. With priority catchments defined, the local and site scale analysis could be targeted, resulting in outcomes that resembled a high-level concept design. Other approaches that did not make use of a multi-scale catchment-based approach (Martin-Mikle et al. 2015; Kaykhosravi et al. 2019; Kuller et al. 2019; Bach et al. 2020), resulted in indications rather than answers for NBS location and type, lacking resolution at the local scale. While the manual GIS analysis required for detailed local and site scale analysis is time and resource intensive (Kuller et al. 2019), by taking a catchment based approach and automating the prioritisation of catchments, benefits of manual analysis can be concentrated (Ariza et al. 2019). While algorithms are exceptionally powerful at solving problems with defined boundaries and objectives, they are limited when confronted with constantly changing boundaries and objectives (Zechman et al. 2013). NBS planning represents an undertaking
where key considerations change between sites and the availability of data and local knowledge. For example, Kuller et al. (2019) compared the difference between results from SSANTO and results from an independent consultancy in the same region, finding that the SSANTO results diverged from the consultancy due to ‘insider information’ that the consultants had access to. This comparison reflects some bias, as ‘insider information’ represents detailed, location-specific contextual information that is a key factor underpinning high-quality urban planning outcomes. Instead, the weakness seems to lie with an algorithmic approach that requires new modules and modification for every piece of new, non-standard information.

2.4 Research gaps and study motivations

To align with local and regional terminology in the City of Helsinki and broader European area, this study adopts the EU definition for NBS (EU Commission 2016; City of Helsinki 2019b). NBS shares many similarities to other water management approaches, but its scope extends beyond just water management. The attractiveness of NBS is related to multi-functionality and a robust framework is needed to assess the different benefits effectively. This study builds upon a modified version of the CIRIA SUDs framework to analyse and assess NBS performance (Lähde et al. 2019). While NBS assets exist in a range of scales and types, this study focuses on catchment-scale, stormwater-based NBS. A range of literature sources was used to form relative performance rankings of selected NBS asset types within the adapted CIRIA framework.

There is a recognised knowledge gap in the strategic planning of NBS (Lähde 2018). The lack of effective multi-criteria prioritisation of NBS reduces value, potential benefits and results in ad-hoc assets and overlooked opportunities (Kuller et al. 2018). Public authorities require tools and techniques to help them effectively answer questions related to the location, type and expected performance of NBS. Earlier efforts have developed prioritisation methods for NBS opportunities to answer these questions systematically, using spatial indices for various environmental, hydrological and social factors to infer the ‘needs’ and ‘opportunities’ for NBS (Martin-Mikle et al. 2015; Kaykhosravi et al. 2019; Kuller et al. 2018; Ariza et al. 2019; Bach et al. 2020). The scale of analysis is critical for the value of the optimisation outputs; wide-scale catchment prioritisation allows for city planning, while local scale analysis is important to identify viable asset opportunities. However, many published efforts have had difficulty balancing scale and detail, often resulting in rasterised maps of large study-areas that are difficult to interpret on a catchment scale and often lacking required detail for local scale analysis (Kuller et al. 2019; Kaykhosravi et al. 2019). Some methods were also held back by their excessive complexity and data requirements, reducing the likelihood of widespread adoption (Ariza et al. 2019; Bach, Kuller, et al. 2020).

A catchment-based approach was identified as key technique to balance spatial detail and scale in NBS optimisation. A catchment-based approach has been not been adopted by most of the earlier research on NBS prioritisation techniques (Ariza et al. 2019). Catchment-based prioritisation provides an overview of the study area that is more digestible and more compatible with existing masterplans and zoning. By narrowing the study area through the definition of priority catchments, this approach can allow for efficient use of localised GIS analysis and manual review of key sites. On a localised scale, manual desktop review still holds significant advantages over the use of algorithms, due the complex considerations and priorities contained within each potential NBS opportunity.
3 Site description and data

The location for the implementation of this study is the City of Helsinki municipal area (Figure 4). The City of Helsinki is located on the coast of the Gulf of Finland and forms part of the Finnish capital area. The city receives a mean annual rainfall of 641mm and experiences an average temperature range of -4.8 °C in February to 17.4°C in July (Finnish Meteorological Institute 2021). The City of Helsinki contains numerous islands, peninsulas and bays and covers 217km² of land area and 502km² of sea area. 2019 average population density was 2,986 inhabitants per sq km of land area, resulting in a total population of 648,000 (City of Helsinki 2019c). The City of Helsinki, along with the neighbouring municipalities of Espoo and Vantaa, together comprise the Helsinki capital region with a combined land area of 700km² and population of 1.5 million.

![City of Helsinki municipal area and the Mätäjoki case study area.](image)

Figure 4 City of Helsinki municipal area and the Mätäjoki case study area.

The study focused on a case study area to the north-west of the City of Helsinki’s municipal area defined by the catchment of the Mätäjoki river. Mätäjoki is Helsinki’s second largest waterway after the Vantaanjoki river (Virtavesien Hoitoyhdistys RY, 2021). The Mätäjoki river has a 24km² catchment area, of which 16km² is contained within the City of Helsinki and 8km² upstream in the City of Vantaa. The catchment area is characterised with a variety of land usages including multi-storey residential areas, forest, industrial area and large highways. The river contains habitat areas for highly endangered sea trout that have been the focus of long running rehabilitation in the area (Virtavesien Hoitoyhdistys RY, 2021). The Mätäjoki catchment was selected as the case study area in consultation with the City of Helsinki, as it represented a mix of land usage, an sensitive waterway and may become an area of future focus for the City.
The City of Helsinki has established several strategies and targets that are directly supported by the four NBS benefit criterion of water quantity, water quality, amenity and biodiversity (City of Helsinki 2019a, 2019b). The City’s Stormwater Management Programme, Flood Strategy, Climate Change Adaptation Policies and Weather & Climate Change Risk strategy highlight the commitment to managing stormwater and improving resilience to flood events (City of Helsinki 2019a, 2019b, 2018). The City’s long term vision is to become ‘climate-proof’, with ‘integrated adaptation’ being undertaken in a ‘continuous’ manner (City of Helsinki 2019b). Referencing water quality, the City has recognised in the Stormwater Management Programme that the treatment and infiltration of stormwater as a goal across the municipality. The sensitivity of the Baltic sea is also a key local driver, with the City of Helsinki participating in the Union of Baltic Cities forum (UBC). The VISTRA I and II green network strategies highlight the importance of holistic planning in achieving high quality public space outcomes in the City of Helsinki (Jaakkola et al. 2016).

Referencing amenity, the City of Helsinki’s Climate Change Adaptation Policies state actions that involve the increase of green-blue infrastructure within the urban environment, as well as the combating of the urban heat island effect. The recent LUMO action plan released by the City also highlights the commitment to secure biodiversity services across the municipality, specifically the ‘ecological quality, accessibility and health impacts of green and blue areas’. The combination of the City of Helsinki’s strategies and policy positions are directly supported by the strategic implementation of NBS.

The focus of the study is firstly the City of Helsinki municipal area before focusing on the case study area of the Mätäjoki catchment (Figure 4). The development of NBS priority indices will be undertaken across the entire City of Helsinki municipal area. However, during the opportunity identification and prioritisation, the spatial scope will reduce to a case-study area defined by the Mätäjoki sub-catchments to the north-east of the municipality.

The data used in the study was compiled from a variety of sources. Table 2 lists the data obtained from each source, further detailed breakdown of each dataset in the context of the methodology to be found in Table 4 and Table 5. The City of Helsinki (HEL), Helsinki Region Environmental Services (HSY), Finnish Environment Institute (SYKE), Geological Survey of Finland (GTK), National Land Survey (NLS) and (Jalkanen et al. 2020) from the University of Helsinki (UNIHEL) form the sources for data used in this study.

For this study, an existing set of sub-catchments from the City of Helsinki were selected to form the basis of the catchment prioritisation (Figure 5). These sub-catchments range in size from the 3ha to 600ha and represent local surface flow and drainage. Less populated areas, particularly to the north-east of the municipality contain a large proportion of the largest sub-catchments. The City of Helsinki’s existing drainage sub-catchment layer formed the spatial units that defined the resolution of the NBS criteria indices.
Table 2 Data sources, datasets and links to open data portals.

<table>
<thead>
<tr>
<th>Data source</th>
<th>Datasets</th>
<th>Links to open data portal</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEL</td>
<td>Recognised swimming locations (.shp)</td>
<td><a href="https://kartta.hel.fi/#">https://kartta.hel.fi/#</a></td>
</tr>
<tr>
<td></td>
<td>Stormwater protected areas (.shp), Agricultural land (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stream and pond catchments (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Traffic load (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Municipal-owned green space (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban streams (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protected habitat (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protected nature areas (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recreational usage areas (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil mapping (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSY</td>
<td>Land coverage (raster)</td>
<td><a href="https://kartta.hsy.fi/">https://kartta.hsy.fi/</a></td>
</tr>
<tr>
<td></td>
<td>Combined sewer catchments (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stormwater drainage pipe network (.shp)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>(obtained with permission from HSY)</em></td>
<td></td>
</tr>
<tr>
<td>SYKE</td>
<td>Pluvial flood extents (raster)</td>
<td><a href="https://paikkatieto.ymparisto.fi/lapio/latauspalvelu.html">https://paikkatieto.ymparisto.fi/lapio/latauspalvelu.html</a></td>
</tr>
<tr>
<td></td>
<td><em>(obtained with permission from SYKE)</em></td>
<td></td>
</tr>
<tr>
<td>GTK</td>
<td>Sulphate soil risk mapping (.shp)</td>
<td><a href="https://hakku.gtk.fi/">https://hakku.gtk.fi/</a></td>
</tr>
<tr>
<td>UNIHTEL</td>
<td>Public green space access (raster)</td>
<td><a href="https://zenodo.org/record/1470099#.YLdLHdgzZUt">https://zenodo.org/record/1470099#.YLdLHdgzZUt</a></td>
</tr>
<tr>
<td></td>
<td>Biodiversity priority ranking (raster)</td>
<td><a href="https://zenodo.org/record/4022597#.YLdLHdgzZUt">https://zenodo.org/record/4022597#.YLdLHdgzZUt</a></td>
</tr>
</tbody>
</table>

Figure 5 City of Helsinki drainage sub-catchments used as spatial units for this study.
4 Methodology

4.1 General outline of catchment-based NBS prioritisation

The methodology for the catchment-based prioritisation analysis was to use spatial indices to represent the four NBS criteria proposed in the NBS multifunctionality framework (Figure 3). These indices are comprised of datasets that communicate relative priority for NBS within their respective criteria. Consequently, each NBS criteria index (water quality, water quantity, amenity and biodiversity) comprises of a combination of separate datasets that represent different elements of the criteria. In general, the raw datasets represent either a threat or vulnerability for a NBS criteria. For example, when considering the water quality criteria, traffic load represents a threat because of the water pollution associated with increased traffic loading. Concurrently, recognised swimming locations can be viewed as a vulnerability because of the enhanced sensitivity of these areas to water quality issues.

The definition of sub-catchments is a critical choice for the application of the proposed catchment-based approach. The City of Helsinki’s drainage sub-catchments form the spatial units that define the resolution of the NBS criteria indices in the study. Each sub-catchment was assigned a score between 0-1 for each processed indicator dataset and subsequent NBS criteria index.

While many common indicators exist between different study locations, the presence of unique local drivers and uncertainty around data availability implies that a methodology must have flexibility to account for variable input indicators. In general, data availability is the limiting factor that determines which indicators can comprise the NBS criteria indices. Figure 6 contains a selection of possible indicator datasets that suit the NBS framework adapted from Lähde et al. (2019).

![Figure 6. Possible indicator datasets that can be used to represent each NBS criteria (NBS framework adapted from CIRIA, 2016; Lähde et al. 2019).](image)

It is important to note that indicator relevance and availability varies for different locations, climates and contexts. Figure 6 is not a comprehensive list of potential indicator types.
used in this study, instead highlighting the range of possible indicators that could be used. Table 4 contains the available indicator datasets that were used in this study.

The catchment-based approach in this study is a heuristic method that considers the available data to provide an outcome that balances accuracy with complexity. If a critical indicator is unavailable, the method can still be advanced with the acknowledgement that the exclusion of this indicator is a limiting factor of the results. Contrarily, if many indicators are available for inclusion into a single NBS criteria index, the relevance of each indicator were questioned to avoid creating a biased index. If two indicators represented the same or very similar processes, only one was included. Furthermore, indicator datasets hold different levels of importance. To address this difference, weightings were used to preference those indicators that are relatively more important than others. These weightings depend on expert opinion of the local context.

For this study, weightings were established for each NBS indicator dataset through an expert workshop. The weightings were applied to each standardised indicator before inclusion into the NBS criteria indices. The weightings represent expert opinion of an indicator’s importance towards the relevant NBS criteria, relative to the other contributing indicators. The weighting procedure makes use of the point allocation method (Odu 2019). Each comprising dataset for a NBS criteria is allocated a weighting score between 0-1, proportional to its relative importance. This results in total weightings for each NBS criterion’s datasets sum to a value of 1 (Equation 1). The workshop included participants with professional backgrounds representing all four NBS criteria, which ensured a balanced discussion during the workshop. To frame the discussion it was useful to highlight whether each dataset represents a threat or vulnerability (see section 4.4.2). Equation 1 shows the example weighting values and formulae for the water quantity index. Table 4 contains the weightings that were assigned to other indicators. Weightings are only relevant to those NBS criteria that have more than 1 indicators.

\[ I_{WQ} = 0.3 I_f + 0.4 I_{imp} + 0.3I_{cs} \]  

Where: 
- \( I_{WQ} \) is the weighted water quantity index
- \( I_f \) is the flood risk index
- \( I_{imp} \) is the impervious surface index
- \( I_{cs} \) is the combined sewer network index

4.2 Standardising of raw indicator datasets

Whether an indicator dataset represents a threat or vulnerability impacts how the data should be manipulated and represented as an index. For example, the status of areas sensitive to water quality depend on the runoff quality from an upstream catchment. For this indicator, it is therefore this upstream area that is a priority for NBS. In contrast, recreational community access to NBS is an indicator that has relevance only within the immediate sub-catchment, with no upstream effects.

For water quantity and quality indicators that are related to stormwater runoff, it was necessary to compute an upstream or downstream area as the area of sensitivity. These data transformations occurred before indexing. Table 4 describes indicators for the City of Helsinki and transformations that have been undertaken to assess the relevant areas of sensitivity before indexing.
While the raw data indicators representing the four NBS criteria used fundamentally different units they were categorised into three types (Table 3). This framework was created to allow for all available spatial data to be processed and included in an NBS criteria. This framework will also assist in the future replication of this method in different locations that have varying data sources and availability.

Table 3. Categories of raw indicator data to be indexed for input to NBS criteria indices.

<table>
<thead>
<tr>
<th>Dataset category</th>
<th>Description</th>
<th>Data value range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>Binary spatial indicator. An area is either classed as a priority or not a priority.</td>
<td>(0 or 1)</td>
</tr>
<tr>
<td>Category 2</td>
<td>Natural index indicator. Areas range in priority value between 0-1.</td>
<td>(0 - 1)</td>
</tr>
<tr>
<td>Category 3</td>
<td>Natural non-index indicator. Areas range in priority value beyond 0-1.</td>
<td>(0 – beyond)</td>
</tr>
</tbody>
</table>

Category 1 in Table 3 refers to datasets that delineate areas of importance and non-importance. These indicators do not contain a continuous range, rather the definition of importance is discrete 0 or 1. An example of this indicator type is the upstream catchment of a sensitive area. In this case the area of importance is clearly defined and can be defined with an index value of 1, while areas of non-importance can be defined with an index value of 0.

The category 2 indicators in Table 3 are defined as datasets that include a natural range between 0-1. Examples of this indicator type is impervious percentage of a catchment or existing standardised indicators. Because of their inherent standardisation, these indicators can be compiled into a criteria index without further manipulation.

The category 3 in Table 3 are datasets that have natural values beyond the range 0-1. An example of this indicator type is traffic loading where natural values represent annual car trips along road lengths. This type of data requires standardisation to a range of 0-1 for compilation into the criteria indices. This was done using quantile normalisation, which delineates natural values into quantiles and then assigns proportional value of 0-1 to each quantile. With each dataset processed into index form, it is possible to combine these indicators to form the overall criteria indices.

4.3 Indicator datasets in the City of Helsinki
For the study area in the City of Helsinki, each criteria index comprises of a collation of the relevant and available datasets as shown in Table 4. The table contains the data source, a brief description of the data, data category, the primary manipulation required to create a spatial index from the raw data and the weighting value.
Table 4 Indicator datasets comprising the four criteria indicators

<table>
<thead>
<tr>
<th>Indicator Dataset</th>
<th>Source</th>
<th>Description</th>
<th>Data Category</th>
<th>Data manipulation</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water Quantity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pluvial flood extent</td>
<td>SYKE</td>
<td>Modelled depth and extent of surface flooding caused by 100-year pluvial rain event.</td>
<td>3</td>
<td>Clipped to contain flooding on impervious surfaces.</td>
<td>30</td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>HSY</td>
<td>Land surface coverage defining impervious surface coverage.</td>
<td>2</td>
<td>Adapted to an impervious surface dataset.</td>
<td>40</td>
</tr>
<tr>
<td>Combined sewer catchments</td>
<td>HSY</td>
<td>Areas containing combined sewer systems.</td>
<td>1</td>
<td>Determined upstream catchments.</td>
<td>30</td>
</tr>
<tr>
<td>2. Water Quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recognised swimming locations</td>
<td>HEL</td>
<td>Areas identified for swimming and beach recreation.</td>
<td>1</td>
<td>Determined upstream catchments.</td>
<td>10</td>
</tr>
<tr>
<td>Stormwater protected areas</td>
<td>HEL</td>
<td>Areas identified for the protection and management of stormwater.</td>
<td>1</td>
<td>Determined upstream catchments.</td>
<td>25</td>
</tr>
<tr>
<td>Agricultural land</td>
<td>HEL</td>
<td>Agricultural land use.</td>
<td>1</td>
<td>Determined containing catchments.</td>
<td>10</td>
</tr>
<tr>
<td>Stream &amp; pond catchments</td>
<td>HEL</td>
<td>Catchment areas that drain into natural streams and/or ponds.</td>
<td>1</td>
<td>None.</td>
<td>15</td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>HSY</td>
<td>Land surface coverage defining impervious surface coverage.</td>
<td>2</td>
<td>Adapted to an impervious surface dataset.</td>
<td>20</td>
</tr>
<tr>
<td>Traffic load</td>
<td>HEL</td>
<td>Autumn traffic load per road.</td>
<td>3</td>
<td>Multiplied trips w. road length, summed within each catchment.</td>
<td>20</td>
</tr>
<tr>
<td>3. Amenity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public green space access</td>
<td>UNIHEL</td>
<td>Population weighted accessibility by foot and bicycle of existing green space.</td>
<td>2</td>
<td>Average raster values within each sub-catchment.</td>
<td>N/A</td>
</tr>
<tr>
<td>Biodiversity priority ranking</td>
<td>UNIHEL</td>
<td>Prioritisation of biodiversity services produced by existing green areas.</td>
<td>2</td>
<td>Trim dataset to contain values 0.3-0.8, sum for catchments.</td>
<td>N/A</td>
</tr>
</tbody>
</table>

4.4 Spatial data analysis

This section will explore how each criteria index was formed from the raw indicator datasets selected for use across the City of Helsinki.

4.4.1 Water quantity priority index

The water quantity index comprises of datasets that represent areas that are sensitive to excess volume of stormwater runoff. The three datasets available to represent this were the 100-year pluvial flood spatial modelling, impervious surfaces and the areas containing combined sewer systems (Table 4).

The raw pluvial flooding dataset was in raster form representing pluvial flood depth and extent across the City of Helsinki. This included large flood extents in areas of undeveloped parkland and forest areas. As such, this portion of data does not represent urban flood risk and should be transformed to better represent hazardous or nuisance flooding to society. This was achieved by clipping the flood extent to paved or impervious surfaces across the City. This isolated the areas of pluvial flood hazard that impact developed areas and critical
urban infrastructure, such as roads and building areas. These higher-risk pluvial flood extents were then assigned to the sub-catchments in which they are located, and the total flood volume of each sub-catchment is summed (Figure 7). The resulting dataset was a category 3 dataset (Table 3) containing natural range of values that exceed 1, and hence was normalised across the city sub-catchments to create an index with a range from 0-1 (see Section 4.2).

![Figure 7. Transformation of processed pluvial flood extent to sub-catchment index.](image)

The impervious surface dataset represents the percentage of each catchment that is covered by impervious surfaces. This percentage was generated by combining the impervious surfaces from the HSY ground coverage dataset and dividing by the total area of each catchment. This resulted in a category 2 dataset with a natural range between 0 and 1 (Table 3), as shown in Figure 8.

![Figure 8 Transformation of impervious surfaces to sub-catchment index.](image)

To process the areas containing combined sewer systems it was first required to find the upstream areas that generate stormwater runoff into these systems. This was achieved by using the catchment function in Scalgo Live (Scalgo Live 2021). The resulting catchments were then exported from Scalgo and into ArcGIS. This data formed a category 1 dataset, where the spatial extent defined the index (see Section 4.2). Hence the sub-catchments containing combined sewer systems were assigned a value of 1 and other areas 0 (Figure 9).
To compute the overall water quantity index, the average of pluvial flooding index and combined sewer index was computed for each sub-catchment across the City of Helsinki (Figure 10). This resulted in an index that highlights the most critical areas for NBS solutions to address water quantity issues.
4.4.2 Water quality priority index

The water quality index comprises of datasets that represent areas that either produce a threat or are vulnerable to high levels of urban stormwater pollution. In the City of Helsinki, six relevant datasets were available: recognised swimming locations, stormwater protected areas, stream and pond catchments, agricultural land, impervious land coverage and traffic load (Table 4). Of these, the first three datasets represent areas that are vulnerable to receiving stormwater pollution, while the last three datasets represent areas with a threat of producing stormwater pollution. ‘Vulnerable’ datasets represent those areas which are specifically sensitive to changes in their upstream catchments. These can include environmental and recreational areas of significance, that will deteriorate in quality with a significant increase in stormwater pollution. The second group of ‘threat’ datasets represent areas that are more likely to produce stormwater of poor quality. This includes point and diffuse sources of nutrients, sediments and other stormwater pollutants.

For the ‘vulnerable’ group of datasets (Figure 11), representing areas sensitive to receiving stormwater pollution, the upstream catchment areas for each location were generated and combined to create a category 1 datasets.

![Figure 11. Category 1 spatial indices for recognised swimming areas (a), stormwater protected areas (b) and stream & pond catchments (c).](image)

For the second group of the datasets representing areas with a high risk to produce stormwater pollution, the analysis varied according the category of dataset. The agricultural field dataset is category 1, impervious land coverage dataset is category 2 and traffic load dataset is category 3 (see category definitions in Table 3). To process the agricultural field dataset, the catchments containing agricultural fields were assigned a value of 1, with all other catchments valued 0 (category 1). The processing of land coverage to produce an imperviousness index begun with the isolation of surface types that are impervious (buildings, roads and other sealed surfaces). After aggregating the impervious surfaces to each sub-catchment, the impervious surface percentage could be calculated for each sub-catchment. This resulted in a range of values between 0-1 (category 2) and requires normalisation to create an index.

To calculate the traffic load index, the traffic load data was manipulated to a unit that represented the length of road and intensity of traffic within a catchment. This was achieved by aggregating roads by sub-catchment and then multiplying the length of road segment with its traffic intensity. This resulted in each traffic load intensity for each segment defined by a value with the units \([\text{trips} \times \text{km}]\) and can be summed for each sub-catchment. This generated a range of values beyond 0 to 1 (category 3) and requires normalisation to create an index.

To create the overall water quality index, the six indicator indices were averaged across each of the sub-catchments (Figure 12). This resulted in the overall water quality priority...
index for the City of Helsinki, highlighting the sub-catchments that hold the highest priority for water-quality outcomes and interventions.

Figure 12. Combination of six water quality indices that creates the overall water quality index.

4.4.3 Amenity priority index

The amenity index represents the priority for social outcomes of NBS, considering issues such as accessibility of green space & biodiversity services. In the City of Helsinki, a study from the University of Helsinki has investigated the level of multi-modal public access to green space (Jalkanen et al. 2020). One of the output datasets from their study was an assessment of population weighted access to green spaces via walking and cycling. Considering NBS planning, this data prioritises potential locations by the number of inhabitants that can access to those spaces. The raw data is a category 2 data set, a raster with values from 0-1 representing the range of local access to natural areas (Figure 13a). Areas with darker green are more accessible while red areas are least accessible for the local population. To process this raw data, the ‘priority’ value of natural areas within each catchment was averaged. By using the average value, a representation can be made of amenity potential for NBS opportunities found within the sub-catchment, rather than the total amount of green space in that catchment (Figure 13b).
4.4.4 Biodiversity priority index

The biodiversity priority index represents the need, potential and value of increased biodiversity services that could be provided by an NBS opportunity. This is a difficult metric to represent, as biodiversity is a wide-ranging theme with a diverse range of species each with varying importance factors and indicators. To create the biodiversity priority index, a broad spatial index or dataset is the desired input as it provides an overall picture of priority areas for biodiversity in the area. Jalkanen et al. (2020) made an effort to develop a spatial metric representing the level of biodiversity services provided across the City of Helsinki. Their study produced a prioritised map representing the potential for land cover across the City to support the 'biodiversity quality' for ten different taxonomic groups (Figure 14a). This dataset forms the highest resolution summary of biodiversity across the City of Helsinki and hence a useful input for the biodiversity priority index. The raw data was a category 2 dataset with a range of 'biodiversity quality' from 0-1.

The purpose of the biodiversity priority index is to assess the most critical locations for the creation of new NBS opportunities. Those areas with the highest scores for ‘biodiversity quality’ should be preserved from excess disturbance and hence are not a priority for a NBS retrofit. Also, the areas with the lowest ‘biodiversity quality’ generally represent the biologically sparse urban realm. The lack of connectivity of these areas also reduces the potential biodiversity services provided by a NBS retrofit. Hence, these areas were removed from consideration and range of the ‘biodiversity quality’ raster was reduced to 0.3-0.8. The resulting data represents those areas with some existing value, that could be enhanced and improved using NBS.

The modified raster values were summed in each catchment to provide the picture of those sub-catchments with the highest biodiversity potential. To generate the biodiversity priority index the summed raster values were proportioned by sub-catchment size to mitigate the effect of larger catchments and the values were normalised into a 0-1 index (Figure 14b).
4.4.5 **NBS priority index**

The NBS priority index was compiled by combining the four NBS criteria indices. Each NBS criteria index contains a priority score from 0-1 for each sub-catchment and by taking the average of these scores for each sub-catchment it is possible to generate the overall NBS priority across the City of Helsinki (Figure 15). This index therefore represents the relative priority of each sub-catchment, considering the four NBS criteria of water quantity, water quality, amenity and biodiversity.

Figure 15. The four NBS criteria indices combine to create the overall NBS priority index.
4.5 Identification of opportunities
This section will detail the process for identifying NBS opportunities within the Mätäjoki case study area using available spatial datasets from the City of Helsinki.

4.5.1 NBS assets types
The types of NBS assets that will be assessed as part of this are listed in Table 1. These assets will be briefly described in their typical forms implemented as stormwater NBS.

Biofilters
A typical biofilter consists of a sand-based filter media where stormwater runoff percolates through to a drainage pipe located at the base of the asset. Biofilter media contains vegetation that uptake stormwater pollution and play other important roles such as transpiration and stabilisation of the media surface. Most biofilters employ an extended detention depth that allows stormwater runoff to temporarily pond on the media surface. This allows biofilters to capture and detain a larger volume of runoff and provide enhanced water quantity benefits. (CRCWSC 2015)

Constructed wetlands
Typically, constructed wetlands aim to mirror the function of natural wetlands; using natural processes to detain runoff, improve water quality and provide rich biodiversity services. All wetlands use some forms of filtration, slowing down stormwater flow and allowing solids to settle, soluble pollutants to be taken up by vegetation and harbouiring microorganisms that also remove pollutants. Stormwater wetlands are typically open water systems that are designed to have multiple deep and shallow sections to promote the varying processes that exist within natural systems. Like biofilters, stormwater wetlands often utilise extended detention depth to temporarily detain runoff above the normal water level. Wetlands are known for their rich biodiversity and provide important habitat to many species of vegetation and wildlife. (EPA Office of Water 2004)

Floating wetlands
Floating wetlands consist of aquatic vegetation suspended on a floating mat within water bodies or large waterways. Similar to constructed wetlands, the presence of vegetation and their suspended root mass serves to uptake nutrients to improve water quality. Floating wetlands also improve the habitat and amenity outcomes for many urban waterbodies. They are often utilised on water bodies with hard concrete edges in urban areas. While there is some potential to slow flow through their suspended root mass, floating wetlands generally provide no detention or water quantity benefits. (Queensland Department of Environment and Science 2018)

Multi-use detention basins
Detention basins are stormwater infrastructure that serve the purpose of detaining stormwater runoff to protect downstream areas from floods and high flow velocities. Traditionally, detention basins have been planned as single-purpose assets, often constructed of concrete and lacking amenity or biodiversity services. In contrast, multi-use detention basins seek to use the often-valuable space occupied for stormwater detention for other purposes between rain events. Typically, outdoor parks, urban squares and sporting fields are used as
detention basins for large rain events, as they are not usually in use in heavy rain. While the specific design of multi-use detention basins can vary, for the purpose of this study the common urban park/sporting field typology will be used. This assumption results in outcomes that often deliver little biodiversity or water quality benefits. (Shinde 2002)

**Stream restorations**

Stream restoration describes a wide variety of actions that are used to restore the processes and outcomes that exist within naturalised streams. Common goals include improving vegetation and habitat, preventing streambank erosion, reducing channel linearity and improving water quality. Generally, stream restoration actions do not have large impacts on runoff detention and water quantity, tending to focus instead on amenity and biodiversity outcomes. However, common stream restorations involve the ‘daylighting’ of stormwater pipes and the creation of open streams. In these projects, the detention capacity of the system generally increases. (Yochum 2018)

### 4.5.2 Assembly of relevant spatial data

To allow for the identification of NBS opportunities within a case study area, key datasets must be assembled to provide insight into appropriate areas, available space and existing risks for NBS implementation. These datasets represent the critical factors to consider in the planning stage of NBS opportunities and the compilation of these into a single workspace allows for their efficient identification. Critical factor categories include 1) available land for NBS, 2) drainage, topography and catchment characteristics, 3) conservation and recreation areas, and 4) geological conditions.

As with the datasets in Table 4, the availability, relevance and selection of datasets to represent critical factors that depend on the local context of the study. Table 5 contains the datasets selected for each critical factor category within the City of Helsinki. Assembling the critical factor datasets creates the NBS opportunity workspace, where available opportunities can be identified and evaluated for feasibility.
### Table 5 Critical factor datasets for the City of Helsinki.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Source</th>
<th>Description</th>
<th>Critical factor category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal owned green space</td>
<td>HEL</td>
<td>Land owned by the City of Helsinki without developments such as roads or buildings</td>
<td>1</td>
</tr>
<tr>
<td>Drainage networks</td>
<td>HSY</td>
<td>Drainage infrastructure information that can describe local drainage catchments</td>
<td>2</td>
</tr>
<tr>
<td>Ground surface elevation contours</td>
<td>NLS</td>
<td>2m and 5m contours generated from NLS DEM</td>
<td>2</td>
</tr>
<tr>
<td>Urban streams</td>
<td>HEL</td>
<td>Urban streams incl. information of sensitive fish habitat</td>
<td>2</td>
</tr>
<tr>
<td>Impervious surfaces</td>
<td>HSY</td>
<td>Land surface coverage defining impervious surface coverage</td>
<td>2</td>
</tr>
<tr>
<td>Protected habitat</td>
<td>HEL</td>
<td>Areas recognised for their habitat for wildlife</td>
<td>3</td>
</tr>
<tr>
<td>Protected nature areas</td>
<td>HEL</td>
<td>Areas recognised for high natural value</td>
<td>3</td>
</tr>
<tr>
<td>Recreational usage</td>
<td>HEL</td>
<td>Areas recognised for recreational use (play areas, allotments, summer huts, manors, dog enclosures, public beaches)</td>
<td>3</td>
</tr>
<tr>
<td>Soil mapping</td>
<td>HEL</td>
<td>Mapping of underlying soil types</td>
<td>4</td>
</tr>
<tr>
<td>Sulphate soil risk</td>
<td>GTK</td>
<td>Mapping of sulphate soil risks</td>
<td>4</td>
</tr>
</tbody>
</table>

#### 4.5.3 Identification of NBS opportunities

Using the NBS opportunity workspace, it is possible to manually identify large scale NBS opportunities based on the three steps described below.

1. **Identify available land in a location that receives runoff from an upstream urbanised drainage catchment.**

   Identifying available land in proximity to an existing stream or drainage pipe is the first step towards locating a potential opportunity. Key assumptions need to be made regarding land deemed ‘available’. For this study, public municipal land that is free from development such as buildings or roads is considered available for a NBS opportunity. It should be noted that this assumption does not imply that the available land is completely vacant to implement an NBS asset. Rather, this stage of the study is seeking to identify those areas where NBS opportunities are technically feasible. This step utilises datasets representing critical factors 1 and 2 (Table 5). Figure 16 shows the NBS opportunity workspace, with the available green space owned by the City of Helsinki shown in green.
2. **Check that the available space does not encroach on conservation or recreation areas.**

Step two is achieved by using datasets representing critical factor 3 (Table 5) to assess if there are any recognised land usages in the selected location that would conflict with an NBS opportunity. In the City of Helsinki, there are spatial records of nature conservation areas and public land usage, such as dog parks, play areas and garden allotments. This step is limited by the available spatial data on public land usage; however, it can ensure that the most obvious conflicts are considered. It should also be noted that a conflict does not wholly inhibit an NBS opportunity; in some cases, the integration of NBS with an existing land usage could produce a positive result for existing users. Generally, this symbiosis can occur when an area with an existing usage can be enhanced by the presence of an NBS asset. An example of this are multi-function detention basins, that leverage existing outdoor activity areas (such as parks and sporting fields) for storm detention during rain events. In this case, the NBS and activity conflict is avoided due to a temporal separation, i.e. the activity space is not used during large rain events, allowing for detention to occur. These possibilities should be assessed on a case-by-case basis.

3. **Use in-situ soil and acid-sulphate area mapping with topography and maintenance access to assess the most appropriate NBS asset type**

The geological conditions are an important consideration when assessing the most appropriate NBS asset type for a certain location. Sand and gravel soil conditions indicate high local infiltration rates, while peat and bedrock can present a barrier to asset construction. Critical datasets 4 (Table 5) are used to assess these considerations. For example, biofilters can be effective assets at reducing stormwater volume within a small footprint when...
contained in high-infiltration soil conditions. Areas with a high risk of acid-sulphate soils represent high risk areas for excavation and construction, generally posing a significant barrier to NBS opportunities. The topography and vegetation are other important considerations when determining asset appropriateness. For example, stream restorations generally suit sites with a steep slope better than a wetland or biofilter, which usually perform better over a gentle slope. Maintenance access is another important consideration for certain asset types. Most NBS assets require some level of maintenance, and larger scale assets often require the use of heavy machinery such as excavators. It is important to note if the proposed site lacks nearby access tracks or contains dense vegetation that may hinder maintenance access.

4.6 Prioritisation of opportunities
Following the identification of NBS opportunities across the target area, each opportunity is assessed and prioritised according to its expected multi-criteria performance. To achieve this, the predicted multi-criteria performance rating for each asset (Table 1) is multiplied with the NBS priority indices created during the catchment analysis (example equation for water quantity is shown in Equation 2). The sum of the priority scores for water quantity, water quality, amenity and biodiversity define the overall opportunity priority score (Equation 3).

\[
PS_{WQ} = PI_{WQ} \times PR_{WQ}
\]

Where: \(PS_{WQ}\) is the opportunity water quantity priority score
\(PI_{WQ}\) is the catchment water quantity priority index
\(PR_{WQ}\) is the asset water quantity performance ranking

\[
PS = PI_{WQ} + PI_{Wq} + PI_{A} + PI_{B}
\]

Where: \(PS\) is the opportunity priority score
\(PI_{WQ}\) is the opportunity water quantity priority score
\(PI_{Wq}\) is the catchment water quality priority index
\(PI_{A}\) is the catchment amenity priority index
\(PI_{B}\) is the catchment biodiversity priority index

The opportunity priority score is defined within a range of 0-12. A higher score indicates that the identified opportunity will display high performance to address the priority issues within its catchment. For example, a constructed wetland opportunity is identified within a sub-catchment. Table 6 compiles the catchment-based indices, asset-based performance rankings and applies formula 2 and 3 to find the overall priority score for the constructed wetland opportunity.
Table 6 Example calculation of the opportunity priority score for a wetland opportunity.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Catchment indices (0-1)</th>
<th>Performance ranking (0-3)</th>
<th>Priority score (0-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Quantity</td>
<td>0.3</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td>Water Quality</td>
<td>0.8</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td>Amenity</td>
<td>1.0</td>
<td>3</td>
<td>3.0</td>
</tr>
<tr>
<td>Biodiversity</td>
<td>0.8</td>
<td>3</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Opportunity priority score (0-12):</strong></td>
</tr>
</tbody>
</table>

The priority score was calculated for every identified opportunity, resulting in a ranked opportunity list. In addition to ranking via the overall opportunity priority score, the opportunity list can be sorted by NBS criteria (water quantity, quality, amenity and biodiversity) to identify the most promising opportunities for each criterion. The resulting opportunity list developed in the City of Helsinki case-study area is discussed in Section 6.

4.7 Sensitivity analysis

A sensitivity analysis was undertaken to understand the contribution of each criteria priority score towards the overall NBS priority score for each asset. The objective was to assess if they were any notable trends between the criterion the overall priority scores. First the criteria scores were split into two groups: water quantity & quality and amenity & biodiversity. This was to ascertain if the results from the ‘water cycle-based’ criterion were significantly different to the others. These results were plotted along with their linear trendlines to help identify differences between the datasets. Secondly, the criteria scores were broken down individually and plotted together to provide insight into magnitude differences of the priority scores of each criterion.
5 Results

The developed methodology was applied as a case study project in the City of Helsinki, Finland. The catchment analysis and NBS priority indices were undertaken across the entire municipal area. The following opportunity identification and prioritisation were undertaken within a smaller area defined by the Mätäjoki catchment falling within the Helsinki municipal area (Figure 4).

5.1 NBS catchment analysis

The results of the NBS catchment prioritisation are presented as sub-catchment priority maps for each criterion across the City of Helsinki. These maps highlight priority of each NBS criteria within each of the City’s sub-catchments.

5.1.1 Water quantity index

The water quantity index highlighted dense urban areas, with the highest priority assigned to three key clusters located in the Helsinki city centre, Kallio & surrounding suburbs and Herttoniemi (Figure 17). The catchments with non-urban land use, such as agriculture or forest plantation, were assigned the lowest priority. Examples of these low priority areas include farmland to the north near Tuomarinkylä and forest plantation to the east near Körnäs. This water quantity index mirrors the imperviousness index and suggests that the dense, inner city sub-catchments are a priority for stormwater quantity intervention. This result is compounded by the fact that the dense, inner city sub-catchments also contained the majority of combined sewer networks.

Figure 17. Weighted water quantity index for sub-catchments across the City of Helsinki.
5.1.2 Water quality index
The water quality index (Figure 18) generally prioritises sub-catchments to the north of the City of Helsinki. These represent sub-catchments with high pollutant generation (agriculture or high-volume traffic) draining into natural streams or recreational areas. Areas with lowest priority are generally sub-catchments containing low levels of urban development and large percentage of natural land coverage. This result was surprising considering that the dense, inner city sub-catchments were ranked quite low, where the scores for imperviousness and traffic load are high. This could suggest a possible over-emphasis of the stormwater protected areas and stream catchment indices that preference the northern sub-catchments. Industrial areas are another source of stormwater pollution, however a representative dataset was not available and hence these areas are not reflected in the water quality results.

5.1.3 Amenity Index
The amenity index (Figure 19) follows the general distribution of population across the Helsinki municipal area. Increased distance from each population centre, reduces accessibility by foot or bicycle and explains the stepped reduction in amenity priority index values. Areas with the lowest priority, in particular the north-east region, have a very low population and are beyond the accessibility distance for foot or bike from the major urban centres. Future NBS interventions planned in sub-catchments with a high amenity index would be most accessible for recreational use by the local population.
5.1.4 Biodiversity index
The biodiversity index (Figure 20) generally prioritises areas in proximity to existing biodiversity values. As expected, highly urbanised areas are of low priority, owing to their lack of connectivity to existing biodiversity services. High priority sub-catchments are identified in areas with existing natural spaces. Sub-catchments in close proximity to Helsinki central park and the coastal area near Viiki are two examples of locations allocated a high priority. The biodiversity index considered only land-based biodiversity values, meaning that the results do not consider biodiversity potential of open-water areas or streams.
5.1.5 NBS Priority Index

The four NBS indices in Figures 17-20 tended to prioritise different areas across the City of Helsinki. In general, the water quantity and amenity indices tended to prioritise dense urban areas, while water quality and biodiversity indices placed higher priority on less dense sub-catchments. When combined, this reduced the range of values of the NBS priority index, resulting in all values contained within a range of 0.2-0.8 (Figure 21). Even so, the index places the highest priority on those sub-catchments containing moderately-dense fringe suburbs. This is due to these areas balancing the opposing priorities of the four NBS criteria.

While the highlighting of fringe suburbs as overall priorities could be useful information during high-level planning exercises, it is difficult to explore the overall NBS priority index in more detail because there is such a large number of contributing datasets. In the more detailed planning stages, it is likely more useful to leverage the individual criteria indices that allow a user to identify the key design outcomes that should be prioritised within a given catchment.
5.2 Opportunity identification and prioritisation

NBS opportunity identification was undertaken within the case-study area, defined by the Mätäjoki catchment located within the Helsinki municipal area. Nineteen large-scale NBS opportunities were identified within the case study area. The breakdown of identified asset types is shown in Table 7. No opportunities for multi-use detention basins were identified, likely due to the lack of dense, urban residential areas in the case-study area.

Table 7 Asset types of identified opportunities.

<table>
<thead>
<tr>
<th>Asset type</th>
<th>Identified opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetland</td>
<td>9</td>
</tr>
<tr>
<td>Biofilter</td>
<td>4</td>
</tr>
<tr>
<td>Stream restoration</td>
<td>3</td>
</tr>
<tr>
<td>Floating wetlands</td>
<td>3</td>
</tr>
</tbody>
</table>

Following identification, the opportunities were prioritised using their predicted performance in the four NBS criteria, and the catchment index scores of the catchments in which they are located. For each opportunity, this process yielded a priority score for each NBS criteria as well as the overall opportunity priority score. Ranging from 0 to 12, the overall opportunity score provides a holistic ranking of the opportunity’s performance across all four criteria. With a range from 0 to 3, the criteria priority scores indicate how well the opportunity addresses each criterion individually.

Those assets that scored highly in the water quantity criteria generally scored lower in the biodiversity criteria and vice versa. This is likely explained by the inverse relationship of
predicted asset performance in the water quantity and biodiversity criteria for most asset types (Table 1). The strong predicted performance of wetlands across the four NBS criteria helps to explain their dominance at the top of the prioritised list. Nine of the top ten prioritised assets are wetland opportunities. The score of zero for floating wetlands in the water quantity criteria reflects the asset’s inability to detain stormwater. Table 8 contains the prioritised list of opportunities, along with corresponding criteria priority scores and overall opportunity priority scores.
Table 8 Prioritised list of NBS opportunities. Assets in the table are sorted per their opportunity priority score.

<table>
<thead>
<tr>
<th>Asset ID</th>
<th>Asset location</th>
<th>Proposed NBS type</th>
<th>Water Quantity</th>
<th>Water Quality</th>
<th>Amenity</th>
<th>Biodiversity</th>
<th>Opportunity priority score (0-12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pelipolku Wetland</td>
<td></td>
<td>1.4</td>
<td>1.7</td>
<td>2.4</td>
<td>3</td>
<td>8.4</td>
</tr>
<tr>
<td>2</td>
<td>Runonlauajantie Wetland</td>
<td></td>
<td>0.53</td>
<td>2.32</td>
<td>3.00</td>
<td>2.40</td>
<td>8.3</td>
</tr>
<tr>
<td>3</td>
<td>Runopulko Stream Restoration</td>
<td></td>
<td>0.3</td>
<td>1.5</td>
<td>3</td>
<td>2.4</td>
<td>7.2</td>
</tr>
<tr>
<td>4</td>
<td>Pannipolku Wetland</td>
<td></td>
<td>0.8</td>
<td>1.7</td>
<td>2.4</td>
<td>1.8</td>
<td>6.7</td>
</tr>
<tr>
<td>5</td>
<td>Parivaljakontie Wetland</td>
<td></td>
<td>0.7</td>
<td>1.7</td>
<td>2.4</td>
<td>1.8</td>
<td>6.6</td>
</tr>
<tr>
<td>6</td>
<td>Laitilantie Wetland</td>
<td></td>
<td>0.4</td>
<td>1.7</td>
<td>2.4</td>
<td>1.8</td>
<td>6.3</td>
</tr>
<tr>
<td>7</td>
<td>Vanhempientie Wetland</td>
<td></td>
<td>0.4</td>
<td>1.7</td>
<td>2.4</td>
<td>1.8</td>
<td>6.3</td>
</tr>
<tr>
<td>8</td>
<td>Haaga Rhododendron Puisto Wetland</td>
<td></td>
<td>1.4</td>
<td>1.9</td>
<td>1.8</td>
<td>0.6</td>
<td>5.7</td>
</tr>
<tr>
<td>9</td>
<td>Päiväläisentie Wetland</td>
<td></td>
<td>1.0</td>
<td>1.1</td>
<td>2.4</td>
<td>1.2</td>
<td>5.7</td>
</tr>
<tr>
<td>10</td>
<td>Muonomiehentie Wetland</td>
<td></td>
<td>1.0</td>
<td>1.1</td>
<td>2.4</td>
<td>1.2</td>
<td>5.7</td>
</tr>
<tr>
<td>11</td>
<td>Trumpettie Floating wetlands</td>
<td></td>
<td>0.0</td>
<td>1.1</td>
<td>2.4</td>
<td>1.8</td>
<td>5.3</td>
</tr>
<tr>
<td>12</td>
<td>Taitajanpolku Biofilter</td>
<td></td>
<td>1.3</td>
<td>1.7</td>
<td>1.2</td>
<td></td>
<td>5.0</td>
</tr>
<tr>
<td>13</td>
<td>Piispantie Stream Restoration</td>
<td></td>
<td>0.5</td>
<td>0.7</td>
<td>2.4</td>
<td>1.2</td>
<td>4.8</td>
</tr>
<tr>
<td>14</td>
<td>Pasuunatie Biofilter</td>
<td></td>
<td>1.3</td>
<td>1.4</td>
<td>1</td>
<td>0.8</td>
<td>4.5</td>
</tr>
<tr>
<td>15</td>
<td>Kalanninpolku Biofilter</td>
<td></td>
<td>0.6</td>
<td>1.7</td>
<td>0.8</td>
<td>1.2</td>
<td>4.3</td>
</tr>
<tr>
<td>16</td>
<td>Adolf Linforsintie Stream restoration</td>
<td></td>
<td>0.5</td>
<td>1.3</td>
<td>1.8</td>
<td>0.6</td>
<td>4.2</td>
</tr>
<tr>
<td>17</td>
<td>Ruoslankuja Biofilter</td>
<td></td>
<td>1.5</td>
<td>1.1</td>
<td>0.8</td>
<td>0.8</td>
<td>4.2</td>
</tr>
<tr>
<td>18</td>
<td>Strömbergintie Floating wetlands</td>
<td></td>
<td>0.0</td>
<td>0.4</td>
<td>1.2</td>
<td>2.4</td>
<td>4.0</td>
</tr>
<tr>
<td>19</td>
<td>Tali Golf Floating wetlands</td>
<td></td>
<td>0.0</td>
<td>0.4</td>
<td>1.2</td>
<td>2.4</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Figure 22 NBS opportunities identified within the Mätäjoki case study catchment.
5.3 Sensitivity analysis

The results of the sensitivity analysis show that differences exist between the water-based criterion compared to amenity & biodiversity. The x-axis of Figure 23 lists the identified opportunities from highest to lowest overall priority score (y-axis). The overall opportunity priority score for each opportunity is shown in orange, along with the contributions from the water-based and non-water-based criterion. Linear trendlines have also been included on the chart to help compare the results. The overall trend for the water quantity & quality and amenity & biodiversity scores follows that of the overall opportunity score. However, there is opposing behaviour displayed between the water and non-water-based criterion. Opportunities that result in a high score for water-based criteria, generally receive a low score for non-water-based criteria and vice versa. This can be seen in Figure 23, in particular for opportunities 8, 9, 11, 12, 13, 16, 17, 18 and 19.

This behaviour can be explained by the inverse performance ratings of different NBS asset types. As seen in Table 1, most assets that perform highly in the water-based criterion, tend to have lower ratings in one or both of the non-water based criterion and vice versa. Wetland assets are the notable exception with strong performance across all criteria.

![Figure 23](image)

**Figure 23** Comparison of overall priority score, water-based criterion and non-water-based criterion.

To better understand the relationship between each criterion, Figure 24 shows the priority scores and resulting trendlines for all four NBS criteria plotted for each opportunity. The amenity criteria resulted in the highest magnitude priority scores for most of the identified opportunities. The amenity, water quality and biodiversity priority scores all displayed consistent scoring behaviour that trending in the same direction from opportunity 1 to 19. However, water quantity displayed a different behaviour. While the water quantity trendline did decrease from opportunity 1 to 19, the gradient was significantly less pronounced than the other three criteria. It was also the criterion with the lowest magnitude for scores, suggesting that water quantity performance of the identified assets will not be as high as the other three criteria.
Figure 24 Priority scores by criteria plotted for each opportunity.
6 Discussion

As anticipated, the proposed methodology produced city-wide NBS criteria maps and a prioritised list of NBS opportunities within the case study area. Through this process, the key questions for public authorities regarding location and type of NBS opportunities are addressed. The third question of expected asset performance is partially answered in a qualitative manner within the adopted NBS criteria framework.

To the best of the author’s knowledge, this study was the first of its kind to combine the three key elements of a multi-criteria assessment, catchment-based analysis and opportunity identification and prioritisation. The use of a catchment-based approach successfully balanced scale in the assessment, simultaneously providing means to undertake a detailed analysis and provide digestible results. Hence, the relative priority of the four NBS criteria is communicated for each sub-catchment, with highest priority locations easily identified.

The use of a catchment-based approach also made it possible to infer stormwater-based benefits based on catchment characteristics (Hewett et al. 2020). Each identified opportunity receives runoff from its containing sub-catchment, which allows for the water quantity and quality criteria to be assessed. This is not possible when using traditional land planning units (e.g. neighbourhoods) (Nachtnebel & Faber 2009). The effectiveness of the NBS opportunity identification was also high, with 19 opportunities identified within the case study area.

Through consultation with a representative from the City of Helsinki, several identified opportunities aligned with existing municipal plans for the implementation of NBS projects. Field visits to confirm the identified opportunity sites also added weight to the validity of the method. The City of Helsinki noted the results from the methodology as useful to their planning processes (City of Helsinki 2021). Compared to previous research in this area (Ariza et al. 2019; Kaykhosravi et al. 2019; Bach, Kuller, et al. 2020; Kuller et al. 2019), the use of sub-catchments as a unit of analysis combined with opportunity identification and prioritisation combines to offer a robust methodology with results that are accessible and useful in the context of local government. While the proposed methodology was successful in the catchment-based identification and prioritisation of NBS opportunities, there are several key themes and limitations that are worth considering in further detail.

A current limitation of the proposed methodology is the inability to consider catchment connectivity. In the determination of catchment priority and opportunity prioritisation, only the characteristics of the immediate sub-catchment are considered. While this acceptable for the amenity and biodiversity criterion, it is not an ideal assumption for water quantity and quality criterion. This is because of the impact of upstream and downstream areas beyond the immediate catchment on NBS opportunities. Currently, the proposed methodology prioritises opportunities according to their ability to address criteria within the sub-catchment that the opportunity is located in. However, if the up- or downstream characteristics of the broader catchment system vary from that in the immediate sub-catchment, the proposed methodology does not recognise water quality or quantity benefits to the broader catchment.

Similarly, the proposed catchment analysis processes data from within each sub-catchment to develop the priority scores for each NBS criteria. While the calculation of upstream catchment areas of sensitive natural and recreation areas is an attempt to address this, limitations remain. Ideally, to assess the priority of a sub-catchment, the characteristics of the
up- and downstream portions of the broader drainage catchment would be considered (Bach et al. 2020).

As an example, consider a sub-catchment in the lower reaches of the case study Mätäjoki catchment with low levels of traffic load and development (Figure 12). This combined with a high level of naturalised ground coverage results in the proposed methodology generating a low priority score for water quality index in this sub-catchment. This result suggests that water quality is not an issue to be addressed in this catchment. However, as this sub-catchment is at the bottom of the Mätäjoki catchment which contains heavily urbanised areas, the stormwater flowing through this catchment can be expected to be of poor water quality. In effect, from a broader catchment perspective, this downstream catchment could contain a good opportunity to treat poor-quality stormwater flowing from upstream.

To refine the results, an acknowledgment of up- and downstream catchment characteristics could be combined with the local characteristics of the sub-catchment. By considering the connected catchment perspective, a better analysis of NBS opportunities could be made (EU Commission 2000). It should also be noted this is proposed only for the water quantity and quality criterion, due to their linkage to the catchment-based behaviour of the water cycle. A future solution for this could be to define the upstream catchment of an identified opportunity and use it as a variable to indicate the potential for water quality performance. The key assumption of this solution is that those opportunities with larger urban catchments will receive a higher pollutant load to treat. While this is recognised a simplification of the multiple sources and forms of urban stormwater pollution, it could be a useful proxy to address the catchment effects that are currently overlooked. One option for integrating an upstream catchment variable could be to create an indicator that is defined as the product of asset surface area and upstream urban catchment area. The ability of most NBS assets to treat stormwater quality load is generally relative to available surface area of the asset (City of Wyndham 2018). By combining the surface area (performance variable) with catchment area (an indicator of pollutant load), assets with the potential to remove the most stormwater pollution could be identified. It should be noted that the numeric value and unit of this suggested asset indicator does not provide a quantitative indication of asset performance, but rather suggests the potential pollutant load reduction performance relative to other opportunities, allowing them to be efficiently identified.

Another point to consider is the relevance of city-wide priority maps for small-scale NBS. While the goal of this study was to identified and prioritised large-scale NBS opportunities, it can be argued that the developed priority maps are also applicable to small-scale implementations of NBS. Small-scale NBS generally refers to street- and lot-scale solutions, which tend to treat a small upstream catchment before runoff enters the wider stormwater system (Department of Planning and Local Government, 2010). Due to their larger footprint and upstream catchment requirements, viable large-scale NBS opportunities are scarcer than their small-scale counterparts. Unlike large-scale systems such as wetlands and stream restorations, small-scale NBS are viable in virtually every sub-catchment across a city. This wide distribution of small-scale opportunities means that strategic implementation can be even more difficult for decision-makers seeking to maximise environmental and social benefits.

The overall NBS priority map in Figure 21, combining the four NBS priority criteria, was not utilised in the proposed prioritisation methodology for large-scale assets. Instead, the four individual NBS criteria maps (Figures 17-20) were used during the prioritisation process. However, as the overall priority map communicates those locations where NBS is most
desirable, this could become a useful tool to improve the strategic implementation of small-scale NBS. By highlighting priority areas, small-scale NBS projects could be embedded into common civil construction and development projects. This could improve the efficiency of small-scale NBS adoption by focusing resources on priority areas.

Data availability is a key consideration of the proposed method and a potential limiting factor in areas where key datasets are not available. While the proposed method has been developed with flexibility regarding input data for the four NBS criteria, there are several key spatial datasets that are required for the methodology to progress. Existing catchment data, elevation and/or drainage information is vital for defining the unit sub-catchments around which the methodology is based. Being related to traditional infrastructure planning, data defining the water quantity and quality criterion may be more commonly accessible from municipal sources. These datasets include those such as land zoning, impervious surfaces and flood risk. However, data defining social amenity and biodiversity may be more difficult to acquire due to these subjects being a more recent focus for many public institutions (Jalkanen et al. 2020). This study was fortunate to benefit from detailed amenity and biodiversity datasets from the University of Helsinki (Jalkanen et al. 2020) to help define these two criteria, however, these datasets do not extend beyond the Helsinki capital region. Hence, while the proposed methodology may be robust enough to accept varying data inputs, it should be recognised that relative data availability will have an impact on the generated results. These impacts can be the underrepresentation of an NBS criteria that is experiencing a lack of defining data or from a subsequent inability to adequately identify opportunities due to lack of contextual information (Geijzendorffer et al. 2020).

In addition to the availability of data, subjectivity remains when considering the representative data to be included within each NBS criteria. The choice of appropriate dataset is sensitive to the local social and environmental context. Cities often have local drivers that emphasise certain themes of NBS criteria (Sharma et al. 2016). Coutts (2014) noted that in certain areas, urban heat may be a driving factor in the amenity criteria, where in other locations there could be a larger emphasis on access to green space. While impossible to quantitatively represent, these contextual differences should be recognised when collecting and weighting the data defining each NBS criteria. As described in the weighting process, professionals with a collective broad, local experience covering the four NBS criteria should be consulted to ensure that the data is representative of the key drivers in the study location (Lähde 2018).

As the proposed method is defined by the sub-catchment as a unit of analysis, the choice of this sub-catchment unit influences the analysis results. Catchments exist at a variety of scales, with sub-catchment defining a catchment area that is part of a broader catchment system. The key choice to be made is the scale of these sub-catchments to be used to define the unit for the proposed method. Smaller sub-catchments are more easily dominated by localised effects, for example, a small section of motorway may be heavily influential within a small catchment. A larger sub-catchment containing the same section of motorway may not be represented in the same way. Hence, the variation of the sub-catchment unit resolution affects the interpretation of the priority indices. Using sub-catchments that are very small is likely to produce neighbouring catchments with large variation in index scores, due to localised effects. On the other hand, excessively large sub-catchments will reduce resolution and the impact of localised drivers.

Following the development of the opportunity priority list, consultation should be made with local authorities to establish the most promising opportunities. This is because several
barriers are expected for identified opportunities that may not be assessed in the preliminary prioritisation (Lähde 2018). Through a process of consultation with local experts and civil servants, the priority list can be scrutinised to find those opportunities that align with the municipality's existing vision and those with barriers to implementation (City of Helsinki 2018). Expected barriers that may arise in this stage include existing development plans (onsite and upstream), existing use of land and a lack of political will in certain areas. On the other hand, opportunities that align with future development plans could be fast-tracked due to the presence of works ongoing in the area. Hence, consultation is required to integrate contextual information beyond that available in spatial data format.

The consultation process is recommended to provide relevant local experts and authorities with the opportunity priority list and then bring their opinions together through a workshop session. Ideally, the workshop participants would be shared the long list of opportunities to allow for detailed consideration prior to the session. To ensure a holistic analysis, Lähde & Di Marino (2019) recommend that participants from a diverse professional background are involved, specifically perspectives on water infrastructure, social and environmental outcomes. Taking this approach, the scrutinised list is worked through, with participants able to raise promise or concerns with each opportunity. Those non-viable opportunities are noted and removed, resulting in a priority opportunity shortlist. This shortlist contains the NBS opportunities that have been confirmed as viable, with the highest expected performance from the four NBS criteria. While consultation was made with several representatives from the City of Helsinki during this study, an expanded consultation process has potential to increase data access, local relevance and final outcomes produced by the methodology.
7 Conclusion

The proposed methodology developed priority NBS index maps across the City of Helsinki, before identifying and prioritising NBS opportunities within the Mätäjoki case study area. The developed method helps to provide a strategic framework to answer municipal NBS decision-makers’ three key questions of location, asset type and performance assessment. The location and asset type questions were answered specifically within the case study area. A relative performance assessment was delivered, detailing which opportunities have potential to provide the highest multi-criteria benefits. However, these multi-criteria benefits were not quantified directly.

Five NBS indices were generated across the City of Helsinki, representing sub-catchment spatial priority for water quantity, water quality, amenity, biodiversity and an overall NBS index combining the four criteria. The indices produced spatially contrasting results, with the water quantity and amenity index highlighting dense, inner-city sub-catchments while the water quality and biodiversity indices tended to prioritise less dense, outer-city sub-catchments.

Within the Mätäjoki case study area, nineteen NBS opportunities were identified and prioritised according to their predicted performance across the four NBS criteria and the priority level of their containing sub-catchment. This resulted in a prioritised list and map of opportunities ranked by their expected multi-criteria performance via a priority score. The sensitivity analysis highlighted the differences between the priority scoring of the NBS opportunities. Water quantity priority scores were noted as an outlier, displaying the lowest magnitudes and variation between the highest and lowest ranked opportunities.

The City of Helsinki was involved throughout the project and noted the potential of the results to improve planning outcomes and better guide investment decisions for NBS. The viability of several identified opportunities was confirmed on-site with a City of Helsinki representative.

Further questions posed by this study include how to effectively quantify the multi-criteria benefits provided by NBS and how to address catchment connectivity. Much research remains to be done to effectively represent the multi-criteria benefits of NBS, when compared against traditional infrastructure responses. Even so, the methodology introduced in this study takes a step forward in providing decision-makers with the key data and direction needed to improve the strategic implementation of NBS.
8 References


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