# FOSTERING HEALTH AND SUSTAINABILITY IN POST-WAR NEIGHBORHOODS THROUGH THE IMPLEMENTATION OF ECOSYSTEM SERVICES

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***ABSTRACT***

*Cities are centers of consumption and sources of waste and pollutants, leading to environmental degradation and posing long-term risks to human health. However, introducing the concept of urban ecosystem services as a way to guide urban planning and design could improve human well-being and enhance urban sustainability. These urban ecosystem services can be enhanced by implementing a range of interventions, which at the same time could improve the current urban space. Particularly, post-war neighborhoods show significant room for improvement, with a lack of social cohesion and unused green spaces. Therefore, this paper aims to assess how the urban landscape and its ecosystem services can be utilized to improve health and sustainability of post-war neighbourhoods. Subsequently, the potential ways to minimize the damage of these neighbourhoods on the environment is addressed. Boerhaavewijk is discussed as a representative post-war neighborhood, showing a decreased overall well-being, lack of social cohesion and low quality public spaces. Urban ecosystem services could be employed in various ways to reduce these problems. These strategies will be presented in this paper.*

***KEYWORDS:*** *Urban ecosystem services; Post-war neighborhood; Human health; Sustainability*

## I. INTRODUCTION

The environment is heavily influenced by humans. As the majority of the world population lives in cities, they can especially play a pivotal role in the transition to a sustainable and healthy society. This link between the urban population and the environment will be described in the next paragraphs.

### 1.1 Humans, cities and the environment

Humans and the environment are closely linked and mutually influence each other. However although all organisms have affected their environment throughout history, humans have had a disrupting effect on the environment far greater then any other species. People have settled all over the world, using Earth's natural resources to their advantage, which has led to the fact that the global population is currently using more of the planet's resources and services than the earth can provide for. This caused the environment and ecosystems to change and often deteriorate (Chu & Karr, 2017). Especially since the Industrial Revolution, the environment is undergoing rapid global changes due to human activities. For example, carbon dioxide concentrations have increased by approximately 50 percent since the Industrial Revolution, mainly by burning fossil fuels (NASA, 2023). This elevation, along with human emissions of other greenhouse gases, has caused changes in the composition of the atmosphere, which makes humans primarily responsible for global warming and climate change (Chu & Karr, 2017; Giorgi, 2024).

Furthermore, regional climates have changed significantly, as humans have altered the Earth's surface through urbanization, agriculture and deforestation (Giorgi, 2024). Especially cities have a major impact on the environment through completely modifying natural ecosystems (Nikodinoska et al., 2018). Moreover, their impact is increasing due to the growing population and urbanization. It is expected that 68% of the global population will live in cities by 2050, which is significantly more than the 55% that is currently living in a city (Elliot et al., 2022). The growing number of urban dwellers goes hand in hand with an increasing demand for Earth's natural products and services, like food and raw materials, in order to maintain people's health and continue their current lifestyle (Bolund & Hunhammar, 1999; Elliot et al., 2022). These products and services can be defined as ecosystem services. Ecosystem services are services produced by ecosystems from which humans benefit in order to provide for their own existence (Millennium Ecosystem Assessment, 2003). As cities are not able to meet the demand for ecosystem services themselves, they heavily depend on ecosystems located far beyond the city boundaries, even on the opposite side of the world (Jansson, 2013). These ecosystems often fulfill important functions essential for life, like carbon sequestration, maintenance of soil fertility and the provision of habitat for animals and plants. As human consumption increases, parts of these natural ecosystems are transformed to enable other functions primarily related to the mass production for humans, like agriculture or livestock farming. Although this ensures that immediate human needs are met, other important ecosystem services decline as less space is available for the original ecosystem (DeFries et al., 2004).

Evidently, cities have both a huge impact and dependency on the environment as their establishment disrupts natural ecosystems or even causes them to disappear completely. In addition, their high population density and therefore demand and use of ecosystem services has extensive consequences for ecosystems in other regions of the world. These ecosystems will be used to meet the production demand from the city and will therefore have to deal with changes in land use. This causes ecosystem services, not primarily meant for human consumption, to diminish. Although this ensures an increased production of short-term human needs, the long-term provision of ecosystem services, and therefore the survival of humanity, may be jeopardized (Foley et al., 2005).

## 1.2 Ecosystem services and human well-being

The influence of nature on health has long been known. However, the role of ecosystems in relation to human well-being remained relatively unclear until the early 2000's. Therefore, in 2000, the United Nations initiated the establishment of a program, the Millennium Ecosystem Assessment, which would study the impact of ecosystem changes on human health. In the first place, the assessment would provide decision makers with the necessary scientific information to manage ecosystems in a sustainable way. Moreover, the report proposed a conceptual framework, which made it possible to analyze the interactions between humans and ecosystems, while having human health as the main objective. Within this framework, ecosystem services, like fresh water and clean air, directly affect human well-being as these services fulfill basic human needs. Preserving, managing and possibly strengthening ecosystems that provide these services therefore becomes crucial to sustain long-term human health (Millennium Ecosystem Assessment, 2003; World Health Organization et al., 2005; Yang et al., 2013).

Since its publication, the concept of ecosystem services has been extensively researched (Hernández-Blanco et al., 2022). The role of urban ecosystem services is also increasingly recognized in literature, as the condition of the urban environment, determines its capacity to contribute to public health, sustainability goals and climate resilience within cities (Tan et al., 2020). In addition to these possible advantages, the urban ecosystem can serve to alleviate pressure on (semi-) natural ecosystems located beyond the city limits (Balzan et al., 2021; Cortinovis & Geneletti, 2019). Hence, it is imperative to assess ecosystem services within urban areas and evaluate their potential contributions to a healthy and sustainable urban environment.

## 1.3 Location

The Netherlands is highly urbanized with 83% of its population living in urban areas (CBS, 2023b). Moreover, the number of inhabitants of this densely populated country continues to increase (CBS, n.d.). This instigates a heightened demand for ecosystem services, consequently imposing significant pressure on the (semi-) natural ecosystems within and outside of the country. In addition, urban areas will need to undergo further densification to effectively address the current housing shortage in the country, thereby intensifying the pressure on ecosystems. In 2019, the average ecological footprint per person was 6.4 global hectares. However, the country's available productive area per person was only 1.1 global hectares. This leads to a substantial ecological deficit, making the country dependent on the biocapacity of other countries and simultaneously contributing to the degradation of their ecosystems (Global Footprint Network, 2023). In order to alleviate the ecological deficit, natural ecosystems need to be restored and demands from the cities reduced. Especially in the Netherlands, where only a quarter of the

landscape exists of fresh water and nature (CBS, 2022), cities can have significant impact on the provision of ecosystem services to their inhabitants. However, increasing the production of urban ecosystem services requires an area-specific approach.
In addition to this, a large part of the Dutch housing stock is in need of a quality upgrade to become sustainable and thereby improve its public space. This upgrade is in particular necessary for the housing stock is located in the post-war neighborhoods (CBS, 2023a). Therefore, this paper will mainly assess the post-war neighborhoods in the Netherlands.

## II. THEMATIC RESEARCH QUESTION AND METHODOLOGY

As described prior, cities are primarily centers of consumption and sources of waste and pollutants (Elmqvist et al., 2015; Mirabella & Allacker, 2018), leading to environmental degradation and posing long-term risks to human health. However, introducing the concept of urban ecosystem services as a way to guide urban planning and design could potentially enhance urban sustainability and improve human well-being (Elmqvist et al., 2015; Tan et al., 2020).
The post-war neighborhoods require improvement in particular, especially in terms of health and sustainability. Since the 1990s, these neighborhoods have been associated with a deteriorating quality of life, marked by various social and physical challenges. The urban ecosystem could potentially contribute to addressing these issues.

In order to address this, the focus of this paper will be on the following thematic research question:
*'How can the urban landscape and its ecosystem services be utilized and optimized to both improve the health and sustainability of post-war neighborhoods in the Netherlands and to minimize their damage on the environment?'*

In order to answer this question, this paper will first review the existing literature on the relation between the urban ecosystem and human health. Thereafter the most relevant urban ecosystem services will be explored, along with their impact on human health and strategies to enhance them. Secondly, the post-war neighborhood and its challenges will be described. Subsequently, the case study, Boerhaavewijk will be introduced. In the following chapter, an assessment of the relevant urban ecosystem supply capacity of Boerhaavewijk will be made. Finally, two scenarios, which include different strategies to improve urban ecosystem services, will be explained and tested. The results will provide insight into the extent to which certain measures influence urban ecosystem services and can contribute to human health without putting more pressure on other regions. The conclusion will respond to the presented research question.

## III. URBAN ECOSYSTEM SERVICES AND HUMAN WELL-BEING

This paragraph will explain the relation between the urban environment, sustainability and human well-being. Furthermore, the functions of various urban ecosystem services which are relevant on a local scale will be described. Additionally, possible interventions which could contribute to the provision of urban ecosystem services will be proposed. These interventions will be evaluated based on their potential to positively impact human well-being and urban sustainability.

### 3.1 Definition and categorization of urban ecosystem services

The urban ecosystem can be interpreted in different ways. In this paper, the urban ecosystem will consist of natural, semi-natural and managed communities of organisms and habitats situated within the city. These communities and habitats encompass vegetated areas which have remained comparatively untouched, for example lakes and forest patches, but also carefully maintained urban green and blue spaces, like public parks, streetscape greenery and gardens (Tan et al., 2020). Moreover, green elements integrated into buildings and infrastructure, like green roofs, are also included (Tan et al., 2020; Elmqvist et al., 2015).
The benefits humans derive from the urban ecosystem are defined as urban ecosystem services. These services have a direct or indirect impact on human well-being. Direct services, such as food, are directly consumed by humans. Indirect services are essential for sustaining the ecosystem itself, for example

pollination (Bolund & Hunhammar, 1999). Ecosystem services also differ in spatial coverage, ranging from local to global scales, based on the nature of the problem to which they are linked and the transferability of the service. Easily transferrable services, like global $CO_2$ sequestering, may not require to be provided near the source of the problem. In contrast, services that cannot be readily transferred, such as recreational nature, must be generated in close proximity to consumers (Bolund & Hunhammar, 1999; Tan et al., 2020). This paper mainly focusses on services which are locally generated and consumed. These services are prioritized as cities are already densely populated areas accommodating a variety of uses and activities within limited space.
The ecosystem services which can be provided within the city, contribute to human well-being in various ways and improve the quality of life. According to the Millennium Ecosystem Assessment (2003), these services can be divided into four categories: supporting, provisioning, regulating and cultural services. The following paragraphs will elaborate on these categories. Furthermore, essential urban ecosystem services within each category will be described. This description will encompass a general overview of the service, its impact on health and sustainability, the source of the service, and strategies for enhancement. Moreover, these descriptions will refer to Appendix H, which shows a section of a stamp in the post-war neighborhood Boerhaavewijk. Each point in Appendix H presents an implementation of one of the strategies to enforce certain ecosystem services.

## 3.2 Supporting services

Supporting services, like soil formation, play a pivotal role in maintaining the other three categories of services, provisioning, regulating and cultural services. The supporting services have an indirect connection to human well-being (Millennium Ecosystem Assessment, 2003). These ensure ongoing health of ecosystems and are therefore crucial for humanity (Pedersen Zari, 2017a). The supporting services which are most relevant for cities are provision of habitats for species & maintenance of biodiversity (Charoenkit & Piyathamrongchai, 2019; TEEB, 2011).

### 3.2.1 Provision of habitats for species and maintenance of biodiversity

Ecosystems offer crucial habitats necessary for different species' life cycles. These habitats encompass all essential elements for the survival of individual plants or animals, including food, water, and shelter. The provision of habitats is essential to maintaining biodiversity. Cities offer habitats suitable for species that can co-inhabitate with humans (Gómez-Baggethun et al., 2013; TEEB, 2011; Pedersen Zari, 2017a). To enhance biodiversity and provide habitats for plants and animals in the neighborhood (see appendix H, point 18), the emphasis lies on adding and connecting habitats and food webs, and generating settling sites and nesting possibilities. This can be realized by connecting green and water structures to establish networks. Furthermore, the expansion of urban green spaces and structures (see appendix H, point 8), like urban forests, parks, tree-lined avenues (see appendix H, point 1), as well as green roofs (see appendix H, point 2 and 7) or facades, contributes significantly (Van den Berg et al., 2022). Moreover, layering and variation of vegetation promotes the number of species as the area then meets the needs of more different animal species. In addition, when introducing plant species, they should preferably be native, as they form an important food source for animals (Synchroon, 2023). Finally, the creation of accommodations and nesting facilities (see appendix H, point 15) serves as a measure to increase biodiversity within the urban context. These facilities can be incorporated into public spaces and gardens, but buildings could also serve as nesting sites by using porous and nature-friendly materials (Van den Berg et al., 2022).

## 3.3 Provisioning services

Ecosystems provide goods and services essential for various facets of human well-being, such as food and fiber. These products are known as provisioning services and fulfill basic human needs (Millennium Ecosystem Assessment, 2003). The most pertinent provisioning services in the urban environment are food supply, fresh water and raw materials (Kain et al., 2016; TEEB, 2011; Pedersen Zari, 2017a).

### 3.3.1 Food supply

Ecosystems create the required conditions for agricultural production. Food is predominantly derived from managed agro-ecosystems outside of the city (TEEB, 2011). As a reaction to population growth, the provision of food is one of the only services which has globally increased over the past 60 years due to the intensification of agriculture, however often at the expense of other ecosystems and thus supporting and regulating services (Pedersen Zari, 2017a). Furthermore, food systems account for 15% of the global use of fossil fuels and one-third of the global emission of greenhouse gasses (Global Alliance for the Future of Food, 2023). Urban food-growing or urban agriculture could offer a solution as it contributes to food security and resilience of the food system (Payen et al., 2022; Pedersen Zari, 2017a). Another advantage is the close proximity of food supply to the consumer, leading to less transportation and therefore pollution emissions. Moreover, the introduction of urban food production sites could contribute to a large range of advantages related to other services and health, like mitigation of the impact of stormwater, reduction of the effects of urban heat island, pollination, biodiversity, stress reduction and recreation (Russo et al., 2017). Despite these advantages, implementing food production in urban areas also poses challenges, as it requires adopting a different lifestyle (Pedersen Zari, 2017a).
To increase food supply in an urban environment various forms of food production sites could be introduced, including urban food forestry, edible urban greening, historic parks, botanical gardens, allotment and community gardens, domestic gardens, edible green roofs (see appendix H, point 3), walls and facades (Russo et al., 2017). However, before the implementation, the suitability of a location should be assessed by considering historical data, soil quality and potentially nearby pollution sources (Russo et al., 2017).

### 3.3.2 Fresh water

Fresh water is essential for human survival and health. The regulation of water flows, purification, storage and retention of water are ecosystems services that play a crucial role in the supply of drinking water to cities (TEEB, 2011; Pedersen Zari, 2017a). Drinking water is primarily sourced from surface water bodies and groundwater reservoirs. The amount of fresh water reaching these sources is dependent on meltwater and rainwater. While humans have no direct control over these quantities, the manner in which they are utilized and managed impact the level of demand. A city can contribute to this by effectively using rainwater, through retaining, storing and directly employing harvested rainwater at a local level (Denchak, 2022). These functions can be fulfilled by technical solutions. For example, rainwater can be temporarily stored on water roofs (see appendix H, point 13) or squares, in water barrels and in infiltration crates. Moreover, rainwater use systems (see appendix H, point 11) can store rainwater for purposes like washing or gardening, consequently reducing the demand for tap water (Amsterdam Rainproof, n.d.; Denchak, 2022). On the other hand, green and blue infrastructure fulfill these functions naturally. Replacing impervious surfaces with permeable surfaces (see appendix H, point 8) reduces the amount of rainwater which would have ended up as runoff. This allows the rainwater to replenish the groundwater instead of in the city sewer system. Moreover, as vegetation and soil absorb, retain and gradually release rainwater, the water is purified before its ending up in the groundwater or atmosphere (Denchak, 2022; Pandey & Ghosh, 2023). Due to the water absorption of nature, a smaller amount of often polluted stormwater flows directly into urban waterways, simultaneously alleviating the pressure on the sewer system (Pandey & Ghosh, 2023).
Various forms of green and blue infrastructure play a role in enhancing efficient and sustainable use of water. Intensive and extensive green roofs and green gardens retain water (see appendix H, point 2 and 3) (Amsterdam Rainproof, n.d.; Denchak, 2022). Additionally, as tree canopies catch the rain, some of it evaporates directly from the foliage and some is absorbed and then re-emitted into the atmosphere via transpiration (see appendix H, point 4). Their root system creates an open network in the soil, increasing the sponge effect of the soil (see appendix H, point 16) (Denchak, 2022; Pandey & Ghosh, 2023). Infiltration strips and façade gardens allow rainwater run-off from streets, facades and roofs to infiltrate the soil. Furthermore, redirecting rainwater from building downsprouts to these areas alleviates pressure on the sewer system (Amsterdam Rainproof, n.d.; Denchak, 2022). In addition, rain gardens and wadi's (see appendix H, point 5) can be implemented to retain and purify rain water. Constructed wetlands (see appendix H, point 9) serve a similar purpose, but they can also treat grey and sewage water (Denchak, 2022; Pandey & Ghosh, 2023).

Thus, the implementation of varies technical and natural solutions could contribute to the ecosystem service of fresh water supply, by either implementing water storing techniques or enforcing the natural abilities of green and blue infrastructures. These natural solutions do not only decrease the demand for tap water, but in addition purify the water and relieve the sewer system.

### 3.3.3 Raw materials

A wide range of materials for construction and fuel is supplied by ecosystems, for example wood and fiber. These materials are directly obtained from both cultivated and wild plant species (TEEB, 2011).
The built environment currently takes up over a third of the materials extracted globally and simultaneously produces one-third of the global waste (Pedersen Zari, 2017a). To reduce these amounts, the selection of materials used in either new construction or retrofits could play a major role. Although the existing urban environment often contributes to the degradation of health and ecosystems, certain materials can do the opposite. For example, various construction materials can contribute to the purification of water and air or generate energy (Pedersen Zari, 2017b). Construction materials which could particularly have a positive effect on the sustainability of the built environment and ecosystem health, are biobased materials. These materials originate from crops and are therefore renewable. Moreover, they capture carbon dioxide through photosynthesis, which is subsequently stored in the building material. Furthermore, biobased materials are acknowledged for their positive influence on moisture regulation, contributing to a more pleasant indoor climate. Various biobased materials also offer technical advantages such as acoustic insulation and vibration absorption. These properties contribute to a positive impact on both sustainability and human well-being (Van Dam & Van Den Oever, 2019).
Although, the production of biobased materials is often not possible in densely populated areas, certain urban edges might be suitable for the cultivation of these materials. Urban fringes are often characterized by exclusively agricultural land use with little biodiversity. A transformation to a production landscape for biobased building materials (see appendix H, point 20) in combination with functions such as recreation (see appendix H, point 19) could offer an opportunity to realize raw material supply at a local level (BOOM Landscape & De Natuurverdubbelaars, 2022).

## 3.4 Regulating services

Ecosystems perform regulating functions, which are vital for the survival of humans and other species. Regulating services are associated with the local and global nutrient cycle, as well as the filtration and transformation of pollutants and wastes. Regulating services, like pollination, regulate and maintain other fundamental ecosystem functions which directly contribute to health (Millennium Ecosystem Assessment, 2003; Pedersen Zari, 2017a). In cities, urban temperature regulation, air quality regulation, moderation of climate extremes and carbon sequestration are essential for human well-being (Charoenkit & Piyathamrongchai, 2019; Kain et al., 2016; TEEB, 2011; Pedersen Zari, 2017a).

### 3.4.1 Urban temperature regulation

High temperatures and heat waves are strongly linked to health and mortality. For example, longer periods with higher temperatures cause excess mortality, worsening of chronic conditions and fatigue (World Health Organization, 2018). Preventing and minimizing a temperature rise therefore becomes essential. In cities, high temperatures are amplified by solar radiation which is absorbed by the built-up urban fabric and the dense population. This phenomenon is known as the urban heat island. The urban ecosystem affects local temperatures and has the ability to counteract the effects of urban heat islands (Gómez-Baggethun et al., 2013; Iungman et al., 2023). Water bodies and green infrastructure (see appendix H, point 8 and 9) mitigate high temperatures by absorbing heat. Green infrastructures do this through evapotranspiration, shading and the reflection of solar radiation (Gómez-Baggethun et al., 2013). For example, green facades and roofs (see appendix H, point 2 and 3) can provide cooling and enhance the reflectivity of buildings. In addition, paved areas can be replaced by vegetated areas. Particularly, the tree coverage (see appendix H, point 4) is crucial to reduce high temperatures and provide shade. An area with a tree coverage of at least 30% is beneficial for human health, as it can reduce the chance of psychological complaints and diseases (Iungman et al., 2023).

Thus, there are multiple potential interventions available to counteract the urban heat island effect. Introducing these measures into the urban fabric can positively affect the mental and physical health of citizens.

### 3.4.2 Air quality regulation

The urban ecosystem is crucial for the regulation of urban air quality, as it purifies the air from pollutants (TEEB, 2011). Air pollution in cities often originates from transportation, waste incineration and industry (Gómez-Baggethun et al., 2013). Pollutants, like ozone, particulate matter ($PM_{10}$) and nitrogen dioxide, have major impact on the environment and health. Air pollution contributes significantly to respiratory and cardiovascular diseases and increased morbidity and mortality (World Health Organization, 2019). Vegetation in the city can play a pivotal role in the improvement of air quality, due to its ability to remove pollutants from the atmosphere. Especially green strips along roads (see appendix H, point 1) could be effective as they directly capture the particulate matter. The ability to purify pollution from the air varies by plant and landscape type. Vegetation with a complex structure, like woodlands, provides a higher degree of air purification than simpler managed vegetation types, like lawns (Vieira et al., 2018).

### 3.4.3 Moderation of climate extremes

As climate extremes are intensifying and becoming more frequent, the adaptability and resilience of cities becomes essential. In the Netherlands, these extremes will most likely occur in the form of heat waves, storms and floods (Gómez-Baggethun et al., 2013). While technical measures, like dikes, have a significant role in protecting cities against natural disasters, the urban ecosystem is crucial for the adaptability of the city and the protection of livelihoods as it provides buffers mitigating the impact of extreme events (Sharifi & Yamagata, 2018; TEEB, 2011).
Measures to prevent human exposure to natural disasters include preventing urban development in risk areas or areas that provide valuable ecosystem services (Sharifi & Yamagata, 2018). For example, urban development should preferably not take place in areas with strong land subsidence, as this could lead to major financial and social consequences. The preservation of wetlands, including peat bogs and raised bogs, should also be prioritized as they are of great importance for the storage of $CO_2$. Other measures include the preservation and extension of urban green and blue infrastructures (see appendix H, point 8) as they are crucial for the regulation of the urban microclimate, offer cooling during heat waves and ensure stormwater absorption through permeable surfaces (Sharifi & Yamagata, 2018).

### 3.4.4 Carbon sequestration

The urban ecosystem serves as carbon storage as plants and trees extract $CO_2$ from the atmosphere and capture it in their tissues. In this way the city contributes to the reduction of greenhouse gases in the atmosphere (TEEB, 2011). Increasing the amount of greenery within cities could enhance the contribution of cities in reducing greenhouse gasses (see appendix H, point 2, 8 and 14). Although this contribution is far from outweighing the emissions from urban areas, the city can still play an important role in carbon sequestration (Gómez-Baggethun et al., 2013).

## 3.5 Cultural services

Ecosystems also contribute to human well-being by providing cultural or psychological benefits. These benefits are based on the human experience of the recreational, educational, aesthetical, cultural and spiritual values of the ecosystem (Millennium Ecosystem Assessment, 2003; Pedersen Zari, 2017a). The urban ecosystem primarily provides the following cultural services: recreation and a sense of place and social cohesion (Charoenkit & Piyathamrongchai, 2019; Gómez-Baggethun et al., 2013; TEEB, 2011).

### 3.5.1 Recreation

The urban ecosystem provides spaces for outdoor recreation, which positively influence mental and physical health. Green and blue infrastructures, like public parks and rivers, offer experiences which can provide a sense of tranquility, reduce stress and improve cognitive functioning and concentration (Coutts & Hahn, 2015; Gómez-Baggethun et al., 2013). Moreover, the presence of green and blue infrastructures promotes physical activity, which contribute to a healthy physique and therefore human health (Coutts & Hahn, 2015; TEEB, 2011). In addition, people are more prone to use walking or biking as transportation when more greenery, especially within a network (see appendix H, point 19), is present, which in turn leads to a decreased use of cars. This change in means of transportation also diminishes the pressure of cars on the urban area, subsequently creating the opportunity for more green and blue infrastructure within cities (Roelofsen et al., 2024). Although the urban ecosystem predominantly offers positive health effects, the design determines its recreational value as this is dependent on the ecological quality of greenery, its safety and accessibility (Gómez-Baggethun et al., 2013).

### 3.5.2 Sense of place and social cohesion

The urban ecosystem contributes to the creation of a recognizable living environment for citizens. How urban residents perceive and experience these places determines their sense of place. This entails the attachment of residents to their living environment and the extent to which it is part of their identity (Ryfield et al., 2019). Attachment to green and blue infrastructure can encourage residents to engage in environmental management. In addition, shared interests in the urban ecosystem can lead to social cohesion. This social cohesion is also promoted by urban green spaces which form a place where habitants can meet one another (Roelofsen et al., 2024). A sense of place and social cohesion often result in neighborhoods in which homes are better maintained and the green and blue infrastructure is used more regularly (Gómez-Baggethun et al., 2013).

## IV. THE POST-WAR NEIGHBORHOOD: BOERHAAVEWIJK

Almost 30 percent of the current Dutch housing stock was built in the post-war period between 1945 and 1975. The 2.6 million houses which were built during that time were a reaction to the major housing shortage in the Netherlands after the Second World War (CBS, 2023a). The rapid and large-scale construction of these houses was mainly done by adding large neighborhoods around existing cities (Blom et al., 2004). These neighborhoods are currently known as the post-war neighborhoods and are often associated with a wide range of social, physical and economic problems.

### 4.1 Challenges in the post-war neighborhood

During the design and construction of post-war neighborhoods, there was a clear vision. The neighborhood was supposed to function as a spatially independent urban community, which encouraged social cohesion. This initially led to a urban plan with the main structures of infrastructure, greenery and water and a spatial segregation of functions. Reinforced by the rise of prefabricated building systems, this resulted in regular, repetitive patterns of residential building blocks surrounding unprogrammed shared green spaces, also known as ‘stamps’ (Blom et al., 2004; Abrahamse & Rutte, 2020).

Currently, the design of these neighborhoods is perceived as austere, monotonous and pragmatic. Moreover, the intended goal of fostering social cohesion among residents through the creation of numerous shared spaces has seen limited realization. The streets lack vibrancy, and the shared green spaces primarily serve aesthetic purposes as their function is often unclear. Moreover, the neighborhood is heavily dominated by the car, evident through the presence of roads, parking spaces, and garage boxes (Schravesande & Himmit, 2023). Other societal challenges relate to well-being and sustainability. Residents in post-war neighborhoods frequently encounter health issues, coupled with elevated levels of loneliness. Furthermore, the existing housing stock often does not meet current needs. There is a mismatch between the supply of housing types and demand, with many units lacking sustainability features and sufficient insulation (Meier, 2006; Obbink, 2016).

### 4.2 Boerhaavewijk

Boerhaavewijk is a typical post-war neighborhood from the 1960s and therefore representative of the post-war neighborhoods in the Netherlands. The neighborhood has approximately 8,200 inhabitants and 4000 homes (Gemeente Haarlem, 2024b). The layout of Boerhaavewijk reflects the 1957 structure plan for Schalkwijk, which was intended as a satellite city for Haarlem. The plan emphasizes the importance of the car as roads were seen as connectors within the city. The main structure of Boerhaavewijk is therefore based on infrastructure, as is the case in most post-war neighborhoods (Haarlems Dagblad, 1957b). Furthermore, the characteristic repetitive stamps are clearly recognizable and Boerhaavewijk deals with similar problems as other post-war neighborhoods, including issues considering overall well-being, for example due to loneliness (RIVM, 2022). Moreover, the public space, including greenery, lacks quality, functionality and variation, and residents report a lack of connection to the neighborhood (Gemeente Haarlem, 2024a).

In many of the post-war neighborhoods, such as Boerhaavewijk, renovation is needed to ensure the sustainability of the housing stock and guarantee the livability of the neighborhood in the future (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Urhahn, 2024). When a neighborhood is eligible for renovation, the inclusion of ecosystem services in the design process can offer many advantages for both its inhabitants and the environment. For example, implementing natural water retention measures in the now unused green areas could provide cooling, temporary water storage and water purification. Moreover, these areas can at the same time contribute to the creation of pleasant and valuable places for its residents. They could for example be transformed into meeting spaces and recreational areas for the residents. Appendix H shows how some of the measures to stimulate ecosystem services can be implemented in the neighborhood. The image on top presents a drawn section of the current state of a stamp within Boerhaavewijk. The section at the bottom depicts the same stamp after the implementation of multiple strategies to enhance ecosystem services. The applied strategies are mentioned at the bottom.

## V. THE SCENARIOS

The previous sections discussed how urban ecosystem services affect human health and well-being, highlighting the crucial role ecosystems play in human survival. Furthermore, design principles to enhance key urban services were explored. For instance, cities can enhance food production through communal vegetable gardens and mitigate the urban heat island effect by promoting tree-based shading and evapotranspiration.

Moreover, the post-war neighborhood was examined as a context to apply these strategies for improved health and reduced environmental impact. This section will assess the current provision of mentioned ecosystem services in the post-war neighborhood. Additionally, two alternative design scenarios will be evaluated on their contribution to ecosystem services and their potential to alleviate environmental burdens. This part of the research mainly intends to show the possibilities of the implementation of urban ecosystem services into the post-war neighborhood.

### 5.1 Quantifying urban ecosystem services

Different plant and animal species and soil types contribute uniquely to the provision of urban ecosystem services, like water filtration and urban heat regulation. The presence of native and diverse species enhances the resilience of urban ecosystems, thereby improving the overall delivery of these services (Synchroon, 2023). Although these different species make unique contributions to urban ecosystem services, this part of the research focusses on different types of vegetation and water structures in order to make the quantification of these services possible. Derkzen et al. (2015) developed a categorization of these structures, which can be seen in appendix A. In their research, these categories are linked to specific ecosystem services and their contributions measured per spatial unit. The values reflecting the contribution of each vegetation and water structure to various urban ecosystem services are primarily derived from Derkzen et al. (2015) and are presented in appendices B and C.

During this research, these values are used to quantify the supply of urban ecosystem services within a post-war neighborhood stamp in Boerhaavewijk. A stamp is chosen as the research area as this area represents typical land use patterns found in such neighborhoods.

The following paragraphs will evaluate distinct design scenarios for the post-war neighborhood stamp and their contributions to the supply of ecosystem services. The scenarios under consideration include the current situation, the urban landscape as a resource, and the urban oasis. The plans for these scenarios are presented in appendix D.

## 5.2 Current situation

The land use within the post-war stamp is characterised by a mix of residential construction, infrastructure and low vegetation, leading to an area which mainly consists of hard surfaces and little variation in vegetation types. This can be seen in the plan in appendix D. The urban ecosystem services produced within this area can be seen in appendix E.

## 5.3 Scenario 1: The urban landscape as a resource

This scenario focusses on provisioning services. It explores the opportunity of the post-war neighborhood stamp as a resource for food (vegetables), household water and raw materials. The plan includes allotment gardens and edible greenery on the flat roofs of the apartment buildings, water collection on the roofs of the row houses and the production of a raw material, in this case cattail, along the urban edge. These measures are combined with the introduction of variation in the vegetation in the current green areas. This can be seen in the plan in appendix D. The urban ecosystem services produced within this area can be seen in appendix F.

## 5.4 Scenario 2: The Urban Oasis

This scenario explores the possibility of the post-war neighborhood stamp as an urban oasis. (vegetables), household water and raw materials. The plan includes a large variation of vegetation types and car infrastructure is replaced by a park-like design. Moreover, the flat roofs of the apartment buildings and garage boxes will be covered with vegetation, optimizing the amount of greenery in the area. This can be seen in the plan in appendix D. The urban ecosystem services produced within this area can be seen in appendix G.

## 5.5 Results

The tables presented in appendix E, F and G provide an analysis of the urban ecosystem supply capacity of the post-war stamp in Boerhaavewijk, showcasing current and scenario-based projections for ecosystem services. In the current capacity (appendix E), trees and woodlands make significant contributions to air quality regulation and carbon sequestration, when compared to other vegetation types. Scenario 1 (appendix F) indicates a shift towards enhanced ecosystem services mainly due to the addition of short shrubs and tall bushes. Moreover, the scenario supports local needs for raw materials as cattail can be used as a construction material. The food supply from local vegetable cultivation enhances food security and reduces reliance on external supply chains, fostering community resilience. The utilization of harvested rainwater for non-potable uses, in this case toilet flushing, conserves potable water resources and alleviates pressure on municipal water systems. In scenario 2, the various green areas have been expanded, replacing some of the former paved surfaces. This results in a larger surface being used for different vegetation types and more variation. The scenario shows the potential for a larger supply of ecosystem services, mainly focussed on supporting and regulating services.

The tables provide general estimates of urban ecosystem supply capacity. However, these values may vary depending on specific species and local conditions. Additionally, the demand for ecosystem services within an urban environment is often unclear, and influenced by community needs and changing environmental factors, which makes precise assessments challenging in urban contexts. So, despite the positive increase in supply of urban ecosystem services in scenario 1 and 2, the demand for ecosystem services is growing, driven by population increases and climate challenges. Effective urban planning must continue to bridge this gap, ensuring that ecosystem supply keeps pace with community needs while fostering a sustainable and resilient urban environment.

# VI. Conclusion

This study addresses the research question: 'How can the urban landscape and its ecosystem services be utilized and optimized to both improve the health and sustainability of post-war neighborhoods in the Netherlands and to minimize their damage on the environment?' The findings emphasize the importance of urban ecosystem services, which can be categorized into provisioning, regulating, supporting, and cultural services. Each category provides distinct benefits that contribute to community well-being and environmental resilience. For example, provisioning services like food production and water supply are essential for fostering local self-sufficiency, while regulating services such as air quality improvement and flood mitigation are vital for addressing climate change impacts.

Focusing on Boerhaavewijk as a representative post-war neighborhood, the analysis identifies how specific enhancements to ecosystem services can address the unique challenges posed by urbanization, environmental degradation, and shifting demographic needs. The scenarios presented demonstrate that increasing green spaces and enhancing vegetation diversity can significantly improve air quality, enhance biodiversity, and provide essential recreational opportunities for residents.

The research highlights that although not all human ecosystem needs can be fulfilled by optimizing the ecosystem capacity in the urban area, the inclusion of elements enhancing the provision of ecosystem services within a neighborhood, offers advantages for both human and wildlife health. Integrating ecosystem services into urban planning is not merely advantageous but imperative for the development of resilient urban environments. By effectively leveraging these services, neighborhoods can mitigate environmental damage and adapt to ongoing challenges, such as climate change and urban sprawl. The strategic implementation of urban ecosystem services in Boerhaavewijk has the potential to improve health outcomes, foster community engagement, and strengthen the relationship between residents and their environment. A section of what this could look like within a post-war stamp is presented in appendix H.

In conclusion, addressing this research question requires a comprehensive approach that integrates ecological principles into urban design. Such strategies will help ensure that post-war neighborhoods like Boerhaavewijk develop into sustainable and dynamic environments that prioritize both human health and ecological integrity.

## REFERENCES


1. Abrahamse, J. E., & Rutte, R. (2020). De woning als massaproduct. *Bulletin*, 38–43. https://doi.org/10.48003/knob.119.2020.4.703
2. Amsterdam Rainproof. (n.d.). *Buurt*. https://www.rainproof.nl/wat-kan-ik-doen/buurt
3. Bakker, J., Van Der Mooren, F., & Boonstra, H. J. (2022, 12 september). *Watergebruik Thuis (WGT) 2021*. Centraal Bureau Voor de Statistiek. https://www.cbs.nl/nl-nl/longread/aanvullende-statistische-diensten/2022/watergebruik-thuis--wgt---2021/7-het-toilet#:~:text=Bij%20het%20volledig%20doorspoelen%20gaat,liter%20per%20persoon%20per%20dag.
4. Balzan, M. V., Zulian, G., Maes, J., & Borg, M. (2021). Assessing urban ecosystem services to prioritise nature-based solutions in a high-density urban area. *Nature-Based Solutions*, *1*, 100007. https://doi.org/10.1016/j.nbsj.2021.100007
5. Bestman, M., Geurts, J., Egas, Y., Van Houwelingen, K., Lenssinck, F., Koornneef, A., Pijlman, J., Vroom, R., & Van Eekeren, N. (2019). Natte teelten voor het veenweidengebied: Verkenning van de mogelijkheden van lisdodde, riet, miscanthus en wilg. In *Veenweiden Innovatiecentrum*. https://www.veenweiden.nl/publicaties/brochure-natte-teelten-voor-het-veenweidengebied/
6. Blom, A., Jansen, B., & Van Der Heiden, M. (2004). De typologie van de vroeg-naoorlogse woonwijken. In *Rijksdienst Voor Het Cultureel Erfgoed*. https://www.cultureelerfgoed.nl/binaries/cultureelerfgoed/documenten/publicaties/2014/01/01/de-typologie-van-de-vroeg-naoorlogse-woonwijken/typologie-van-de-vroeg-naoorlogse-woonwijken.pdf
7. Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*(2), 293–301. https://doi.org/10.1016/s0921-8009(99)00013-0
8. BOOM Landscape & De Natuurverdubbelaars. (2022). Biobased (ver)bouwen in Groot Haarzuilens. In *College Van Rijksadviseurs*. https://www.collegevanrijksadviseurs.nl/projecten/Adviezen-publicaties/publicatie/2022/07/14/biobased-verbouwen
9. CBS. (2022, May 18). Toename bebouwd gebied ten koste van landbouw. *Centraal Bureau Voor De Statistiek*. https://www.cbs.nl/nl-nl/nieuws/2022/20/toename-bebouwd-gebied-ten-koste-van-landbouw
10. CBS. (2023a, May 31). *Voorraad woningen; standen en mutaties vanaf 1921*. CBS Statline. https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82235NED/table?dl=7A6BD
11. CBS. (2023b, December 18). *Regionale kerncijfers Nederland*. CBS Statline. https://opendata.cbs.nl/StatLine/#/CBS/nl/dataset/70072ned/table?ts=1704821286481
12. CBS. (n.d.). *Bevolkingsteller*. Centraal Bureau Voor De Statistiek. https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/bevolkingsteller
13. Charoenkit, S., & Piyathamrongchai, K. (2019). A review of urban green spaces multifunctionality assessment: A way forward for a standardized assessment and comparability. *Ecological Indicators*, *107*, 105592. https://doi.org/10.1016/j.ecolind.2019.105592
14. Chu, E. W., & Karr, J. R. (2017). Environmental Impact: concept, consequences, measurement. *Reference Module in Life Sciences, B978-0-12-809633-8.02380-3*. https://doi.org/10.1016/b978-0-12-809633-8.02380-3
15. CLO. (2023, August 15). *Jaarlijkse hoeveelheid neerslag in Nederland, 1910-2022*. Compendium Voor De Leefomgeving. https://www.clo.nl/indicatoren/nl050809-jaarlijkse-hoeveelheid-neerslag-in-nederland-1910-2022
16. Cortinovis, C., & Geneletti, D. (2019). A framework to explore the effects of urban planning decisions on regulating ecosystem services in cities. *Ecosystem Services*, *38*, 100946. https://doi.org/10.1016/j.ecoser.2019.100946
17. Coutts, C., & Hahn, M. (2015). Green infrastructure, ecosystem services, and human health. *International Journal of Environmental Research and Public Health*, *12*(8), 9768–9798. https://doi.org/10.3390/ijerph120809768
18. DeFries, R. S., Foley, J. A., & Asner, G. P. (2004). Land-use choices: balancing human needs and ecosystem function. *Frontiers in Ecology and the Environment*, *2*(5), 249–257. https://doi.org/10.1890/1540-9295(2004)002

19. Denchak, M. (2022, July 25). *Green Infrastructure: How to manage water in a sustainable way*. NRDC. https://www.nrdc.org/stories/green-infrastructure-how-manage-water-sustainable-way

20. Derkzen, M. L., Van Teeffelen, A., & Verburg, P. H. (2015). Quantifying urban ecosystem services based on high-resolution data of urban green space: an assessment for Rotterdam, the Netherlands. *Journal of Applied Ecology*, *52*(4), 1020–1032. https://doi.org/10.1111/1365-2664.12469

21. Elliot, T., Goldstein, B., Gómez-Baggethun, E., Proença, V., & Rugani, B. (2022). Ecosystem service deficits of European cities. *Science of the Total Environment*, *837*. https://doi.org/10.1016/j.scitotenv.2022.155875

22. Elmqvist, T., Setälä, H., Handel, S., Van Der Ploeg, S., Aronson, J., Blignaut, J. N., Gómez-Baggethun, E., Nowak, D., Kronenberg, J., & De Groot, R. (2015). Benefits of restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability*, *14*, 101–108. https://doi.org/10.1016/j.cosust.2015.05.001

23. Gemeente Haarlem. (2024a). *Sociaal*. Haarlem in Cijfers. https://haarlem.incijfers.nl/mosaic/gebiedsanalyses/sociaal

24. Gemeente Haarlem. (2024b). *Wonen*. Haarlem in Cijfers. https://haarlem.incijfers.nl/mosaic/haarlem-in-cijfers---dashboard/buurten-en-wijken-4

25. Giorgi, F. (2024). Climate modeling of the Anthropocene. In *Quantitative Sustainability* (pp. 69–76). Springer, Cham. https://doi.org/10.1007/978-3-031-39311-2_5

26. Global Alliance for the Future of Food. (2023). *Food systems account for at least 15% of all fossil fuels*. https://story.futureoffood.org/power-shift/

27. Global Footprint Network. (2023). *Open data platform*. https://data.footprintnetwork.org/?_ga=2.5966131.122513205.1705339332-1198551586.1705339332#/

28. Gómez-Baggethun, E., Gren, Å., Barton, D. N., Langemeyer, J., McPhearson, T., O'Farrell, P. J., Andersson, E., Hamstead, Z. A., & Kremer, P. (2013). Urban Ecosystem Services. In *Springer eBooks* (pp. 175–251). https://doi.org/10.1007/978-94-007-7088-1_11

29. Haarlems Dagblad. (1957, March 27). Structuurplan-Schalkwijk voorziet in autonome stad met eigen karakter. *Krantenviewer Noord-Hollands Archief*. https://nha.courant.nu/issue/HD/1957-03-27/edition/null/page/3

30. Hernández-Blanco, M., Costanza, R., Chen, H., deGroot, D., Jarvis, D., Kubiszewski, I., Montoya-Zumaeta, J. G., Sangha, K. K., Stoeckl, N., Turner, K., & Van 't Hoff, V. (2022). Ecosystem health, ecosystem services, and the well-being of humans and the rest of nature. *Global Change Biology*, *28*(17), 5027–5040. https://doi.org/10.1111/gcb.16281

31. Iungman, T., Cirach, M., Marando, F., Barboza, E. P., Khomenko, S., Masselot, P., Quijal-Zamorano, M., Mueller, N., Gasparrini, A., Urquiza, J., Heris, M. P., Thondoo, M., & Nieuwenhuijsen, M. (2023). Cooling cities through urban green infrastructure: a health impact assessment of European cities. *The Lancet*, *401*(10376), 577–589. https://doi.org/10.1016/s0140-6736(22)02585-5

32. Jansson, A. (2013). Reaching for a sustainable, resilient urban future using the lens of ecosystem services. *Ecological Economics*, *86*, 285–291. https://doi.org/10.1016/j.ecolecon.2012.06.013

33. Kain, J., Larondelle, N., Haase, D., & Kaczorowska, A. (2016). Exploring local consequences of two land-use alternatives for the supply of urban ecosystem services in Stockholm year 2050. *Ecological Indicators*, *70*, 615–629. https://doi.org/10.1016/j.ecolind.2016.02.062

34. Meier, S. (2006). *Tussen leefstijl en wijkgedachte*. Stichting De Driehoek. https://www.stichtingdriehoek.nl/_downloads/meier.pdf

35. Millennium Ecosystem Assessment. (2003). Ecosystems and Human Well-being. In *Ecosystems and Human Well-being: A Framework for Assessment*. Island Press. https://www.millenniumassessment.org/documents/document.301.aspx.pdf

36. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties & Urhahn. (2024). Handreiking Woonwijken van de Toekomst. In Mooi Nederland. Geraadpleegd op 2 mei 2024, van https://www.mooinederland.nu/app/uploads/2024/05/Handreiking-Woonwijken-van-de-toekomst-vormgeven-aan-de-naoorlogse-wijk-in-transitie-30-04-2024-beeldscherm-lowres.pdf

37. Mirabella, N., & Allacker, K. (2018). The Assessment of Urban Environmental Impacts through the City Environmental Footprint: Methodological Framework and First Approach to the Built Environment. *Procedia CIRP*, *69*, 83–88. https://doi.org/10.1016/j.procir.2017.11.063

38. NASA. (2023, November). *Carbon dioxide*. Global Climate Change: Vital Signs of the Planet. https://climate.nasa.gov/vital-signs/carbon-dioxide/#:~:text=Since%20the%20onset%20of%20industrial,of%20its%20value%20in%201750.

39. Nikodinoska, N., Paletto, A., Pastorella, F., Granvik, M., & Franzese, P. P. (2018). Assessing, valuing and mapping ecosystem services at city level: The case of Uppsala (Sweden). *Ecological Modelling*, *368*, 411–424. https://doi.org/10.1016/j.ecolmodel.2017.10.013

40. Obbink, H. (2016, December 4). Naoorlogse woonwijken niet meer van deze tijd. *Trouw*. https://www.trouw.nl/nieuws/naoorlogse-woonwijken-niet-meer-van-deze-tijd~bfb94c99/

41. Payen, F. T., Evans, D., Falagán, N., Hardman, C. A., Kourmpetli, S., Liu, L., Marshall, R., Mead, B. R., & Davies, J. (2022). How much food can we grow in urban areas? Food production and Crop Yields of Urban Agriculture: A Meta-Analysis. *Earth's Future*, *10*(8). https://doi.org/10.1029/2022ef002748

42. Pedersen Zari, M. (2017b). Ecosystem services analysis: Incorporating an understanding of ecosystem services into built environment design and materials selection. In *Materials for a Healthy, Ecological and Sustainable Built Environment* (pp. 29–63). Woodhouse. https://doi.org/10.1016/b978-0-08-100707-5.00002-2

43. Pedersen Zari, M. (2017a). Utilizing relationships between ecosystem services, built environments, and building materials. In *Elsevier eBooks* (pp. 3–27). https://doi.org/10.1016/b978-0-08-100707-5.00001-0

44. Rijksoverheid. (2023). *Kaarten*. Atlas Leefomgeving. https://www.atlasleefomgeving.nl/kaarten

45. RIVM. (2022). *Gezondheid en leefstijl per buurt, wijk en gemeente*. Buurtatlas. https://buurtatlas.vzinfo.nl/#home

46. Roelofsen, H., Van Den Wittenboer, S., Dekker, J., Horst, M., Josemans, M., & Spek, T. (2024). Kennisagenda Groenblauwe Dooradering : Een onderzoeks- en actieprogramma ten behoeve van 10% GBDA in het landelijk gebied. https://doi.org/10.18174/653270

47. Russo, A., Escobedo, F. J., Cirella, G. T., & Zerbe, S. (2017). Edible green infrastructure: An approach and review of provisioning ecosystem services and disservices in urban environments. *Agriculture, Ecosystems & Environment*, *242*, 53–66. https://doi.org/10.1016/j.agee.2017.03.026

48. Russo, A., & Cirella, G. T. (2023). Urban Ecosystem Services: Advancements in urban green development. *Land*, *12*(3), 522. https://doi.org/10.3390/land12030522

49. Ryfield, F., Cabana, D., Brannigan, J., & Crowe, T. (2019). Conceptualizing 'sense of place' in cultural ecosystem services: A framework for interdisciplinary research. *Ecosystem Services*, *36*, 100907. https://doi.org/10.1016/j.ecoser.2019.100907

50. Schravesande, M., & Himmit, I. (2023, January 9). *Succesvol netwerken in naoorlogse wijken*. Gebiedsontwikkeling.nu. https://www.gebiedsontwikkeling.nu/artikelen/succesvol-netwerken-in-naoorlogse-wijken/

51. Sharifi, A., & Yamagata, Y. (2018). Resilience-Oriented urban planning. In *Resilience-Oriented Urban Planning* (Vol. 65, pp. 3–27). Springer. https://doi.org/10.1007/978-3-319-75798-8_1

52. Snep, R. P. H., & Clergeau, P. (2012). Biodiversity in Cities Biodiversity in Cities, Reconnecting Humans with Nature. In *Encyclopedia of Sustainability Science and Technology* (pp. 938–961). Springer. https://doi.org/10.1007/978-1-4419-0851-3_296

53. Synchroon. (2023). Natuurinclusief ontwikkelen. In *Kennisportaal Klimaatadaptatie*. Retrieved May 2, 2024, from https://klimaatadaptatienederland.nl/hulpmiddelen/overzicht/gids-natuurinclusief-ontwikkelen/

54. Tan, P. Y., Zhang, J., Masoudi, M., Alemu, J. B., Edwards, P. J., Grêt-Regamey, A., Richards, D. R., Saunders, J., Song, X. P., & Wong, L. W. (2020). A conceptual framework to untangle the concept of urban ecosystem services. *Landscape and Urban Planning*, *200*, 103837. https://doi.org/10.1016/j.landurbplan.2020.103837

55. TEEB. (2011). *TEEB Manual for Cities: Ecosystem Services in Urban management.*

56. https://teebweb.org/publications/other/teeb-cities/

57. Van den Berg, J., Oosterheerd, I., Van Der Made, H., & Riccetti, A. (2022). *BiodiverCITY - a matter of vital soil!: Creating, Implementing and Upscaling Biodiversity-based Measures in Public Space*. Nai010 Publishers.

58. Van Dam, J., & Van Den Oever, M. (2019). Catalogus biobased bouwmaterialen 2019: Het groene en circulaire bouwen. In *Wageningen University & Research*. Propress. https://doi.org/10.18174/461687

59. Vieira, J., Matos, P., Mexia, T., Silva, P., Lopes, N., Freitas, C., Correia, O., Santos-Reis, M., Branquinho, C., & Pinho, P. (2018). Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks. *Environmental Research*, *160*, 306–313. https://doi.org/10.1016/j.envres.2017.10.006

60. Voedingscentrum. (z.d.). *Schijf van Vijf-vak: groente en fruit*. https://www.voedingscentrum.nl/nl/gezond-eten-met-de-schijf-van-vijf/wat-staat-in-de-schijf-van-vijf-en-wat-niet/groente-en-fruit.aspx

61. World Health Organization. (2018, June 1). *Heat and health*. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

62. World Health Organization. (2019). *Air pollution*. https://www.who.int/health-topics/air-pollution#tab=tab_1

63. World Health Organization, Corvalán, C., Hales, S., & McMichael, A. J. (2005). *Ecosystems and human well-being: Health Synthesis*. World Health Organization. https://iris.who.int/handle/10665/43354

64. Yang, W., Dietz, T., Liu, W., Luo, J., & Liu, J. (2013). Going beyond the Millennium Ecosystem Assessment: an index system of human dependence on ecosystem services. *PLOS ONE*, *8*(5), e64581. https://doi.org/10.1371/journal.pone.0064581

# A. Appendix A – Categorization Urban Vegetation and water Types

Table 1. Categorization of urban vegetation and water types and examples (Payen et al., 2022)

| **Urban Ecosystem type** | **Examples** |
|---|---|
| Water body | Lake, river, canal, pond |
| Tree | Individual trees |
| Woodland | Urban forest |
| Tall bush | Woody plants (2-5 m) |
| Short shrub | Woody plants (< 2 m) |
| Low vegetation | Grasses, mosses and herbs |
| Garden | Domestic garden |
| Other | Green roof, green façade, allotment garden |

# B. APPENDIX B – URBAN ECOSYSTEM SERVICE INDICATORS AND SUPPLY VALUE PER URBAN VEGETATION TYPE

Table 2. Urban ecosystem service indicators and supply value per urban vegetation type [1] (Derkzen et al., 2015; Payen et al., 2022)

| **Urban ecosystem type** | **Provision of habitats [2] ($m^2$)** | **Air quality regulation/ air purification [3] ($g/m^2/year$)** | **Moderation of climate extremes (floods): runoff retention [4] ($L/m^2$)** | **Carbon sequestration [5] ($kg/m^2$)** | **Recreation [6] (Index value/$m^2$)** |
|---|---|---|---|---|---|
| Water body | | - | 10,00 | - | 2,20 |
| Tree | | 3,97 | 8,40 (per tree) | 10,64 | 2,15 |
| Woodland | | 2,69 | 8,70 | 15,62 | 2,90 |
| Tall bush | | 2,05 | 7,30 | 7,79 | 2,55 |
| Short shrub | | 2,05 | 7,30 | 5,61 | 2,55 |
| Low vegetation | | 0,90 | 8,00 | 0,17 | 2,55 |
| Garden | | 0,82 | 6,00 | 1,07 | - |
| Other | | 0,82 | 6,00 | 1,07 | 2,35 |

[1] Urban temperature regulation (cooling) is not included as the impact of urban green spaces is heavily dependent on the temperature as well as the season and time of day. However, as cooling is mainly caused by shading and evapotranspiration, trees, woodland and tall bushes contribute the most (Derkzen et al., 2015; Gómez-Baggethun et al., 2013).

[2] An indicator for the provision of habitats is the percentage of green and blue area (Charoenkit & Piyathamrongchai, 2019). However, then the supply rates for each urban vegetation type would all be at a 100 percent. So in this case the surface area of each urban vegetation type is indicated as possible habitat for species. The total surface area for each scenario can then be compared. Although this is not a complete representation of the actual provision of habitats, in this case it may give an indication of the general provision.

[3] Air purification from particle matter ($PM_{10}$); Although other pollutants exist in the air, $PM_{10}$ is the most damaging to human health. In addition, vegetation also absorbs more pollution as its concentration increases. As a result, the purification concentration of trees in the 50 meter zone of Professor Eijkmanlaan was doubled (Derkzen et al., 2015).

[4] Runoff retention happens through tree canopies intercepting rain, some of it evaporates directly from the foliage and some is absorbed and then re-emitted into the atmosphere via transpiration. Rainwater can also be absorbed into the permeable soil surface through direct infiltration (Pandey & Ghosh, 2023). These processes slow down the peak flow, reducing runoff and alleviating the pressure on the sewer system. The table shows the amount of rainwater intercepted or absorbed by vegetation (and soil) during a 10 mm rainfall, which is a light to medium rain in the Netherlands (Derkzen et al., 2015).

[5] In order to sequester carbon, biomass volume is crucial, as trees extract carbon dioxide from the atmosphere and capture it in their tissues (TEEB, 2011). Trees are therefore of great importance for CO2 storage (Derkzen et al., 2015).

[6] The recreation index value is based on people's preference for vegetation over water, level of naturalness and level of variation, according to literature (Derkzen et al., 2015).

## C. Appendix C – Urban space type and supply of food

Table 3. Urban space type and supply of vegetables (Payen et al., 2022)

| **Vegetable production on different urban spaces** | **Average vegetable yield (kg/m$^2$/cycle)**<br>Average cycle: 1 year |
|---|---|
| Ground | 7,9 |
| Rooftop | 2,86 |
| Indoor | 2,2 |
| Green space | 3,6 |

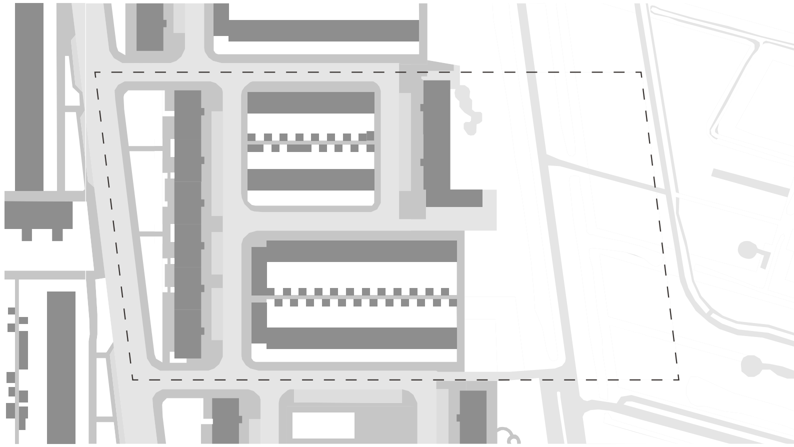
**Average cattail yield**: 1,2 kg/m$^2$/cycle

**Average cycle**: 0,5 year

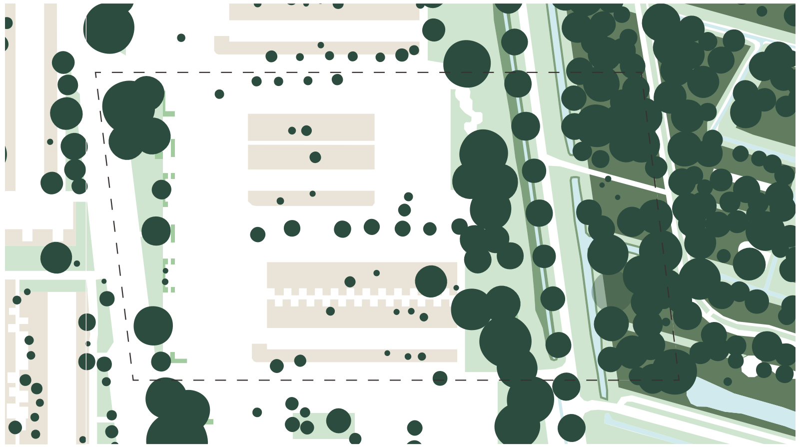
(Bestman et al., 2019)

## D. Appendix D – Plans stamp: Current situation and scenario 1 & 2

See next pages.



**Legend**
- - Border stamp/research area
- Buildings
- Pavement
- Parking spots
- Infrastructure

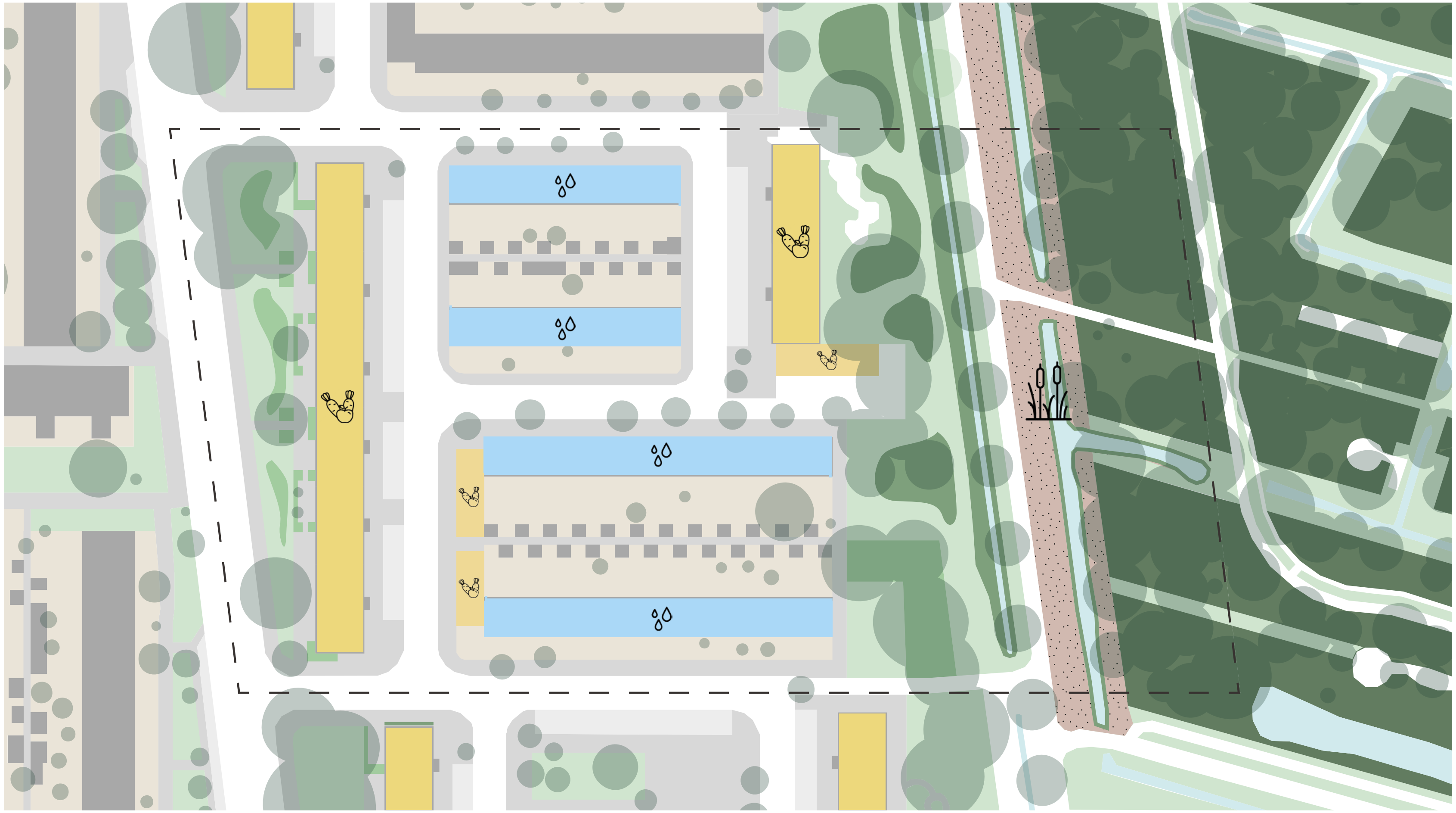


**Legend**
- - Border stamp/research area
- Water
- Garden
- Low vegetation: grasses
- Short shrub
- Tall bush
- Woodland
- Tree canopies

## CURRENT SITUATION

**Legend**
- - Border stamp/research area
- Buildings
- Pavement
- Parking spots
- Infrastructure
- Water
- Garden
- Low vegetation: grasses
- Short shrub
- Tall bush
- Woodland
- Tree canopies

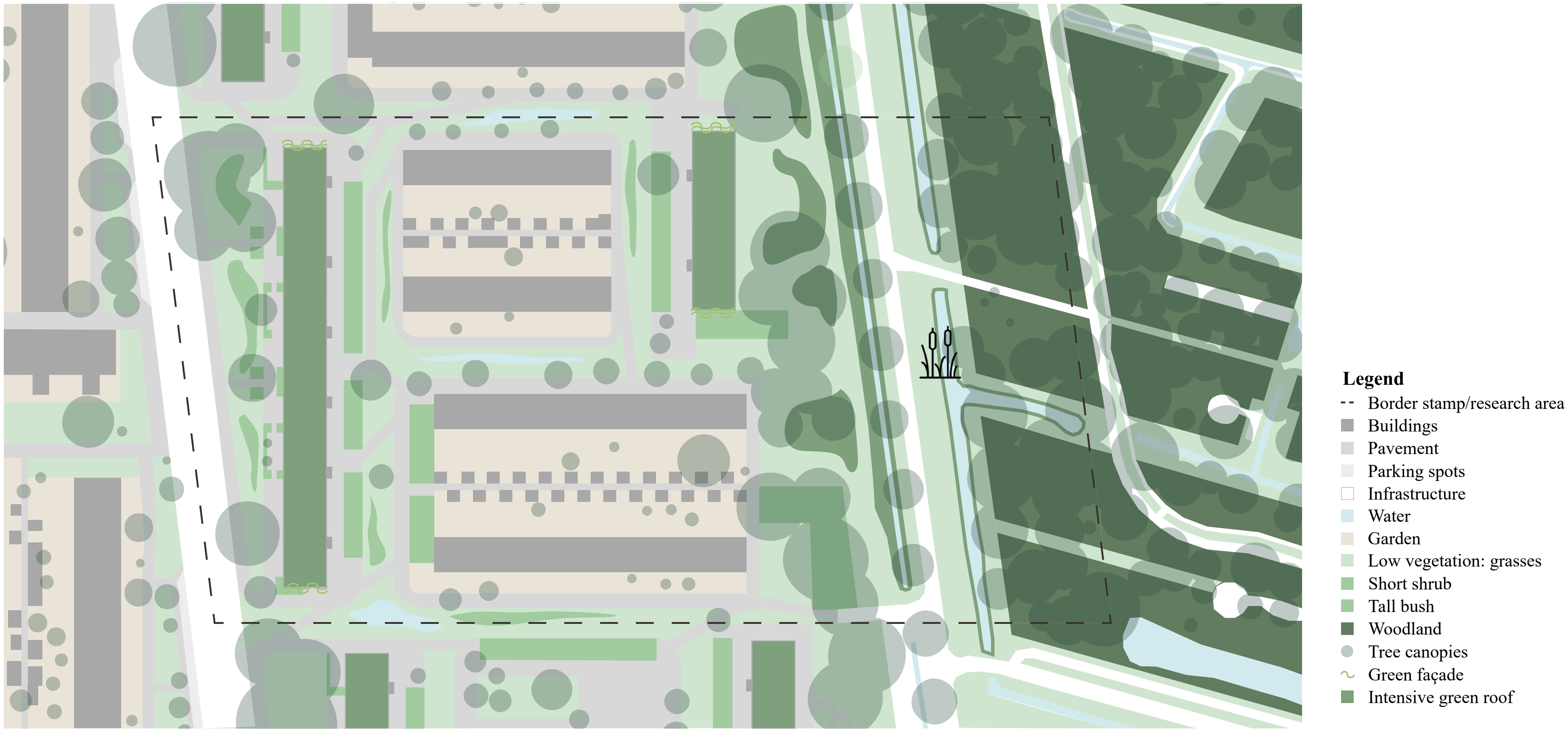
## SCENARIO 1



**Legend**

- - Border stamp/research area
- Buildings
- Pavement
- Parking spots
- Infrastructure
- Water
- Garden
- Low vegetation: grasses
- Short shrub
- Tall bush
- Woodland
- Tree canopies
- Edible green roof: vegetables
- Water collection
- Cattail

## SCENARIO 2


Legend
Border stamp/research area
Buildings
Pavement
Parking spots
Infrastructure
Water
Garden
Low vegetation: grasses
Short shrub
Tall bush
Woodland
Tree canopies
Green façade
Intensive green roof

# E. Appendix E – Current Urban ecosystem supply capacity on Boerhaavewijk stamp

Table 4. Current urban ecosystem supply capacity on Boerhaavewijk stamp

| **Urban ecosystem type** | **Area ($m^2$)** | **Provision of habitats ($m^2$)** | **Air quality regulation/ air purification ($g/m^2$/year)** | **Moderation of climate extremes (floods): runoff retention ($L/m^2$)** | **Carbon sequestration ($kg/m^2$)** | **Recreation (Index value/$m^2$)** |
|---|---|---|---|---|---|---|
| Water body | 500 | 500 | - | 5000 | - | 1100 |
| Tree | 5700 | 5700 | 26202 | 840 | 60648 | 12255 |
| Woodland | 2580 | 2580 | 6940 | 22446 | 40300 | 7482 |
| Tall bush | 715 | 715 | 1466 | 5220 | 5570 | 1823 |
| Short shrub | 500 | 500 | 1025 | 3650 | 2805 | 1275 |
| Low vegetation | 5005 | 5005 | 4505 | 40040 | 851 | 12763 |
| Garden | 3060 | 3060 | 2509 | 18360 | 3274 | - |
| Other | - | - | - | - | - | - |
| Total | | 18060 | 42647 | 95556 | 113448 | 36698 |

# F. APPENDIX F – SCENARIO 1: URBAN ECOSYSTEM SUPPLY CAPACITY ON BOERHAAVEWIJK STAMP

Table 5. Scenario 1: urban ecosystem supply capacity on Boerhaavewijk stamp

| **Urban ecosystem type** | **Area ($m^2$)** | **Provision of habitats ($m^2$)** | **Air quality regulation/ air purification ($g/m^2/year$)** | **Moderation of climate extremes (floods): runoff retention ($L/m^2$)** | **Carbon sequestration ($kg/m^2$)** | **Recreation (Index value/$m^2$)** |
|---|---|---|---|---|---|---|
| Water body | 500 | 500 | - | 5000 | - | 1100 |
| Tree | 5700 | 5700 | 26202 | 840 | 60648 | 12255 |
| Woodland | 2580 | 2580 | 6940 | 22446 | 40300 | 7482 |
| Tall bush | 1900 | 1900 | 3895 | 13870 | 14801 | 4845 |
| Short shrub | 940 | 940 | 1927 | 6862 | 5273 | 2397 |
| Low vegetation | 4565 | 4565 | 4109 | 36520 | 776 | 11641 |
| Garden | 3060 | 3060 | 2509 | 18360 | 3274 | - |
| Other | 1880 | 1880 | 1542 | 11280 | 2012 | 4418 |
| Total | | 21125 | 47124 | 115178 | 127084 | 44138 |

Table 6. Scenario 1: Supply of provisioning services on Boerhaavewijk stamp

| **Provisioning service** | **Area ($m^2$)** | **Supply (per year)** |
|---|---|---|
| Raw material: Cattail | 1300 | 3120 kg |
| Food supply: vegetable | 1880 | 5380 kg [1] |
| Household water | 2000 (surface of roofs) [2] | 1750000 L [3] |

[1] According to the Dutch nutrition center, adults need approximately 250 grams of vegetables per day (Voedingscentrum, z.d.). Meaning design scenario 1 could in theory provide vegetables for approximately 60 people each year.

[2] Area is equal to the total roof surface of the row houses.

[3] Based on an average rainfall in the Netherlands of 875 mm/year (CLO, 2023). The water supply could be reused in the houses, for example for flushing the toilet. On average a person uses 30,2 liters of water per day to flush the toilet (Bakker et al., 2022). If all of the rainwater can be temporarily stored and reused, the rainwater would provide for the annual toilet flushing needs of approximately 160 people.

# G. APPENDIX G – SCENARIO 2: URBAN ECOSYSTEM SUPPLY CAPACITY ON BOERHAAVEWIJK STAMP

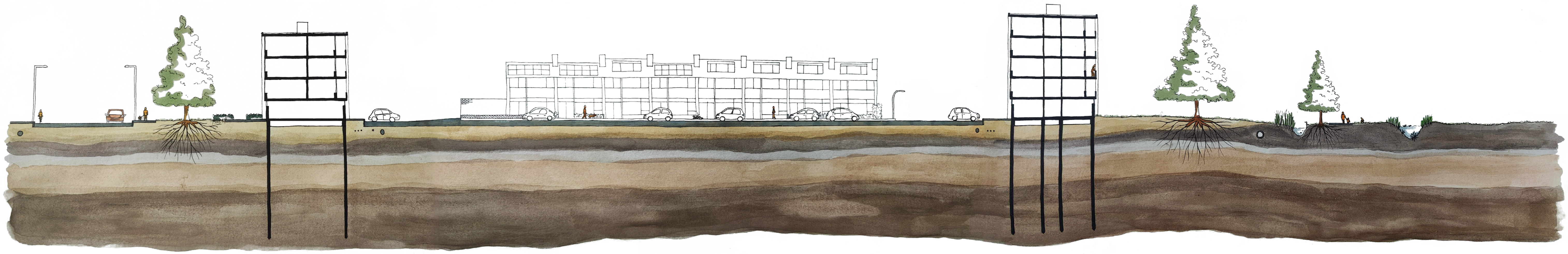
Table 7. Scenario 2: urban ecosystem supply capacity on Boerhaavewijk stamp

| **Urban ecosystem type** | **Area ($m^2$)** | **Provision of habitats ($m^2$)** | **Air quality regulation/ air purification ($g/m^2/year$)** | **Moderation of climate extremes (floods): runoff retention ($L/m^2$)** | **Carbon sequestratio n ($kg/m^2$)** | **Recreation (Index value/$m^2$)** |
|---|---|---|---|---|---|---|
| Water body | 660 | 660 | - | 6600 | - | 1452 |
| Tree | 6000 | 6000 | 27393 | 924 | 63840 | 12900 |
| Woodland | 2580 | 2580 | 6940 | 22446 | 40300 | 7482 |
| Tall bush | 1900 | 1900 | 3895 | 13870 | 14801 | 4845 |
| Short shrub | 1550 | 1550 | 3178 | 11315 | 8696 | 3953 |
| Low vegetation | 5625 | 5625 | 5063 | 45000 | 956 | 14344 |
| Garden | 3060 | 3060 | 2509 | 18360 | 3274 | - |
| Other | 1535 | 1535 | 1259 | 9210 | 1642 | 3607 |
| Total | | 22910 | 50237 | 127725 | 133509 | 48583 |

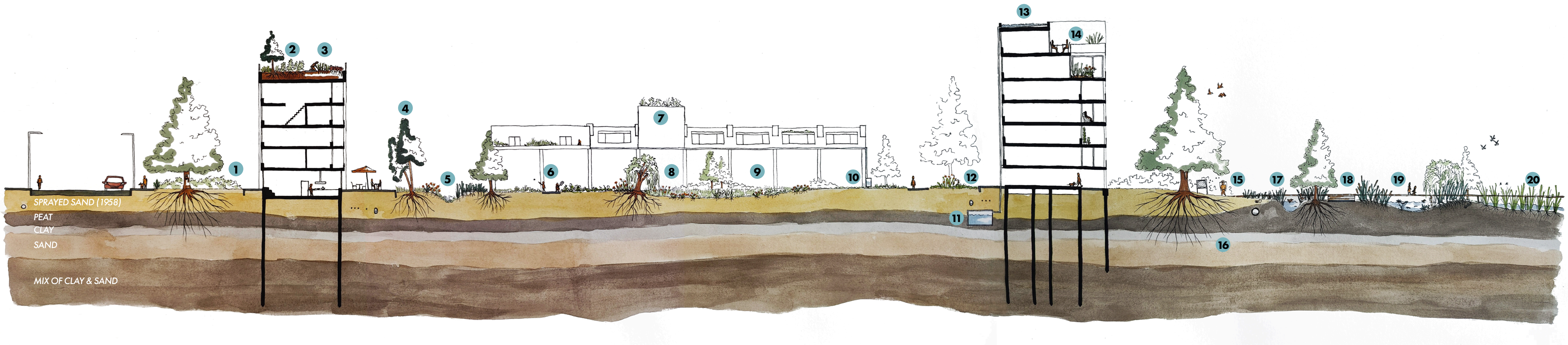
# H. APPENDIX H – SECTION OF BOERHAAVEWIJK CURRENTLY & AFTER IMPLEMENTATION OF ECOSYSTEM SERVICES

See next page.

# CURRENT SITUATION



# SITUATION AFTER IMPLEMENTATION OF ECOSYSTEM SERVICES




1. Extension of urban green infrastructure near roads
2. Rooftop garden
3. Edible green roof
4. Tree canopy
5. Swale
6. Walkways through urban park
7. Adding greenery to building stock
8. Extension of urban green infrastructure
9. Constructed wetland
10. Water storage
11. Rainwater use system
12. Replacement of paved areas by vegetation
13. Water roof
14. Vegetated outdoor private space
15. Accomodation and nesting facilities for animals
16. Root system
17. Elevation of water table
18. Diversity of micro climates
19. Heightened pathway through peat meadow landscape
20. Production of raw materials