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Hub4Circularity

A First of a kind Hub for circularity demonstrator for Attica and peripheral regions

Grant Agreement No 101178059

D7.5 A blueprint for use of NBS for rainwater/stormwater harvesting in urban and peri-urban areas

Work Package: 07 Water Symbiotic Flows

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Publishable summary

Within the framework of the THESEUS project, this deliverable presents the design approach, implementation strategy, and evaluation of Nature-Based Solutions (NBS) for water recovery and reuse in urban environments, focusing on the Attica region and, specifically, the pilot application at KAPAPS Urban Park in the Municipality of Athens.

The report is compiled in response to the increasing challenges affecting urban water systems in Mediterranean cities due to climate change, rapid urbanisation, and growing pressures on water resources. In Attica, rising temperatures, prolonged drought periods and water scarcity, as well as more frequent extreme rainfall events that increase flood risks, result in an unsustainable and less resilient region. As a result of these challenges, and due to the extensive amount of impermeable surfaces of the Athens metropolitan area, substantial volumes of stormwater flow across the urban areas (e.g. streets, pavements, green spaces). Despite its potential value, this resource remains practically untapped, while potable water continues to be used for the irrigation of urban parks. To address these challenges, circular and distributed water management solutions should be implemented initially at a local scale and then further expanded through a strategic approach at a larger city scale so as to have an actual impact on the urban environment.

The deliverable first outlines the conceptual framework of urban Nature-Based Solutions (NBS), and examines their technical aspects as well as their social and environmental benefits. It then presents a literature review of existing urban water NBS systems, including representative examples, to establish the technical background and research conducted for the purposes of this study.

The study focuses in the KAPAPS Park, an urban green space at the heart of Athens that faces both water scarcity and flooding issues. The report presents the site's key characteristics, including its spatial configuration, environmental and climatic conditions, as well as the specific constraints and opportunities associated with a densely built environment. Furthermore, the study evaluates the irrigation needs of the existing green spaces, explores the integration of additional drought-resilient plants, and develops a detailed water balance analysis in order to quantify the potential for rainwater harvesting, storage, and reuse with the parallel reduction of dependence on potable water resources.

Based on this assessment, a replicable and extendable NBS concept design is proposed that combines nature based elements such as a rain garden, a bioswale, permeable surfaces, infiltration areas, and a subsurface storage and recovery system. The proposed interventions are designed as a basis that can be expanded either to the particular park to or to other parks with similar challenges with the main concept to capture, treat, store and reuse rainwater for non-potable uses, as well as to retain and delay the flow of water and prevent flood events.

The report further presents the technical design of all the interventions as well as the configuration of the entire system, including the spatial integration of the NBS components into the existing morphology and landscape of the park. Special attention is given to the integration of the proposed interventions within the surrounding urban environment, to the enhancement of existing vegetation with new to the increase of

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biodiversity through the selection of a variety of climate resilient plants, and the improvement of the overall microclimate and environmental conditions of the site.

The performance assessment shows that NBS can help reduce flooding, decrease runoff, and improve the city's capacity to retain and infiltrate surface water into the subsurface for storage, reuse and aquifer recharge. In addition, these systems provide a set of benefits that include urban cooling by lower local temperatures, enhanced aesthetic and increased social value through greater community engagement. The integration of NBS into the urban space supports both the sustainability of the interventions and their acceptance by the end users.

In addition, the deliverable highlights some challenges of the operation phase after implementation that includes the installation and maintenance of monitoring and control systems, the compliance with the legal and regulatory framework, and the continuation of stakeholder engagement. It should be noted it is crucial to ensure early involvement of the local authority and its competent departments, the local communities and potential associations, as well as the regular end users of the site in order to ensure that all parameter and constraints are taken into account, any relevant proposals are integrated, and the interventions remain sustainable in the long term.

The report also examines the replicability and upscaling potential of the proposed interventions. Due to their flexible and expandable design, these solutions can be further implemented either to other areas of the particular park or be transferred to a wide range of urban Mediterranean parks facing water scarcity and flood risks. Implementing such solutions in the KAPAPS Park therefore goes beyond local intervention and serves as a demonstration project for designing, implementing and optimiseing circular urban water management systems.

Overall, the findings of this deliverable confirm that Nature-Based Solutions constitute a viable and effective strategy to address interconnected urban challenges related to water management, climate adaptation, and environmental sustainability. By combining state-of-the-art technologies with environmental benefits and social acceptance, the proposed interventions can be a blueprint that supports the transition towards more resilient and adaptive cities.

In conclusion, this deliverable provides a roadmap through which the technical design for implementing NBS solutions, along with the social engagement and the procedural aspects of the interventions, can form a strategic basis for the wider integration of such approaches in cities like Athens. This supports the transition from conventional linear systems, such as rainwater drainage systems, towards more circular and sustainable urban water models based on rainwater harvesting, storage, recovery and reuse in Attica and beyond.

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Abbreviations

Abbreviations	Full name
EEMK	Small-Scale Construction Permits
EYDAP	Athens Water Supply and Sewerage Company
HDPE	High-Density Polyethylene
HRT	Hydraulic Retention Time
IDF	Intensity–duration–frequency
IoT	Internet of Things
IWS	Internal Water Storage
KAPAPS	Park for Children and Culture
LID	Low-impact development
LLDPE	Linear Low-Density Polyethylene
NBS	Nature-Based Solutions
NOA	National Observatory of Athens
NS	Nominal Size
PP blocks	Polypropylene blocks
PV panels	Photovoltaic panels
UHI	Urban Heat Island

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1. Introduction and objectives

Water management in urban environments is one of the most significant and complex challenges of sustainable development of the cities, particularly under the current conditions of climate change. Rising temperatures, changes in hydrological cycles, the increasing frequency of extreme weather events, and prolonged drought periods directly affect both the availability and quality of water resources, posing significant pressures and challenges for cities.

These challenges cannot be effectively addressed through short-term or ad hoc measures. By the time water-related problems become fully visible in public discourse—whether in the form of water scarcity, heat stress or flooding events—it is often already too late for timely and efficient interventions. Urban water management therefore requires long-term planning, integrated strategies, consistency, and combination of multiple policies, technologies and governance approaches.

In general terms, integrated water resource management is structured around three key pillars: increasing water availability, retaining and reducing water consumption, and improving infrastructure. Circular economy solutions play a crucial role in this effort, especially through water reuse, and the local utilisation of water resources at different scales—from centralised systems to small-scale, distributed applications—which can significantly enhance the resilience of cities in the face of climate change challenges.

1.1 Setting the scene: water circularity and climate resilience in Athens

The Attica region, in which the City of Athens is located, hosts nearly 40% of Greece's population, and faces significant pressures on its water resources. Decades of rapid urbanisation, coupled with extensive surface sealing and limited green spaces, have reduced the natural capacity for water infiltration and groundwater recharge, while increasing urban flooding. Climate change is further intensifying these challenges, through hotter and drier summers, more frequent drought periods, and increasingly intense rainfall events.

Climate change is not only raising temperatures in Athens but also changing precipitation patterns. Rainfall events are becoming less frequent but more intense, which increases the risk of urban flooding, while seasonal water scarcity is becoming more common and more severe. Together, these pressures place additional stress on water resources that are needed to maintain public green spaces and help reduce the impacts of climate change.

In addition to this irregularity in precipitation patterns, a large share of rainfall is lost as surface runoff, rapidly flowing along the streets into drainage network systems instead of being retained, infiltrated into the soil, or even locally reused. This represents a significant missed opportunity to increase water availability for greening cities, while also mitigating floods risk and urban overheating.

The highly urbanised fabric of Athens along with the extensive coverage by impermeable surfaces such as concrete and asphalt, and the lack of sufficient green spaces, contribute to the urban heat island effect. As a result, temperatures in central areas of the city can be up to 10°C higher than in surrounding areas,

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especially during the summer period. Additional heat generated by vehicles, buildings, and air conditioning systems further increases thermal stress and energy demand for the residents making the need of healthy green areas more necessary than ever.

As climate change leads to more prolonged dry periods water availability becomes a key element for maintaining and enhancing urban green spaces. In Athens, where green areas are relatively limited, parks and other green spaces serve as essential cooling zones that help mitigating heat stress and improve the environmental quality.

To enhance the resilience of the city of Athens a more integrated and circular approach to urban water management and public space design is required, with particular emphasis on Nature-Based Solutions (NBS). Such approaches aim to improve local water availability and promote efficient use of water, while also introduce flood mitigation practices in the urban environment. Through the use of permeable surfaces, infiltration zones, and subsurface water recovery and reuse systems, NBS can contribute to irrigation with non-potable water, flood mitigation, groundwater recharge, biodiversity enhancement, and the overall sustainability of the urban space.

1.2 Role of Nature-Based Solutions within the THESEUS project

Nature-Based Solutions (NBS) offer ways to address the urban challenges, particularly those related to water management and climate adaptation. By supporting and restoring natural hydrological cycles within the cities, NBS contribute significantly to improved water availability and sustainability of urban spaces with a wide range of environmental, social and economic benefits.

Water-related NBS interventions, that include the development of rain gardens, bioswales, permeable pavements, green corridors, and constructed wetlands, collect, treat, and retain stormwater for reuse and infiltration in the aquifer. These systems reduce reliance on potable water for irrigation that is brought to Athens from 300 Km away and contribute to improved health of the parks and thus the urban environments in general.

NBS also provide a wide set of benefits that support the expansion and sustainability of green in cities such as Athens. They regulate microclimate, provide shading and cooling at a local level, support biodiversity, improve environmental quality, and create a more attractive urban landscape. In addition, in densely built environments, NBS contribute to a more diverse and appealing public space increasing the overall resilience and posing an example of future resilient and sustainable cities.

Implementing NBS in Athens is not purely a technical objective but an environmental and engaging activity, as the common practice is to have a more linear strategy with regard to the management of resources. The main innovation is the rethinking of water management across the city, from schools, building yards and small plazas to larger parks and public areas. The challenge is to extend beyond the deployment of individual NBS interventions, and pilot several initiatives that can be a paradigm for further scaling-up forming part of a more strategic plan of NBS interventions to address the city challenges at a larger scale.

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Within this context, the THESEUS project intents to demonstrate a particular pilot at a local scale that can be an innovative example to mimic, expand and upscale. Through this process, the competent authorities and the end users also mature and are ready for a greater change in the way they perceive circularity in the urban environment. Also, the younger generations that visit the park can experience a real world implemented solution that can be further applied to other cases and areas.

By identifying, evaluating, and demonstrating Nature-Based Solutions at the particular pilot site, a broader strategic master plan for such interventions can be started to be formulated. The project seeks to demonstrate how the city can be reconnected with its natural water cycles and promote the local retention, treatment, and reuse of water resources.

The pilot application at KAPAPS Park aspired to be a reference point of this broader strategic approach, demonstrating how NBS systems can contribute to urban resilience, environmental sustainability, and improved public space quality within dense Mediterranean urban environments.

1.3 Purpose of the deliverable

This deliverable, within the scope of THESEUS project, provides a comprehensive framework for the selection of a site, the design, and insight for the implementation of a pilot NBS system in an urban area of the city of Athens, at KAPAPS Urban Park for Children and Culture.

The report presents the existing site conditions, identifies key environmental and urban challenges, and describes the conceptual and technical design of the proposed interlinked interventions. The proposed systems aim to support rainwater harvesting, flood mitigation, and local water reuse for irrigation of urban green spaces. Particular emphasis is also given to water treatment and the quality parameters to be satisfied for the efficient and safe irrigation of the park. Finally, the aspect of engagement of the local communities from the design phase, along with the matters of demonstration and education of the visitors are well explored and integrated in the particular pilot.

In addition, the deliverable addresses the integration of the proposed interventions within the landscape of the park. A water balance and demand analysis is also carried out to assess actual water needs and to support the design of the systems accordingly. Furthermore, the deliverable examines the system performance along with monitoring and operational aspects. Finally, it evaluates the replicability and upscaling potential of the proposed interventions, providing guidance for the wider implementation of similar solutions across other urban areas.

Through this process of developing an NBS system in a public space that is widely used by both local residents and visitors from other areas, the site can serve as demonstrator and a living laboratory, in which environmental education and awareness-raising activities can be organised by the Municipality and other involved actors. By demonstrating how urban parks can capture, retain, and reuse local water resources through integrated nature based systems, the concepts of circular water management and climate adaptation become visible and more easily understood by the public. Furthermore, showcasing approaches

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that reduce freshwater consumption and utilise stormwater runoff, can provide inspiration and generate significant social value for the urban communities.

Ultimately, the deliverable, through an actual real world application, supports the transition from conventional linear water management practices towards more circular and resilient urban systems. Through the implementation of flexible and replicable NBS, this initiative lays the groundwork for a more sustainable and climate-resilient approach to urban water management in Athens and the wider Attica region.

2. Conceptual framework of urban Nature-Based Solutions

Nature-Based Solutions (NBS) have emerged as a key set of solutions to address challenges such as water availability and flood risk in the urban environment, especially due to climate change impacts on water sufficiency in cities. According to the United Nations, NBS are actions that “protect, conserve, restore, and sustainably manage ecosystems”, while delivering environmental, social, and economic benefits.

NBS are recognised as an effective alternative or even a complementary element to conventional linear infrastructure. Unlike the traditional engineered systems that often lead rainwater to the drainage systems, these solutions focus on more circular and efficient approaches on water resources management.

2.1 Common water-based urban Nature-Based Solutions

Water-based Nature-Based Solutions are designed to mimic natural hydrological cycles within an urban area, and support stormwater management and flood mitigation, as well as water reuse and aquifer recharge. In contrast to the conventional drainage systems, which are designed to collect and discharge stormwater away from urban areas, NBS aim to retain, infiltrate, treat, store, and reuse water locally.

A wide range of water-based NBS systems can be implemented in urban areas, depending on water needs, local spatial development and characteristics of the area as well as environmental conditions. The main solutions include rain gardens, bioswales, Sustainable Urban Drainage Systems (SUDS), permeable surfaces, infiltration systems, green corridors, detention and retention areas, and constructed wetlands.

These systems are generally designed as vegetated areas in the surface that due to high infiltration capacity, urban runoff can be captured, infiltrated, and treated. Their main design characteristics include soil layers with high infiltration capacity, linear channels and dikes that allow water to flow in a controlled manner, and carefully selected vegetation, typically resilient species tolerant to both wet and dry conditions. Also there are permeable pavements that can convey rainwater from adjacent impermeable areas (streets, sidewalks) to the infiltration area. Additional components may include gravel layers, geomembrane and geotextile configurations that prevent or allow or water to pass through, depending on the system requirements. Overflow structures allow water to exit a rain garden, when its ponding area is full; leading it either to the existing drainage system or to an artificial recharge area so that soil moisture of the park is enhanced. This structure is necessary in order to prevent flooding of the area as well as to decrease the erosion risk.

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From a functional perspective, water-based NBS aim to reduce runoff volumes and peak flows, improve stormwater quality through natural filtration and treatment processes, promote infiltration and groundwater recharge, enhance local water availability, and support the reuse of harvested rainwater for irrigation purposes.

These systems apart from the technical functions, they provide other environmental and social benefits, such as urban cooling, biodiversity enhancement, and improved aesthetic value of public spaces. However, their performance can be constrained by the need of regular monitoring and maintenance, including sediment removal and vegetation preservation. In addition, in dense urban environments, space limitations and competing uses of the public areas may restrict their wide application and reduce their optimal technical efficiency.

2.2 Examples of water urban NBS

Nature-based solutions (NBS) have become in many cities a rather important approach for addressing urban stormwater management and water reuse. A literature review of 176 studies published between 2016 and 2022 showed a significant interest in implementing NBS systems in the United States, China, and several European countries. The majority of these studies focused on the environmental performance of the NBS systems, while the social acceptance, the maturity of competent authorities as well as economic feasibility received less attention. The review also highlighted the need for more interdisciplinary and collaborative approaches to support the wider use and integration of NBS in urban planning and stormwater management (Su et. al., 2023). Below are key examples from European cities that have implemented water NBS such as rain gardens, bioswales, SUDS, green corridors, etc.

Copenhagen – Cloudburst Management Plan (Sponge City Approach)

Copenhagen is considered a prominent example of large-scale implementation of Sustainable Urban Drainage Systems (SUDS). Following severe flooding events caused by intense rainfall, the city developed the *Cloudburst Management Plan*, based on the "Sponge City" approach, integrating rain gardens, bioswales, sunken parks, multifunctional retention spaces, and blue-green corridors for controlled stormwater conveyance. Streets and public spaces were redesigned to temporarily store and manage excess runoff, reducing pressure on sewer network and mitigating flood risks. The approach combined water management with urban design and public space enhancement, achieving runoff reductions of up to approximately 40% in some districts while improving urban resilience and environmental quality (C40 Cities, 2016; Liu & Jensen, 2017).

Gdańsk, Poland (Rain Gardens as a Nature-Based Urban Drainage Strategy)

Gdańsk is among the first cities in Poland to implement a series of rain gardens on a broad scale across various urban settings, including parks, the city centre, major intersections, and parking areas. These installations incorporate a range of technical adaptations designed to fit the surrounding urban context, including historic architecture and public spaces. At present, the city has around a dozen rain gardens, and

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its policy requires new residential developments to include nature-based solutions without relying on conventional stormwater drainage systems (Kasprzyk et. al., 2022).

Alicante, Spain – La Marjal Floodable Park (Hybrid Corridor Logic)

The La Marjal Floodable Park in Alicante, Spain, is an exemplary nature-based solution that integrates flood control, stormwater management, and water reuse in a Mediterranean urban environment. Created to address water scarcity and frequent flash floods in southeastern Spain, the project incorporates distributed drainage features such as vegetated retention basins, infiltration zones, stormwater storage systems, and the controlled reuse of collected water for irrigation and urban services. Built with a capacity of 45,000 m^3 and an investment of €3.3 million, the park has effectively reduced flood risks in the San Juan district while promoting sustainable water management. As the first floodable park in Spain and the second in Europe, La Marjal illustrates how water-oriented nature-based solutions can combine ecological design with urban resilience, helping cities adapt to both flood and drought conditions (Jódar-Abellán et al., 2018).

Rotterdam Urban Waterbuffer – An NBS for climate-adaptive urban water management

In Rotterdam, the rapid urban development and changes in the demand of land-use have led to an increasing extent of impermeable surfaces, placing increasing pressure on the existing drainage system of the city. In addition, more frequent intense rainfall events and prolonged drought periods have further posed a challenge in the capacity of the existing urban water system. To address insufficient water retention in the Spangen neighbourhood, the city implemented a hybrid nature-based solution known as the Urban Waterbuffer. The project explored the opportunities and constrains that are associated with implementing this system, with regard to its costs, benefits, and overall performance compared with conventional grey infrastructure. The study identified several insights regarding the effectiveness and feasibility of nature-based solutions for urban water management in the particular case. It also showed how small-scale interventions can support climate adaptation strategies and help guide a more resilient urban planning across the cities of Europe (Dartée, 2023).

Berlin, Germany – Becoming a sponge city

Based on this research, Berlin aimed to become a sponge City following two main approaches: first the planned scaling, where pilot projects are developed, tested, optimised and then implemented across the city, and second the permanent experimentation, where interventions are implemented at a local level. Using Berlin's transition toward a "sponge city" as a case, it finds that institutional and structural constraints make large-scale standardisation difficult, suggesting that urban adaptation is more likely to progress through continuous, site-based experimentation rather than city-wide scaling, with important implications for planning and policy (Roggero, M., 2025).

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3. Study area description and selection criteria

3.1 Site overview

The Park for Children and Culture (KAPAPS) is located in the Ano Ampelokipi district, within the administrative boundaries of the City of Athens, in close proximity to the Panormou Metro station. The park occupies an entire urban block surrounded by Lampsa, Trifillias, Mpellou, Lakonos, and Chatzikonstanti streets.

Covering an area of approximately 6,000 m², it constitutes an important public green space within a densely built urban environment. The site is characterized by medium-density vegetation, including a mix of trees, shrubs, and grassed areas, contributing to both its ecological value and its role as a neighborhood recreational space.

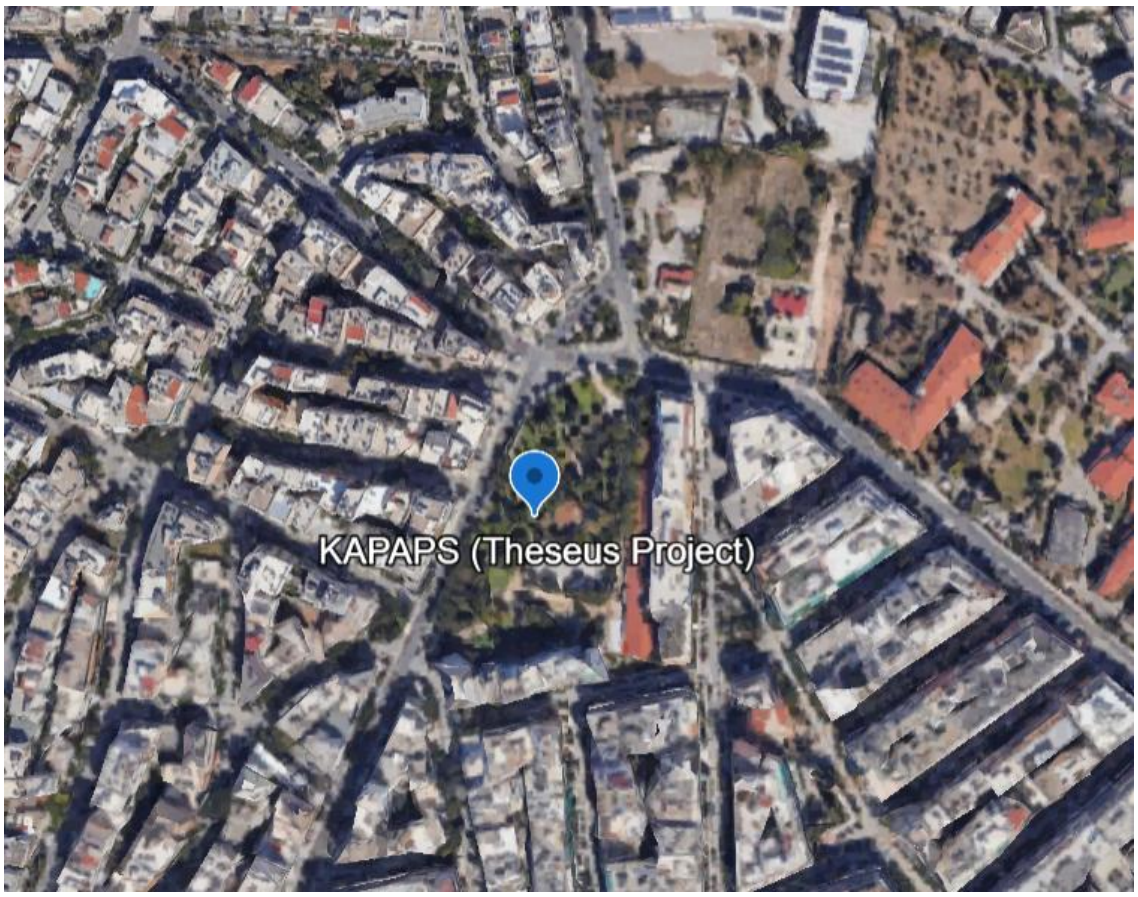


Figure 1. Map of the KAPAPS Park

Source: Screenshot from Google Earth

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3.2 Functional organisation of KAPAPS

KAPAPS Park operates as a multifunctional public space that supports recreation, social interaction, and community engagement for both residents and visitors. Its role extends beyond that of a typical urban green area, serving as a local cultural landmark where a wide range of cultural, social, and environmental activities are regularly hosted. These activities encourage the active use of public space and reinforce the park's dual identity as both an ecological asset and a community hub (Figure 1).



Figure 2. Exemplary pictures of KAPAPS Park

Source: Cultural Association of Ano Ampelokipi, https://anoampelokipi.gr

The park's spatial organisation reflects a strong emphasis on inclusivity and accessibility, particularly for children, families, and individuals with mobility impairments. Key functional components include renovated historic buildings that host cultural and educational uses—such as the children's and infants library, event spaces, and a café—alongside green areas, pedestrian pathways, a modern playground, and open spaces designed for informal play and outdoor activities. Together, these elements support a balanced mix of passive and active uses, enhancing the overall functionality, usability and attractiveness of the park.

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Figure 3. Picture of KAPAPS Park from the team's site visits

The park was originally developed in the early 2000s on the site of a former military facility with buildings that hosted the Rehabilitation Center for Civil War Disabled. The park forms part of a broader municipal strategy aimed at regenerating underutilized urban land into accessible public open spaces. Today, it accommodates a range of community-oriented amenities, including the KAPAPS Municipal Library and the Myrtillo Café, a notable social enterprise that promotes the inclusion and empowerment of people with disabilities. Over time, the park has evolved into a focal point for social cohesion, supporting community initiatives and fostering cultural exchange, as well as shared experiences within the public realm.

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Figure 4. View of the Myrtillo Café Social Cooperative Enterprise
Source: POPAGANDA cultural online magazine, https://popaganda.gr/



Figure 5. Children and Toddler Municipal Library located inside the KAPAPS Park
Source: City of Athens, https://cultureisathens.gr/venue/vrefiki-vivliothiki

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3.3 Environmental and climate conditions

From an environmental perspective, KAPAPS Park plays a critical role within one of the most densely built areas of Athens, functioning as a key green infrastructure node that contributes to microclimate regulation, urban cooling, and biodiversity enhancement. The surrounding urban fabric is characterized by a high proportion of impervious surfaces, which significantly limits natural infiltration and increases surface runoff. In addition, upstream areas—particularly towards the Tourkovounia hills—exhibit relatively steep slopes that enhance runoff production and accelerate its conveyance during rainfall events toward lower elevations, leading to the accumulation of water within and around the park, as well as along adjacent streets, where localised flooding has been reported.

From a hydrological perspective, the park is influenced by an upstream catchment of approximately 1.5 hectares (Figure 6), which is predominantly composed of impermeable surfaces and lacks adequate stormwater drainage infrastructure. Runoff generated in the upstream catchment is rapidly transported downstream through the street corridors toward the area of KAPAPS Park. The existing limited and fragmented drainage network can cover only part of the capacity, leaving significant areas of the catchment insufficiently served. As a result, surface flows are frequently conveyed through streets and open surfaces, with water accumulating at the upper boundary of the park and partially entering its boundaries during rainfall events.



Figure 6. Upstream catchment area of KAPAPS Park (in purple) and rainwater drainage system (in blue)

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The climate of Attica is classified as Mediterranean according to the Köppen system (Peel et. al., 2007) characterised by hot, dry summers and mild, wet winters. The Ampelokipi district, where KAPAPS Park is located, reflects these conditions, further intensified by dense urbanisation and extensive existence of impermeable surfaces.

During the summer period (June-August), air temperatures frequently exceed 32°C and can occasionally surpass 36°C, especially in July and August. Winter months (December - February) are relatively mild, with temperatures typically ranging between 4°C and 12°C and only rare occurrences of frost. The urban heat island effect is quite evident in the area due to the high level of urbanisation and surface sealing, which intensifies thermal discomfort during the summer months.

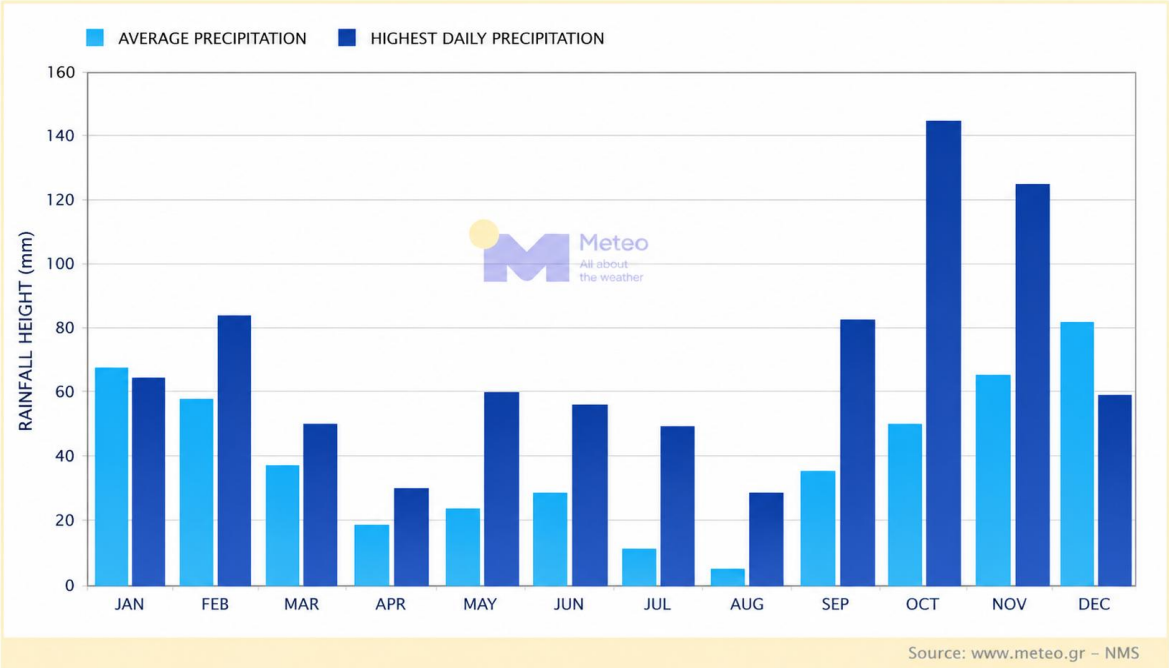
Depending on the year, precipitation can be generally low and unevenly distributed. Extended dry periods are common, with more than 18 dry days per month on average. Rainfall events are infrequent, particularly during summer (approximately 3 rainy days per month), while winter months may experience up to 10–11 rainy days. Monthly precipitation typically remains below 10 mm during summer and increases to approximately 50–70 mm in winter. Importantly, rainfall events occur mainly in autumn and early winter, often in the form of short-duration, high-intensity storms that generate significant surface runoff in urban areas.

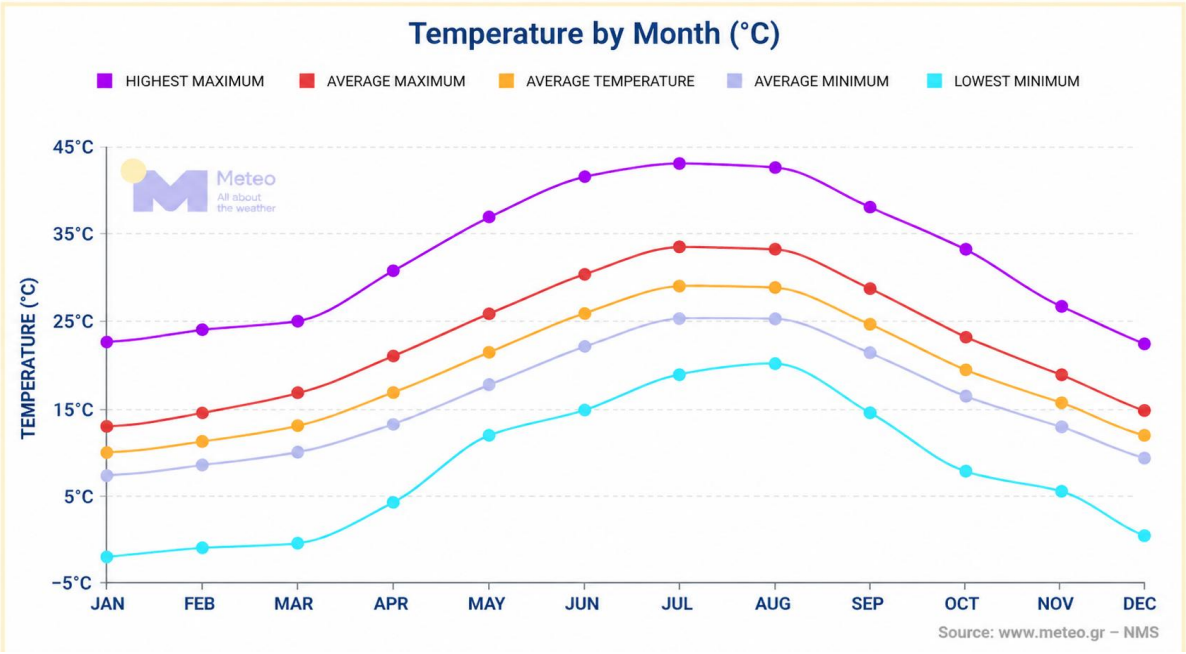
Figure 7 presents the main climatic parameters—temperature and precipitation—for the study area, based on data from the National Observatory of Athens (NOA) meteorological station in Ampelokipi.

Storm rainfall characteristics relevant to the design of the proposed interventions were derived using the national intensity–duration–frequency (IDF) relationships developed by the National Technical University of Athens for the General Directorate for Water of the Ministry of Environment and Energy. These relationships provide a consistent, nationwide framework for estimating rainfall intensity and depth, based on statistically processed historical precipitation data. The IDF parameters are available across Greece on a 5 km spatial grid and allow for site-specific estimation through spatial interpolation.

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Legend: Top panel – Temperature. *From the top to bottom: Absolute Maximum, Average Maximum, Overall Average, Average Minimum, Absolute Minimum Monthly Temperature (in °C).* ***Bottom panel – Precipitation.*** *Light blue: Average precipitation, Dark blue: Maximum daily precipitation (mm).* ***Station data:*** *NOA Station Ambelokipi, Elevation 136 m, Location: 6th Technical Lyceum of Athens, Temperature/Humidity sensor height: 2.5 m, Anemometer height: 2.5 m.*

Figure 7. Hydroclimatic data for the Ambelokipi area

Source: National Observatory of Athens - NOA

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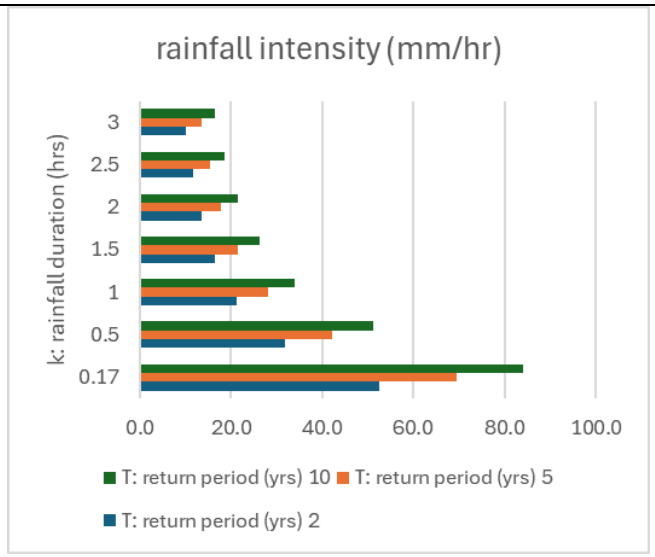
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For the Ampelokipi area, rainfall intensities and corresponding storm depths are calculated for durations ranging from 10 minutes to 3 hours and return periods of 2, 5, and 10 years (Figure 8). These parameters are commonly used in the design and dimensioning of urban drainage systems and NBS interventions.

KAPAPS Park

rainfall intensity (mm/hr)
T: return period (yrs)

k: rainfall duration (hrs)	2	5	10
0.17	52.54	69.41	84.15
0.5	31.95	42.21	51.18
1	21.27	28.10	34.07
1.5	16.39	21.65	26.25
2	13.52	17.87	21.66
2.5	11.61	15.34	18.60
3	10.23	13.52	16.39



rainfall height (mm)

k: rainfall duration (hrs) T/k	2	5	10
0.17	8.76	11.57	14.03
0.5	15.98	21.11	25.59
1	21.27	28.10	34.07
1.5	24.59	32.48	39.38
2	27.05	35.73	43.32
2.5	29.03	38.35	46.50
3	30.70	40.56	49.18

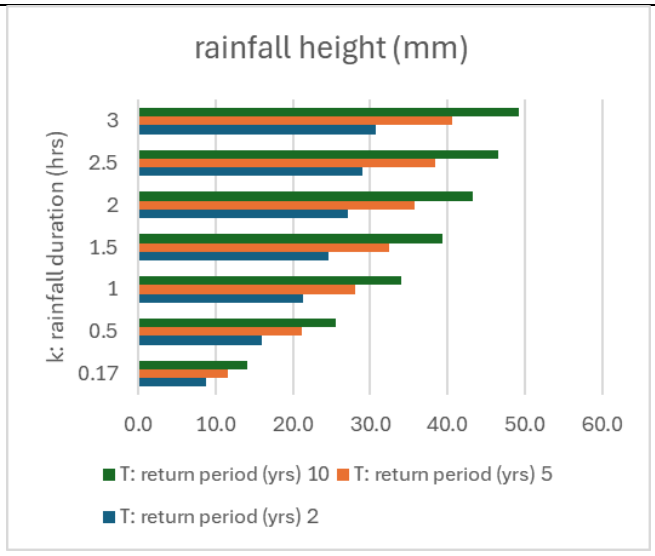


Figure 8. Rainfall intensity and height for the KAPAPS area

Overall, the interplay of dense urban development, extensive impervious surfaces, and limited green space leads to increased surface runoff, reduced infiltration capacity, and heightened thermal stress within the local microclimate. These environmental pressures not only degrade site performance but also highlight its

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strategic potential for the implementation of Nature-Based Solutions (NBS), particularly in advancing stormwater management and water-sensitive urban design.

3.4 Challenges and opportunities

KAPAPS Park, despite its important role as a public green space and community hub, it also faces several challenges that may affect its functionality and long-term sustainability. These are mainly linked to its dependence on potable water for irrigation supplied by the municipal network, a practice particularly unsustainable under increasing temperatures and prolonged periods of drought.

In addition the presence of plants with high water demand as well as the irrigation practices, with a sprinkler-based irrigation system that contributes to unnecessary water losses through evaporation.

Due to surrounding topography and morphology of the area, the surface runoff generated in the upstream areas is conveyed toward the park, particularly along the surrounding street, with part of the runoff entering the park and the remainder being redirected toward Lampsas Street and, to a lesser extent, Trifillias Street. These conditions result in high flood risk at a local scale.

The above morphology characteristics are not only challenges but also significant opportunities, as there no rainwater harvesting systems exists to store and reuse the surface runoff, which leads to significant loss of a potential resource. In this context, KAPAPS Park serves as a strong opportunity for the implementation of Nature-Based Solutions (NBS). By capturing, retaining, treating and storing stormwater on-site, peak runoff can be reduced, mitigating local flood risk, and alleviating pressure on downstream drainage systems. Furthermore, rainwater harvesting and reuse systems could provide an alternative irrigation source, and reduce dependence on potable water with apparent economic and environmental benefits.

Beyond hydrological issues, the area is also affected by broader environmental pressures, such as rising temperatures and more frequent heatwaves. Moreover, irregular rainfall patterns increase drought vulnerability and increase competition for water resources across urban uses (for potable and irrigation purposes). Therefore, enhanced vegetation with resilient native plants can contribute to the improvement of microclimate, increasing biodiversity and in general improvement of the quality of the public space. Given the fact that the park is popular with people from a wider area, it is considered particularly suitable for a pilot site so as to demonstrated integrated NBS systems to the wider possible audience.

Finally, implementing NBS at a central park of Athens can provide valuable insights for wider urban water applications in the area. In addition, the experience and the lessons learned can support the scaling up of such solutions and the development of a Strategic Master Plan on Water Circularity at a municipal level.

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4. Water balance and demand analysis

This section presents an assessment of water availability and irrigation demand for irrigation of the green areas of the KAPAPS Park. The analysis uses regional datasets for the wider Athens Metropolitan Area with site-specific assumptions, so as to evaluate the potential contribution of alternative water resources, particularly rainwater harvesting, storage and reuse.

The objective is to support the design and dimensioning of the proposed NBS system, and ensure the efficient use of rainwater, improve circularity, and reduce dependence on potable water. The section begins with the analysis of water demand, the estimation of water supply, and the overall water balance of the particular site.

4.1 Urban green water demand in Attica

Water use for irrigation of urban green spaces in the region of Attica exhibits significant temporal fluctuations, mainly due to the seasonal climatic conditions and water needs. As illustrated in Figure 9, an average annual cycle is estimated, that shows more uncertainty during the summer period (Theseus D7.1).

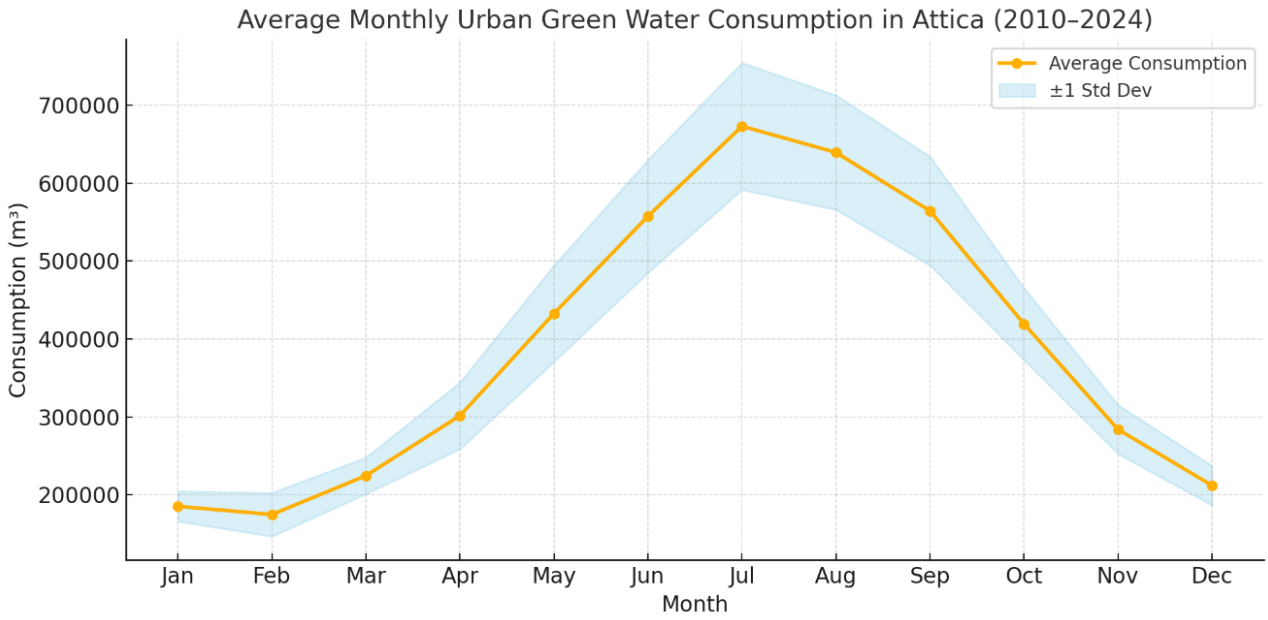


Figure 9. Average monthly urban green water consumption in Attica for period 2010-2024

Source: EYDAP billing data, K2 type

On average, consumption reaches its lowest levels during winter months (December-February), corresponding to the cooler and wetter conditions when irrigation demand is minimal. Demand begins to gradually increase in early spring (March and April), reaching a peak in consumption during the summer

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months (June-August). The highest average monthly consumption occurs in July, at approximately 6.8 million m^3, while January records the lowest levels, below 1.8 million m^3 (Theseus D7.1). Seasonal fluctuations are relatively consistent across the examined years, as indicated by the relatively narrow standard deviation confidence intervals. It is noteworthy that confidence intervals widen during the summer months, suggesting that consumption during this period is more influenced by external factors, whereas winter demand remains relatively stable.

To further investigate long-term trends and seasonal dynamics, an additive time-series decomposition was applied to the monthly consumption data using a classical seasonal model (Theseus D7.1). To further analyse and interpret the temporal patterns of urban green water demand, an additive time series decomposition was performed. Figure 10 presents the result of this decomposition, using the classical seasonal model with monthly frequency.

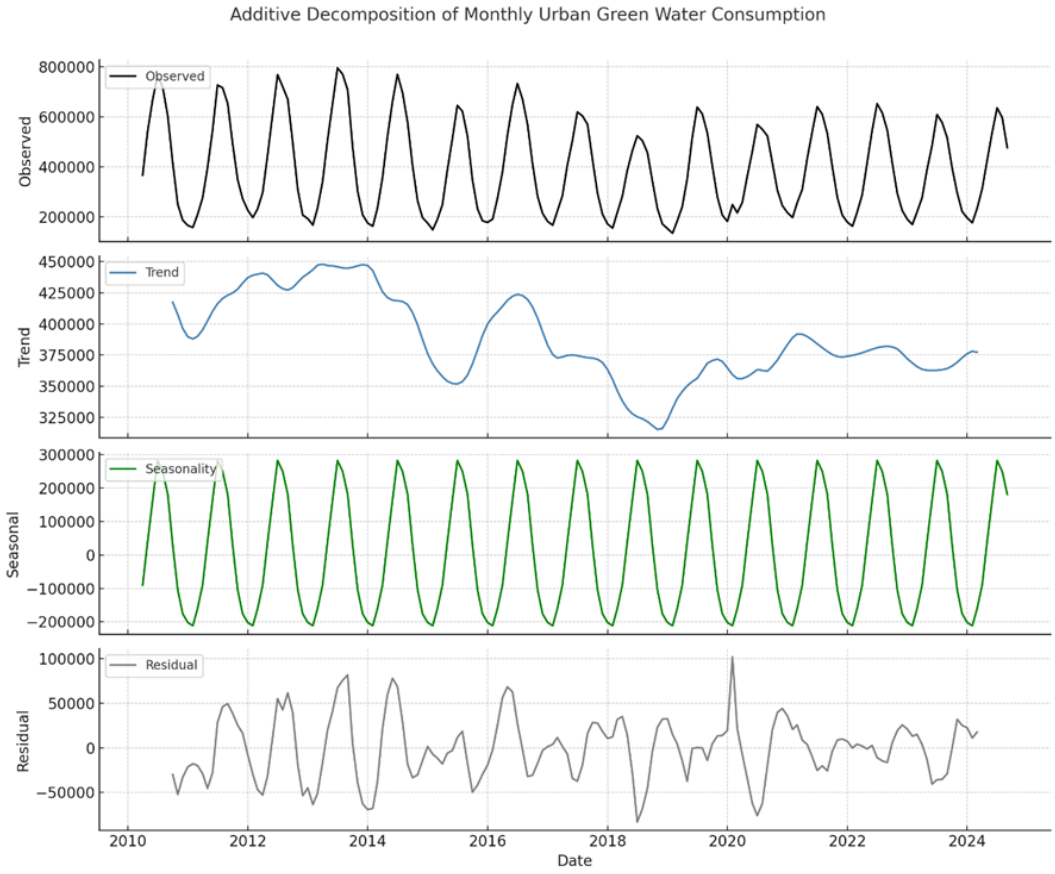


Figure 10. Decomposition (trend, seasonality, residual) of monthly urban green water consumption

Source: EYDAP billing data, K2 type

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The trend component indicates the gradual increase in overall urban green consumption from 2010 to approximately 2019, followed by signs of stabilisation in recent years. This is consistent with previous observations that are based on annual totals. The seasonal component displays a regular annual cycle, and reflects the strong influence of irrigation needs due to climatic conditions. Finally, the residual component captures the short-term anomalies which may be associated with weather extremes, or data irregularities.

4.2 Irrigation demand assumptions

Efficient irrigation practices, when combined with drought resilient vegetation, can significantly reduce the overall water demand in an urban green space.

The requirements of sustainable irrigation in Mediterranean urban environments vary depending on the vegetation type, soil conditions and data availability on climate conditions. A typical landscaping in parks is often grass along with other water-demanding species that typically requires between 600 and 800 mm/year. In contrast, in efficient irrigation systems (such as drip irrigation and smart scheduling) combined with resilient plant species the water needs can be reduced to approximately 300–500 mm/year.

For the purposes of this study, a sustainable and representative scenario is adopted:

Irrigation demand ≈ 400 mm/year = 0.4 m/year

This value represents a balanced assumption that accounts for the water needs of the plants and the efficiency gains through improved irrigation practices and systems. It is used as a reference parameter for estimating the irrigated area that can be supported through harvested rainwater.

4.3 Rainwater potential and availability

The estimation of rainwater availability is based on regional climatic data, as site-specific long-term rainfall records for the Ampelokipi area are not directly available. Therefore, data from the broader Athens Metropolitan Area are used as a representative reference. According to the National Observatory of Athens, the mean annual rainfall in Athens is approximately 400-430 mm.

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Table 1. Monthly and annual rainfall of a 15-year period in Athens

Year/ Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total (mm)
2009	83	50	91.6	32.6	4.8	0.4	4	1.2	68.8	88.3	39.8	103	567.5
2010	31.2	52.6	11	0	7	12	0	0	22.6	81.8	15.6	25	258.8
2011	68.4	77.6	25.6	40	40.8	30.4	0	0.6	3.4	38.4	2.2	100.8	428.2
2012	38.2	113.4	16.4	37	21.8	0	0	0.2	9	11.6	93.8	144.1	485.5
2013	88.6	187.6	14.6	2.6	6.2	12	0	0	0	24.8	137.6	65.8	539.8
2014	129.6	22	55	39	5	22.6	21.8	2.8	2.8	39	43.8	175.1	576.5
2015	48.4	55.4	90.2	8.8	31.8	15.8	0.8	0.4	53.6	94	39.8	1	440
2016	24.8	15.8	42.6	0	1.6	25.2	0	0	6.8	60.4	102.4	23	302.6
2017	50	17.8	79.8	5.4	57.2	69.2	7.4	1.4	20	6.6	130.2	27	472
2018	51.4	80	11.2	1.8	67.8	57.2	65.2	6.4	44	0	51.6	73.8	510.4
2019	125	59.2	26.8	115	2.2	2.6	1	0	4.8	23.4	120.4	90.6	571
2020	16.4	12	48.2	18.6	32.2	16.8	0	17.4	5	35.2	4.6	119.8	326.2
2021	33.4	18.8	7.2	11.6	0	34.2	0	0	1	116.8	64.4	36	323.4
2022	55.8	36.4	11.8	3	4.6	0.6	9.4	82.4	18.4	7.2	43.2	8.6	281.4
2023	62.6	11.6	14	13.4	12.2	16.2	0	0	97.8	1.6	20.6	53.2	303.2
Average													**425.8**

Using a 15-year dataset (2009–2023), the average annual rainfall is calculated at 425.8 mm, confirming the semi-arid Mediterranean climate characterized by relatively low precipitation and strong seasonal variability, with most rainfall occurring during the winter months.

The potential volume of harvested rainwater is calculated using the standard runoff equation:

$$V = C \times A \times I$$

where:

- ✓ V = harvested water volume (m^3/year)
- ✓ C = runoff coefficient (dimensionless), depending on surface type
- ✓ A = catchment area (m^2)
- ✓ I = annual rainfall (mm/year)

For a representative impervious surface:

- ✓ C= 0.80-0.90 (typical for asphalt or sealed surfaces)
- ✓ A ~ 1000 m^2
- ✓ I = 426 mm / year = 0.426 m / year

At this point it should be noted that reducing the runoff coefficient to 0.65 from its theoretical value (C ≈ 0.85) corresponds to typical real-world losses in urban environments that excludes first flush diversion. These losses include evaporation, minor infiltration, and inefficiencies of the drainage systems. Additional

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reductions are also due to morphological uncertainties and alternative infiltration pathways that prevent runoff from being fully captured. This adjusted coefficient provides a more realistic estimate of rainwater harvesting potential under actual operating conditions in dense urban areas such as Ampelokipi. Despite these losses, relatively small impervious surfaces can still generate substantial volumes of reusable water.

Assuming an adjusted runoff coefficient of 0.65, the estimated harvested volume becomes:

$$V \approx 0.65 \times 1000\ m^2 \times 0.426\ m/year \approx 277\ m^3/year$$

This simplified calculation indicates that even relatively small impervious areas can generate substantial volumes of reusable water. When scaled to the full contributing catchment area, the total potential becomes significant for supporting irrigation demand and reducing reliance on potable water.

4.4 Water balance and irrigated area coverage

The relationship between water supply (harvested rainwater) and irrigation demand can be expressed through the estimation of the irrigated area supported by the available volume:

$A_{irr}=V / D$

where:

- A_{irr} = irrigated area (m^2)
- V = harvested water (m^3/year)
- D = irrigation demand (m/year)

Substituting the calculated values: $\mathbf{A_{irr} = 277 / 0.4 \approx 700\ m^2}$

This result indicates that rainwater harvested from a 1000 m^2 catchment area can support approximately 700 m^2 of irrigated green space annually under efficient irrigation practices. This corresponds to a coverage efficiency of approximately 70%, which is relatively high for a Mediterranean context.

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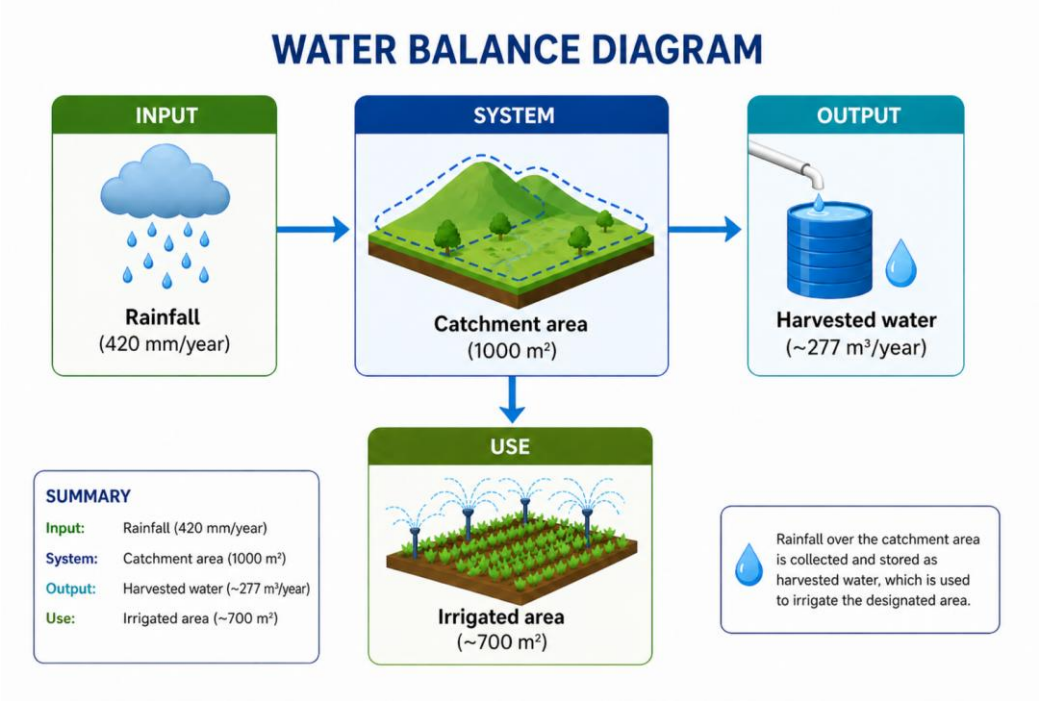


Figure 11. Water Balance Diagram of the KAPAPS Park

An important limitation arises, however, from the temporal mismatch between water availability and demand. Rainfall occurs predominantly during the winter months, while irrigation demand peaks in summer. This discrepancy necessitates the incorporation of storage infrastructure (such as buffer tanks) as well as complementary Nature-Based Solutions, such as rain gardens, bioswales, and soil moisture retention strategies.

Additionally, the fluctuations of water availability within the year as well as the increase of drought frequency may highlight the importance of such circular NBS water related systems.

Key issues for NBS design

Several key implications for the design and operation of the proposed NBS system at KAPAPS Park are mentioned below:

- Rainwater harvesting can serve as an additional water source to cover the water needs of a system, particularly during transitional seasons such as spring and autumn.
- The seasonal inconsistency of rainfall events and irrigation demand, underscores the need for storage and reuse solutions, policies and strategies.
- The peak seasonal water demand highlights the importance of implementing efficient irrigation practices and selecting resilient plants.
- The integration of NBS to an existing green space system can reduce dependence on potable water and increase autonomy and sustainability of the green area.

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Overall, while rainwater harvesting alone is unlikely to fully meet the irrigation needs of urban parks in the Mediterranean regions, it's targeted integration within a border, circular water management strategy can reduce dependence on potable water and ensure water security and contribute to a long-term sustainable environment.

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5. NBS concept design

5.1 Introduction

This section presents the conceptual design of an integrated innovative urban water management system, based on Nature-Based Solutions (NBS) for the collection, temporary storage, treatment, and reuse of rainwater from surface runoff within the urban environment.

The main concept of intervention is to promote s circular and efficient water management system that reduces dependency on potable water for non-potable uses, while increases the retention capacity of water, so as to prevent flooding events. A key element of the proposed approach is the implementation of a combination of various Nature-Based Solutions for stormwater management in a single location. These systems combine engineered design relying mainly on gravity to regulate surface runoff, improve water quality through natural treatment processes, and mitigate peak flows during heavy rainfall events. In addition, these interventions contribute to regulating of microclimate, enhancing of biodiversity, and the upgrading of the public space.

The proposed system is implemented in the Park for the Child and Culture (KAPAPS), as part of the Municipality of Athens' strategic framework for city resilience. The interventions aim to demonstrate how such solutions can improve water availability at a local level, reduce pressure on the municipal drainage systems, and increase the self-sufficiency of the park.

Overall, the proposed measures aim to function as a demonstration project of a technically robust and scalable NBS system that shall strengthen urban resilience while offering a transferable model that can be replicated in other public spaces.

5.2 System components

At KAPAPS Park, the design integrates Nature-Based Solutions with supporting hydraulic infrastructure to form a multifunctional stormwater management and water reuse system (Figure 12). The system enables controlled runoff interception, peak flow attenuation, water quality improvement, and reuse for irrigation purposes within the park.

Runoff is partially diverted from surrounding streets, namely Trifylias Street, Efstathiou Lampsa Street, Kantouni Street, and Nikolaou Florou Street. The collected flows are directed through a sequence of treatment and storage components, designed to progressively improve water quality while regulating water volumes with the aim of reusing them for urban green irrigation.

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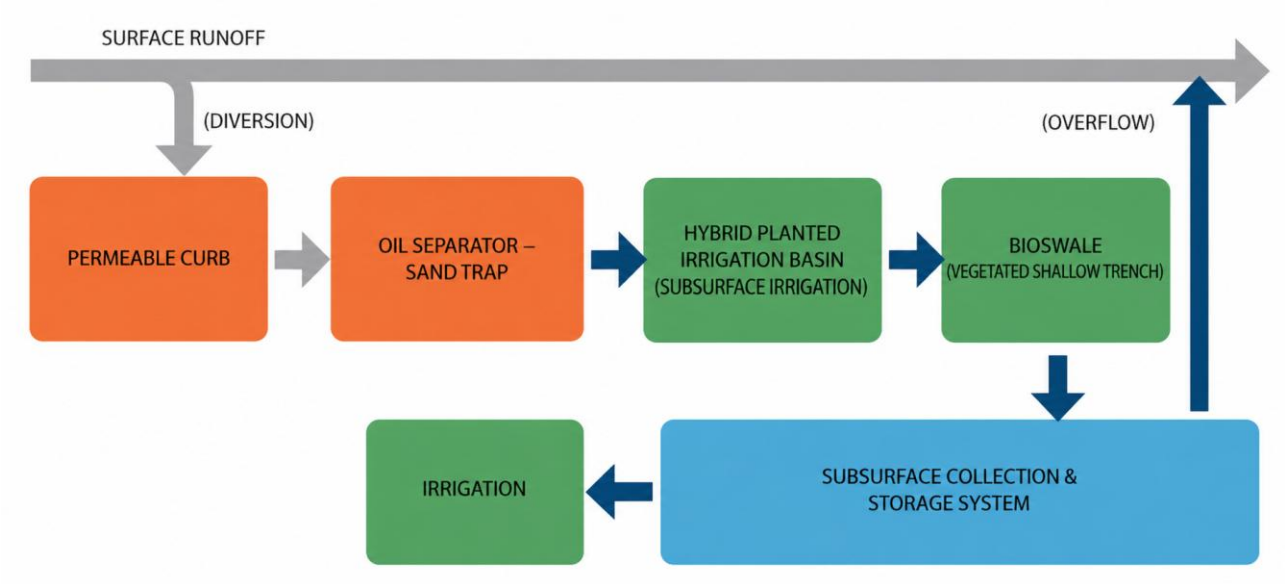


Figure 12. Diagram of Nature-Based Solutions for rainwater management and utilization

5.2.1 Surface water pretreatment and first rain garden

Stormwater entering the system is initially intercepted at street level through a modified sidewalk section incorporating a permeable curb (Figures 12 and 13). This element enables controlled inflow while acting as a first filtration barrier. At this stage, coarse debris such as litter, plastics, and suspended solids is partially retained.

Following this initial interception, water passes through a pretreatment unit consisting of an oil and sand separator. This stage improves water quality by removing hydrocarbons, sediments, and fine particulate matter, ensuring suitability for subsequent ecological treatment processes.

After pretreatment, the flow is directed into a hybrid planted basin functioning as a primary rain garden and flood attenuation structure. This system combines a subsurface storage system with vegetated soil components, enabling multiple interconnects functions:

- Controlled infiltration
- Reduction of peak stormwater discharge
- Temporary subsurface water storage
- Microclimate improvement

The integration of these NBS interventions enhance the quality of water due to filtration processes and the treatment through vegetation.

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5.2.2 Secondary treatment through Bioswale

Downstream of the rain garden, water is conveyed via gravity to a vegetated bioswale system (Figures 12 and 13). This linear drainage system provides secondary treatment through filtration, sedimentation, and biological processes. The bioswale improves water quality by reducing nutrient loads and suspended solids while slowing the velocity of the flow, thereby improving water retention, infiltration and aquifer recharge of the area.

A portion of the water infiltrates into the surrounding soil, contributing to localised groundwater recharge and supporting the health of the subsurface area of the park. After this secondary treatment phase, the remaining water is directed to a subsurface storage system designed for controlled collects and later reuse.

5.2.3 Water storage system

The final storage subsystem operates as both a retention and buffering structure, incorporating an additional rain garden zone that provides overflow capacity beyond the primary storage volume (Figures 12 and 13). This configuration enhances system resilience during high-intensity rainfall events by temporarily accommodating excess stormwater and preventing surface flooding.

Once water quality meets the required standards, stored volumes are allocated for non-potable reuse, primarily for drip irrigation of landscaped areas within the park. In cases of extreme rainfall events that exceed the capacity of the system, controlled overflow redirect excess flows safely back to the municipal drainage network, to preventing localised flooding.

5.2.4 Water reuse subsystem

The water reuse subsystem consists of a pressure regulation unit and an automated drip irrigation network (Figures 12 and 13). The system incorporates automated drip emitters and electrically controlled valves that enable precise irrigation based on demand and the requirements of the vegetation.

This configuration supports the efficient use of water resources by minimising evaporation losses, as the all the systems are in the subsurface, while at the same time surface runoff is reduced, and irrigation is based according to the vegetation needs and the monitored climatic conditions.

The final supporting subsystem includes the pressure unit and the drip irrigation network, equipped with self-regulating drip lines and solenoid valves for the control and scheduling of irrigation, ensuring the rational use of water.

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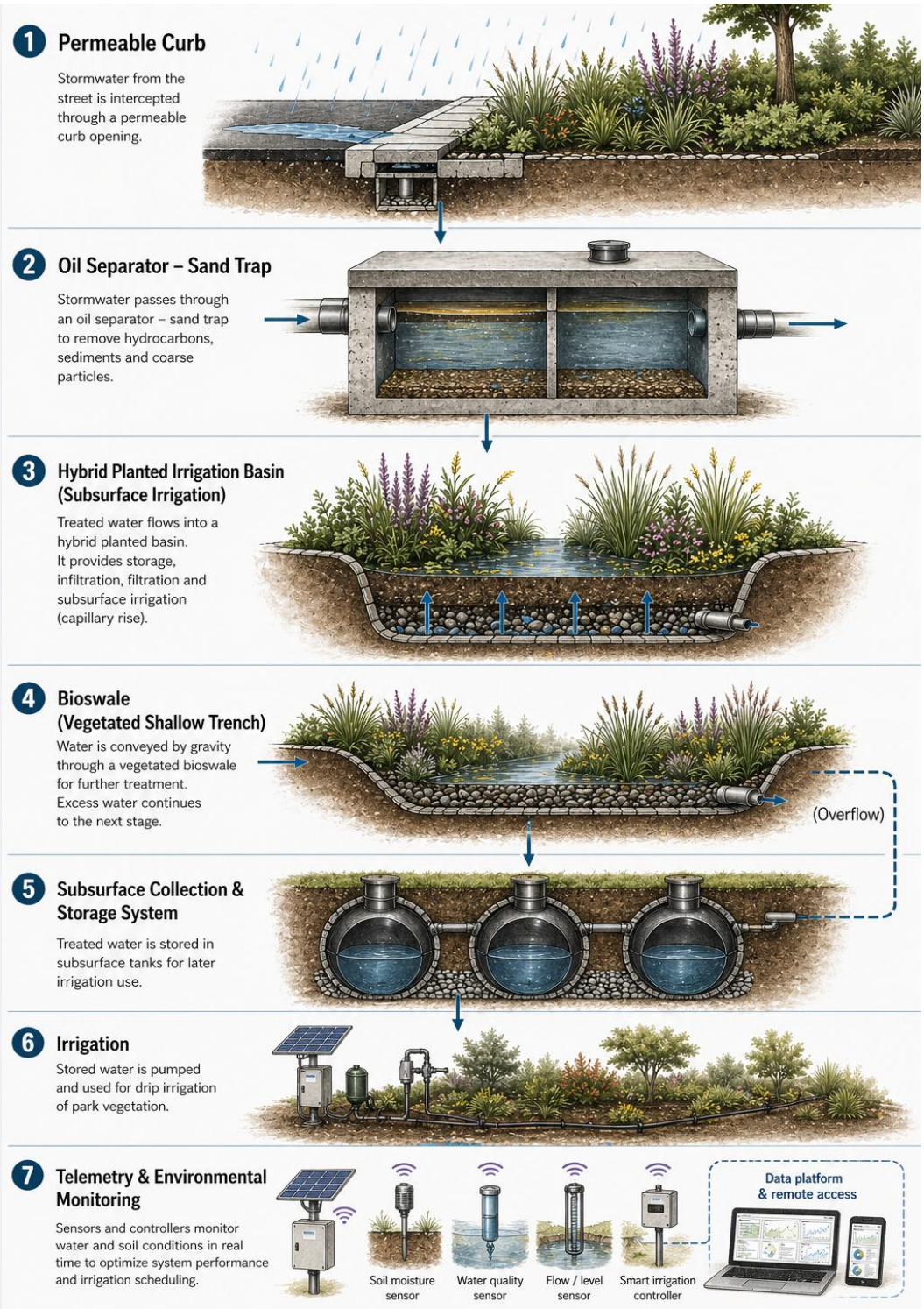


Figure 13. Visualisation of the various stages of rainwater management and reuse in KAPAPS Park

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5.2.5 Telemetry and Environmental Monitoring

The project is proposed to be complemented by the installation of a remote telemetric system that will include soil and water quality sensors, as well as a smart irrigation controller with programming capabilities and remote access (Figures 12 and 13). The entire telemetry monitoring system is proposed to be energy efficiency through the use of integrated photovoltaic panels (PV panels).

The system is complemented by an integrated telemetry and monitoring infrastructure designed to support real-time data acquisition and operational control. The monitoring system includes:

- Soil moisture sensors
- Water quality sensors (turbidity, conductivity, basic pollutant indicators)
- Flow and level measurement devices
- Smart irrigation controllers with programmable logic and remote access capabilities

All control and monitoring systems operate as part of a centralized digital platform enabling continuous performance assessment and adaptive management of the hydrological network.

Energy autonomy is achieved through integrated photovoltaic (PV) panels that supply power to sensors, controllers, and communication modules, ensuring operational independence and sustainability.

This monitoring framework enhances system responsiveness, improves maintenance efficiency, and supports long-term optimization of water management performance under varying climatic conditions.

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6. Technical architecture and system configuration

The proposed Nature-Based Solutions (NBS) stormwater management system (Figure 14) is strategically positioned at the boundary between the surrounding road network and the inner landscape of KAPAPS Park. By following the site's natural slope, the system ensures gravity-driven water flow while minimizing disruption to the park's existing terrain and mature trees.



Figure 14. Siting and spatial arrangement of the different NBS components in the KAPAPS Park

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6.1 Landscape integration and spatial layout of NBS components

The spatial arrangement follows a linear, multi-stage treatment and attenuation sequence, illustrated in Figure 15 and the cross section in Figure 16.

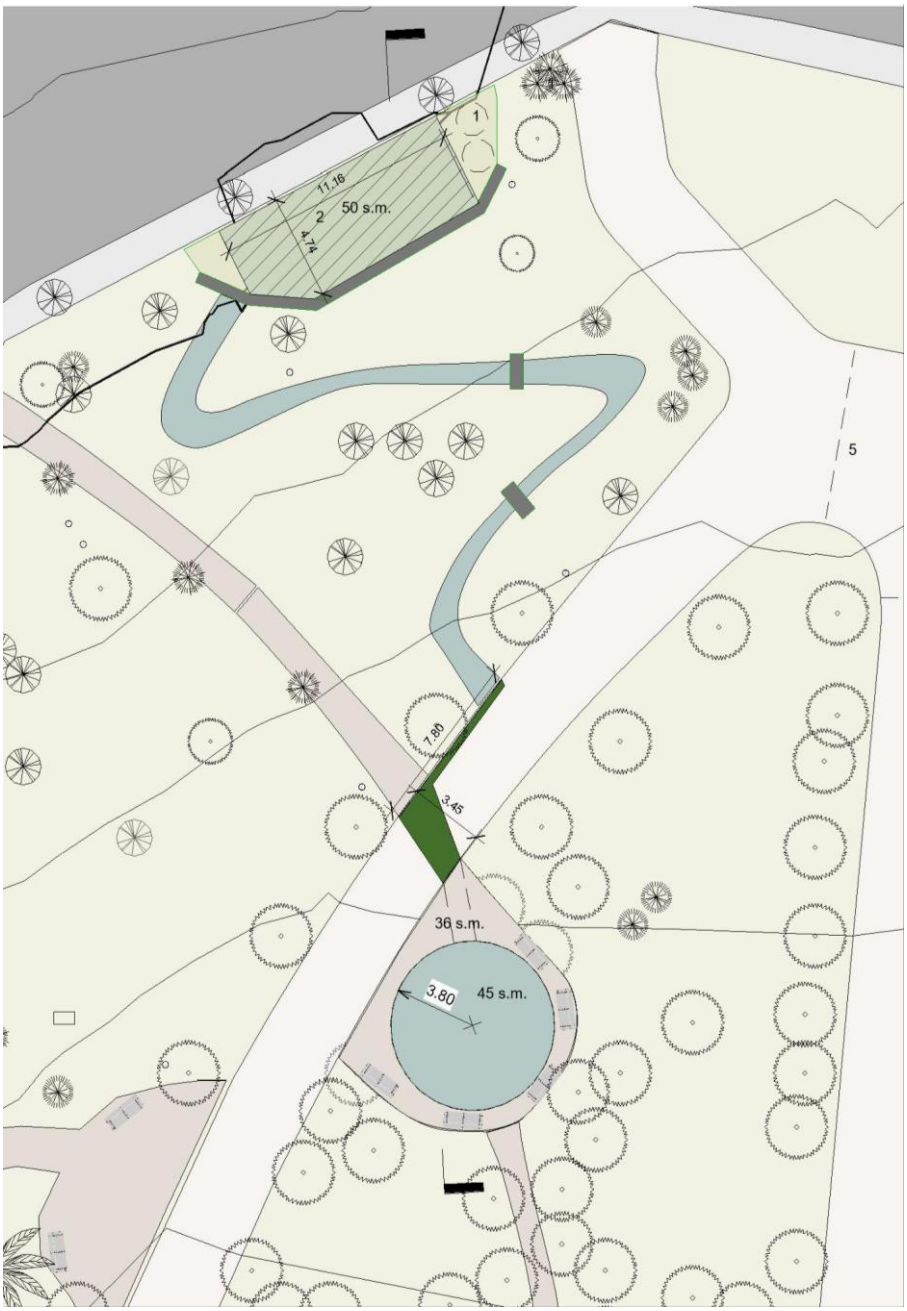


Figure 15. More detailed spatial arrangement of the different NBS components in the KAPAPS Park

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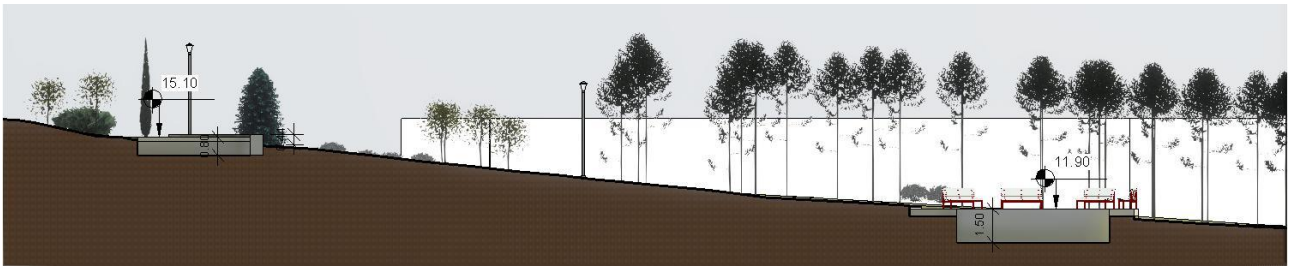


Figure 16. Cross section of the spatial arrangement of the different NBS components in the KAPAPS Park

- **Interception and Pre-treatment (Upstream Boundary):** Stormwater interception originates along Trifylias Street, where the system integrates directly with the curb line and sidewalk infrastructure. Permeable curb inlets are strategically positioned at certain topographic points along the roadway edge to capture and divert surface runoff into the park, providing attenuation of flood volumes from downstream areas and reducing discharge into the municipal drainage system. A compact, subsurface oil separator and sand trap is integrated immediately downstream of the capture points; its strategic placement near the park boundary optimises maintenance accessibility. This near-street placement minimises the conveyance distance of untreated runoff, ensuring that coarse sediments and hydrocarbons are efficiently removed before entering the vegetated ecological zones, while remaining safely outside high-activity pedestrian areas.

- **Primary Retention and Biofiltration:** Following pre-treatment, the runoff is directed into the **primary hybrid-rain garden (planted irrigation basin)**. Positioned within a designated soft-landscape zone will cover an area of approximately 50 m²**.** The basin will be slightly depressed relative to the surrounding terrain, enabling gravity-driven inflow and temporary surface ponding. It will be filled with a specialized planting substrate designed to enhance infiltration, moisture retention, and capillary water movement. During the summer period, an innovative capillary rise mechanism will allow stored water to be transported upward, passively irrigating the overlying vegetation through a zero-energy irrigation process while also contributing to evaporative cooling of the surrounding microclimate. The garden is carefully sited to align with existing vegetation clusters and soil zones, ensuring seamless aesthetic and ecological integration. It maintains a safe spatial buffer from highly paved or heavily utilized public spaces (e.g., the playground, library, and cafe) while acting as a focal landscape feature.

- **Conveyance and Secondary Treatment (Bioswale):** Downstream of the primary hybrid-rain garden, the system transitions to a **bioswale (vegetated shallow trench)**. This linear feature follows the natural slope of the park, functioning dually as a hydraulic conveyance corridor and a biofiltration element. The bioswale's elongated, meandering geometry facilitates gradual water flow, enhancing pollutant removal and promoting localized soil infiltration. Minor earthworks, such as shallow swales and small berms, are introduced to dictate flow direction and increase retention times within the vegetative corridor. To preserve pedestrian mobility without disrupting the system's hydraulic continuity, two dedicated path bridges (passerelles) span the bioswale at designated

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crossing points. The bioswale will terminate at a manhole, from which a conveyance pipe will transfer the treated runoff to the final subsurface storage tank.

- **Subsurface Storage and Overflow:** At the lowest elevation zone of this innovative hydro system, a **subsurface collection and storage unit will be** deployed. It will consist of a modular array of underground storage chambers with a total capacity of approximately 60 m^3, utilising the site's hydraulic low point to enable efficient gravity-fed accumulation. The system will be strategically located near utility-accessible areas and positioned to avoid interference with critical tree root zones, thereby minimising excavation impacts and preserving existing vegetation.
    - ***System Coverage**:* This system is designed to be covering **approximately 45 m^2**.
    - ***Active Reuse**:* An active subsurface drip irrigation network extends from this central hub to supply surrounding tree clusters and planting beds, carefully avoiding paved surfaces.
    - ***Overflow Pathways**:* Integrated subsurface overflow pipeline network provides a failsafe mechanism, redirecting excess volume back into the municipal drainage network (EYDAP) during extreme precipitation events, ensuring complete hydraulic safety.
- **Slope Drainage Control and Subsurface Diversion System:** The main internal pedestrian pathway of the park, due to steep slope, has been observed to generate intense surface runoff, resulting in erosion in the downstream sections of it. To address this issue, a transverse trench will be constructed across the pathway, functioning as an interception and infiltration point. The trench will be filled with permeable granular material to temporarily store and infiltrate runoff, while the water will be conveyed by gravity directly to a manhole, which will act as a collection and control point. From the manhole, a subsurface pipe system will convey the excess water downstream and will discharge it outside the park boundaries into the municipal drainage network (EYDAP).
- **Telemetry and Smart Monitoring:** To ensure optimal operational performance, a network of environmental monitoring sensors (tracking water levels, soil moisture, and water quality) is distributed across the rain garden, bioswale, and storage nodes. The central control unit, coupled with photovoltaic (PV) panels for energy autonomy, is installed in an accessible yet unobtrusive location near the storage infrastructure. This enables efficient remote system management without visual disruption of the parks functions.

Overall, the selection of the site process as well as the design of the system reflects a sophisticated sequence of components that are based on gravity. The entire design integrates with the park's spatial functionalities, constraints due to other conflicting uses, leaves intact the pedestrian accessibility pathways, maximising the collection of water and the prevention of flooding events in the park.

6.2 Technical description of key components

The technical design of the Nature-Based Solutions system at KAPAPS Park is based on a stormwater management strategy aimed at the capture, retention, treatment, subsurface storage, and reuse of urban runoff within a circular water management framework. The intervention combines decentralised

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components of an integrated system specifically designed to reduce runoff peaks, alleviate pressure on municipal drainage systems, and reuse excess treated rainwater for irrigation purposes instead of using potable water.

The system is structured as a sequential treatment and management configuration that starts with the controlled diversion of surface runoff from surrounding streets through permeable curb inlets and inflow structures. Initial pretreatment components provide debris, sediment, sand, and hydrocarbon removal, safeguarding downstream systems from clogging and erosion, to achieve the maximum performance of the system.

The entire system is further supported through subsurface storage infrastructure and Internal Water Storage (IWS) zones, enabling temporary water retention and delayed discharge. Controlled overflow and emergency bypass pathways ensure the safe NBS system operation during heavy rainfall.

Advanced telemetry, soil moisture sensors, water quality monitoring and automated irrigation controls, are integrated to support real-time monitoring to assess the performance, as well as operational control, and long-term sustainability.

Overall, the proposed technical NBS design represents a demonstration intervention, a replicable blueprint for an innovative NBS resilient, circular, and technically advanced stormwater management along with water collection, recovery and reuse component in dense Mediterranean urban environments.

6.2.1 Runoff capture: Curbed Bioretention and Interface Design

The optimal design choice for capturing and conveying stormwater runoff into bioretention facilities depends mainly on the particular parameters of the site, such as location, land use, grade, and the velocities of the peak flow. In a highly dense urban environments with limited space for application, curbed bioretention designs are prevalent. Unlike low-density applications that rely on unconfined sheet flow, curbed bioretention facilities strictly require precisely engineered inlets to efficiently convey runoff from the surrounding catchment area into the treatment practices. At the critical interface between the street gutter and the pedestrian sidewalk, proper inlet design is essential for ensuring that surface runoff is effectively captured, while simultaneously maintaining structural integrity and pedestrian safety. An example of such a curbed bioretention facility is shown in Figure 17.

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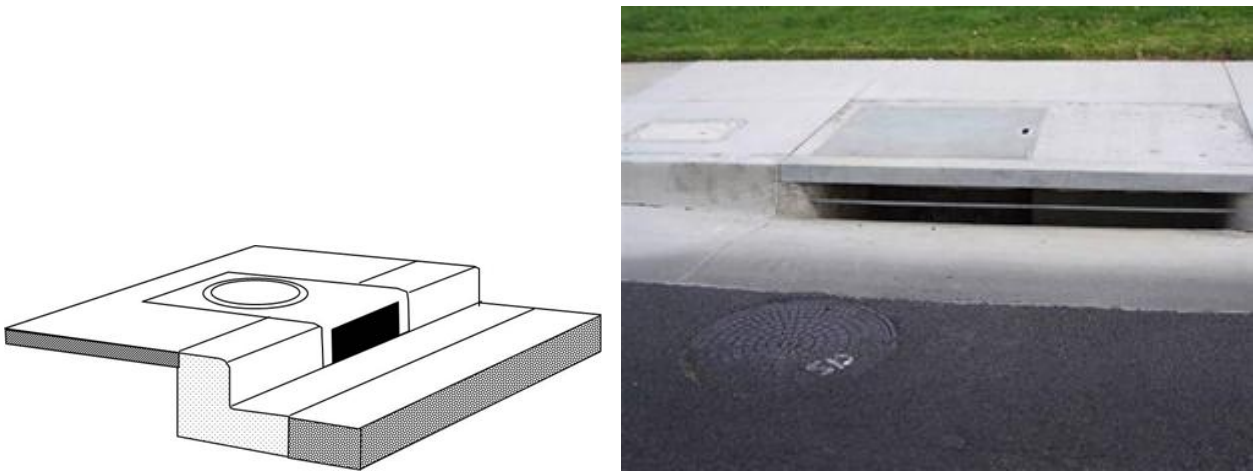


Figure 17. Example of a curbed bioretention facility

Technical Specification: Precast Covered Curb Inlet

To facilitate the controlled diversion of surface runoff from the roadway into the Nature-Based Solution infrastructure of KAPAPS Park, a specialized Precast Covered Curb Inlet will be utilized. This component will act as the primary hydraulic intake structure, seamlessly integrated into the existing sidewalk profile.

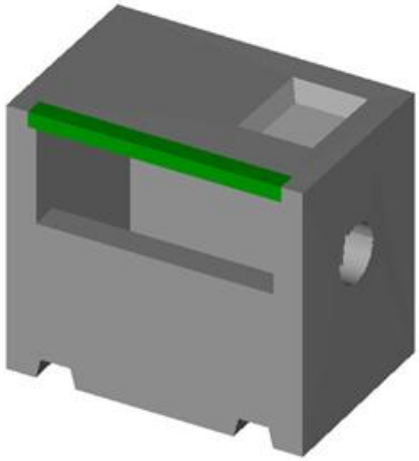


Figure 18. Precast Covered Curb model

The main key technical characteristics of precast covered curb inlets include:

- Structural Composition: Manufactured as a heavy-duty, monolithic precast concrete unit, designed to withstand standard pedestrian and lateral roadway loads while serving as an integral segment of the sidewalk matrix.

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- Intake Geometry & Durability: The unit features a wide, horizontal rectangular throat opening along the curb face, maximizing the hydraulic capture efficiency of longitudinal gutter flow. The upper lip of the throat is reinforced with an integrated, galvanized steel angle edge to protect the concrete against mechanical impact and wheel wear.
- Debris Exclusion: A rigid horizontal steel bar or grates can be installed across the primary intake opening. This acts as a primary coarse screen, preventing large debris and floating trash from entering and clogging the downstream pretreatment units. Although they can be effective, they must be maintained, or they will clog.
- Maintenance & Accessibility: The top slab of the precast unit is cast flush with the surrounding pedestrian pavement. It incorporates a standardized access hatch (manhole or rectangular steel cover), allowing maintenance crews direct vertical access for inspection and sediment cleanout without disrupting adjacent vehicular traffic.
- Hydraulic Routing: A pre-formed circular knockout on the lateral or rear face of the concrete vault facilitates a direct, watertight pipe connection, routing the intercepted flow directly into the primary oil/sand separator or biofiltration basin.

To achieve efficient runoff interception without unnecessary over-dimensioning, the curb inlet opening length is set at approximately 0.80–1.00 m, corresponding to a design intake capacity of about 11–15 L/s (0.011–0.015 m^3/s) under high-intensity rainfall conditions. This ensures compatibility with downstream conveyance limits while avoiding excessive construction and manufacturing costs.

Under typical operating conditions, assuming shallow sheet flow with a depth of 3–4 cm (0.03–0.04 m) and a characteristic velocity of 0.15–0.20 m/s, the approaching unit discharge can be estimated using , resulting in 0.0045–0.008 m^2/s per meter width. For an effective inlet length of 1.0 m, this corresponds to an incoming flow of approximately 4.5–8 L/s (0.0045–0.008 m^3/s), which is notably lower than the maximum design capacity.

Given the inlet opening geometry 0.10 m × 1.0 m (HxW), hydraulic capacity is not the controlling factor; instead, interception efficiency governs performance. Assuming a realistic capture efficiency of 50–70% for flow approaching parallel or slightly oblique to the curb, the effective captured discharge is estimated at approximately 2–5 L/s (0.002–0.005 m^3/s).

Over a duration of one hour, this corresponds to a total intercepted runoff volume in the range of approximately 7–18 m^3, with a representative value around 10–12 m^3. These estimates remain indicative and depend on local slope, crossfall, surface roughness, and flow alignment.

Vault Volume and Economic Optimization

The system is supported by a compact precast concrete vault with a footprint of approximately 600 mm × 600 mm, minimizing excavation and material costs. This lean design approach allows resources to be allocated more efficiently toward the implementation of the primary Nature-Based Solutions, including the hybrid detention basin and the capillary-driven subsurface irrigation system.

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6.2.2 Pretreatment Infrastructure: Hydrocarbon and Sediment Separation Unit

The curb inlet will be hydraulically linked to the downstream pretreatment unit through a diameter of 125 mm (Φ125 mm) conduit, which acts as the governing hydraulic control of the system. Under gravity-driven, free-surface flow conditions and assuming a longitudinal slope of 1.0–2.0%, the conduit provides a nominal discharge capacity of approximately 11–15 L/s, effectively regulating the transfer of intercepted runoff toward the compact precast concrete vault.

Initial pretreatment components provide essential debris, sediment, sand, and hydrocarbon removal, safeguarding downstream Nature-Based Systems from clogging, erosion, and performance degradation. Sited immediately downstream of the precast curb inlets, the primary pretreatment unit consists of a highly efficient, dual-chamber prefabricated separator.

Technical Specifications and Materiality

- Structural Integrity: The underground tanks are manufactured from Linear Low-Density Polyethylene (LLDPE), guaranteeing absolute watertightness and superior resistance to corrosive wastewater and urban runoff. All hydraulic connection fittings are constructed from high-durability PVC.
- Standard Compliance: The system is strictly specified according to the European Standard EN 858. To ensure the maximum ecological protection of the downstream bioretention facilities (bioswale and rain garden), an EN 858 Class I system is utilized.

Operational Stages and Hydraulic Processing

The treatment process is gravity-driven and divided into two distinct functional chambers:

- Sludge and Sand Trap (stage 1): This primary chamber exploits density differentials and gravity to remove coarse sand, inert solids, and granular waste. By significantly reducing the flow velocity, it provides sufficient retention time for sedimentation, thereby preventing abrasive wear and detrimental sediment accumulation in the downstream vegetated matrix.
- Oil and Hydrocarbon Separator (Stage 2): Following sedimentation, the runoff enters the second chamber where lighter-than-water hydrocarbons are separated via flotation. The efficiency of this process is exponentially enhanced through the integration of a coalescence filter. As microscopic oil droplets pass through the filter, they agglomerate into larger volumes, allowing them to rapidly rise to the surface.

Hydraulic Dimensioning and Separator Sizing

The hydraulic dimensioning of the pretreatment unit is rigorously calibrated against the catchment's calculated peak hourly stormwater runoff. For this specific urban intervention, the maximum design flow rate is established at 10 to 12 m^3/h.

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Technical Sizing Criteria

- Flow Conversion and Nominal Size (NS): To comply with EN 858 sizing methodologies, the peak volumetric flow must be expressed in liters per second (L/s). The maximum targeted flow of 12m^3/h equates to a peak hydraulic discharge of approximately 3.33 L/s. Consequently, to safely manage this peak load while incorporating an adequate safety margin, the system is specified with a Nominal Size 4 (NS 4).

- Hydraulic Retention Time (HRT): Selecting an NS 4 separator guarantees that the hydraulic capacity exceeds the 3.33 L/s peak flow, thereby preventing turbulent bypass. This precise dimensioning ensures sufficiently extended hydraulic retention time within the dual-chamber unit.

- Volumetric Optimization: The calculated NS 4 capacity dictates a highly compact subsurface footprint for the LLDPE tanks (typically requiring a total internal volume of roughly 1,000 to 1,500 liters). This volume is perfectly optimized to decelerate the influent water, allowing the gravity-driven settlement of inert solids in the sludge trap and the efficient flotation of agglomerated hydrocarbons in the coalescence chamber, without oversizing the civil works.



Figure 19. Hydrocarbon and Sediment Separation Unit

6.2.3 Integrated Subsurface Storage and Hybrid-Rain Garden System

The proposed stormwater management solution introduces a radical and holistic approach that simulates the natural water cycle, transforming the urban space into a modern "sponge city." This system organically combines natural retention (via a rain garden) with an advanced subsurface storage and energy-autonomous irrigation mechanism utilizing capillary rise.

System Architecture and Operation

The water system is developed across two interacting tiers (surface and subsurface), imparting a highly multifunctional character to the installation:

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- Surface Level (Rain Garden): This acts as the supplementary flood attenuation volume above the active storage space. It receives pre-treated stormwater, decelerating surface runoff, filtering pollutants through biofiltration, and enhancing the aesthetic and ecological value of the landscape.
- Subsurface Level (Storage Chambers): Beneath the rain garden, a two-dimensional, modular subsurface storage system is installed (comprising semi-cylindrical, corrugated tunnel chambers). Following infiltration, rainwater is collected in these underground reservoirs, which effectively replace traditional, cost-intensive, and energy-consuming storage tanks.



Figure 20. Schematic representation of a two-tier water management system, illustrating the surface rain garden layer with vegetation for biofiltration and flood attenuation, and the subsurface modular storage chambers for underground water retention and controlled collection

Technical Dimensioning and Material Configuration:

The spatial and volumetric sizing of the hybrid-rain garden node is specifically calibrated to manage localized peak runoff while ensuring continuous passive irrigation:

- Volumetric Capacity & Chamber Configuration: The system is engineered for a net water storage capacity of 30 m^3. To achieve this, the layout utilizes a standardized modular array consisting of 9 corrugated tunnel chambers and 6 end caps, integrated with a sedimentation/filter shaft and a central pump sump.
- Spatial Footprint: The array is distributed over a rectangular footprint of 11 x 4.5 m, covering a total surface area of approximately **50 m^2**.

Base Sealing & Substrate: To facilitate the capillary mechanism and prevent premature deep percolation, the system's base is sealed using 60 m^2 of 1.5 mm HDPE geomembrane liner. The tunnel modules are enveloped in 57 m^3 of high-porosity gravel, providing structural load-bearing capacity while maximizing the void space for rapid water distribution and retention.

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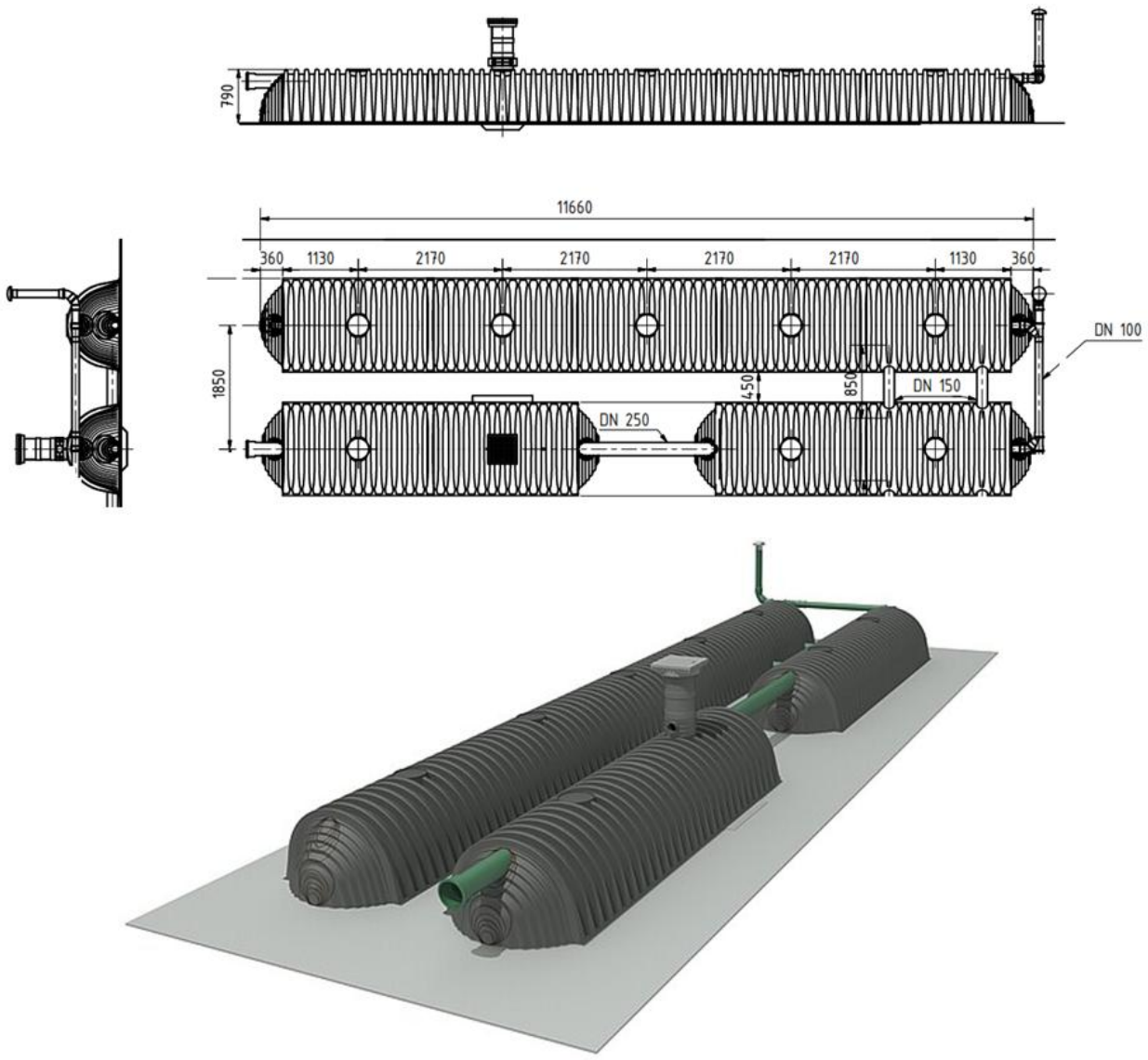


Figure 21. General Arrangement Drawing (Plan, Elevation & Section)

The Capillary Rise Mechanism

The core innovation of this system (utilizing patented technology) lies in its method of water recovery. Instead of requiring mechanical pumping to bring water to the surface, the accumulated water in the subsurface chambers naturally ascends back to the root system of the rain garden's vegetation via the capillary effect.

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This process establishes a continuous, self-sustaining cycle:

- Storage & Infiltration: The system fills during heavy rainfall events, relieving the burden on municipal sewage networks and mitigating urban flood risks.
- Passive Irrigation: The water rises gradually, maintaining the soil at optimal moisture levels without any electrical energy consumption (zero-energy irrigation).
- Evaporation & Cooling: Through the natural evapotranspiration of the plants, significant cooling of the surrounding environment is achieved, drastically reducing the Urban Heat Island (UHI) effect.

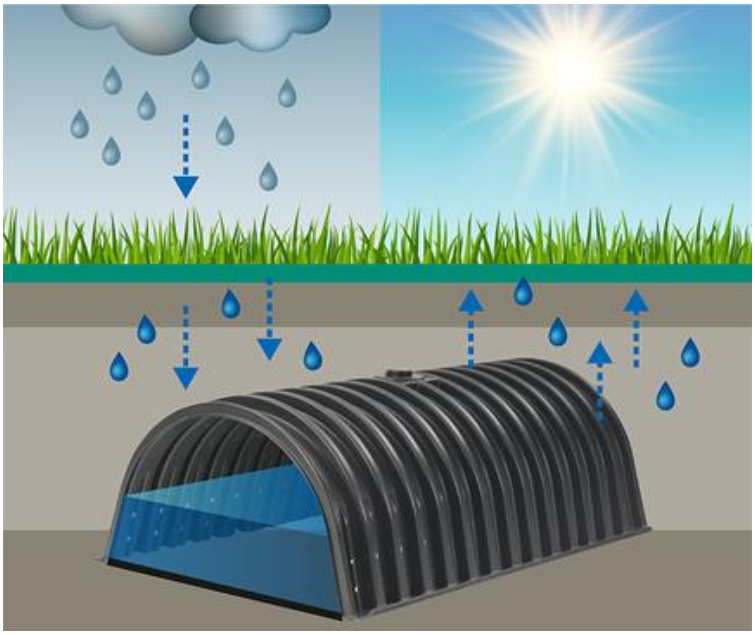


Figure 22. Schematic Diagram of Capillary Rise Mechanism in a Subsurface Rainwater Storage System

Technological and Environmental Impacts

The integration of this technology into the KAPAPS Park under the THESEUS project offers multiple measurable benefits, fully aligning EU climate adaptation goals:

- Zero-Energy Irrigation Requirements: The subsurface irrigation of the overlying green infrastructure is entirely passive (driven by capillary action), completely eliminating the need for pumps within this specific subsystem.
- Microclimate Regulation: The evaporation process provides substantial cooling to the urban environment, yielding a cooling potential of approximately 670 kWh per cubic meter of evaporated water.
- Flood Mitigation ("Reverse Sponge" Effect): The continuous capillary rise and subsequent evaporation gradually deplete the subsurface chambers. This continuous emptying recreates

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available buffer space to attenuate the next extreme weather event. Furthermore, the consistent soil moisture drastically increases the soil's natural infiltration capacity, reducing surface runoff.

- Stormwater Purification: The combination of phytoremediation (provided by the rain garden) and mechanical sedimentation/filtration significantly improves water quality before it percolates down to recharge the underlying groundwater aquifer.
- Biodiversity & Resilience: The system ensures the viability of urban greenery—even during periods of prolonged drought—while minimizing maintenance requirements and fostering favourable conditions for local biodiversity.

The system operates as an interactive subsurface "sponge-reservoir" connected directly to the surface vegetation. It effectively transforms the challenge of urban stormwater management (flooding) into a nature-based solution for mitigating water scarcity and extreme heatwaves within the urban fabric.

6.2.4 Conveyance and Secondary Treatment (Bioswale)

The excess water collected from the Hybrid Rain Garden System will be conveyed downstream to a landscape-integrated bioswale for further treatment, before being transferred to the final storage tank.

Technical Dimensioning and Material Configuration

The bioswale is precisely engineered to balance surface flow deceleration with efficient subsurface drainage:

- Spatial Geometry: The vegetated trench extends over a total longitudinal length of 45 meters. The cross-sectional profile is designed with a maximum depth of 70 cm and a maximum top width of 100 cm.
- Basal Sealing and Subsurface Drainage: To prevent uncontrolled deep percolation and to deliberately direct the treated water toward the downstream storage array, the trench invert is lined with a 1.5 mm HDPE geomembrane. Immediately above this impermeable liner, a 50-meter flexible, double-structured wall PE drainage pipe (360° perforated) is installed. This component acts as the primary subsurface artery, ensuring the efficient collection and longitudinal transport of the filtered runoff.
- Filter Media: The core of the trench is backfilled with 25 m^3 of graded gravel (10-40 mm). This highly porous aggregate matrix provides structural stability to the channel while maintaining exceptional hydraulic conductivity for rapid infiltration to the basal drainage pipe.

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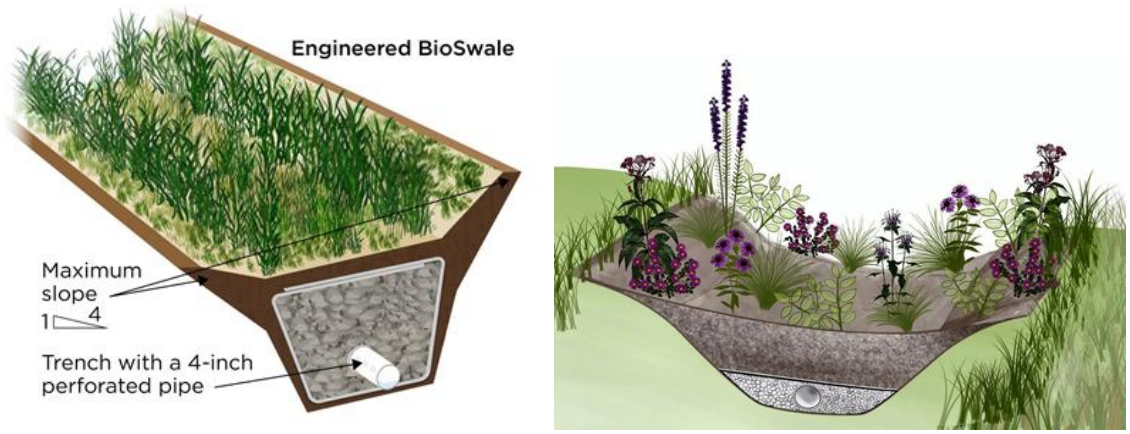


Figure 22. Technical configuration and cross-sectional schematic of an engineered bioswale, illustrating geometry, impermeable lining, subsurface drainage pipe, and gravel filter media for controlled infiltration and conveyance of treated stormwater.

Hydraulic Processing and Ecological Integration:

- Flow Attenuation: The bioswale's elongated, meandering geometry naturally facilitates gradual water flow. To further optimize the hydraulics, minor earthworks—including shallow swales and internal transverse berms (check dams)—are strategically introduced. These dictate the flow direction, reduce peak hydraulic velocity, and maximize the retention time within the vegetative corridor.
- Phytoremediation: The lateral banks and edges of the trench are stabilized and planted with carefully selected, water-tolerant native flora. This targeted vegetation exponentially enhances the biofiltration of residual pollutants and promotes localized moisture retention along the upper soil horizons.
- Pedestrian Infrastructure: To preserve public mobility and park accessibility without disrupting the system's hydraulic continuity, two dedicated path bridges (passerelles) are constructed to span the bioswale at designated pedestrian crossing points.

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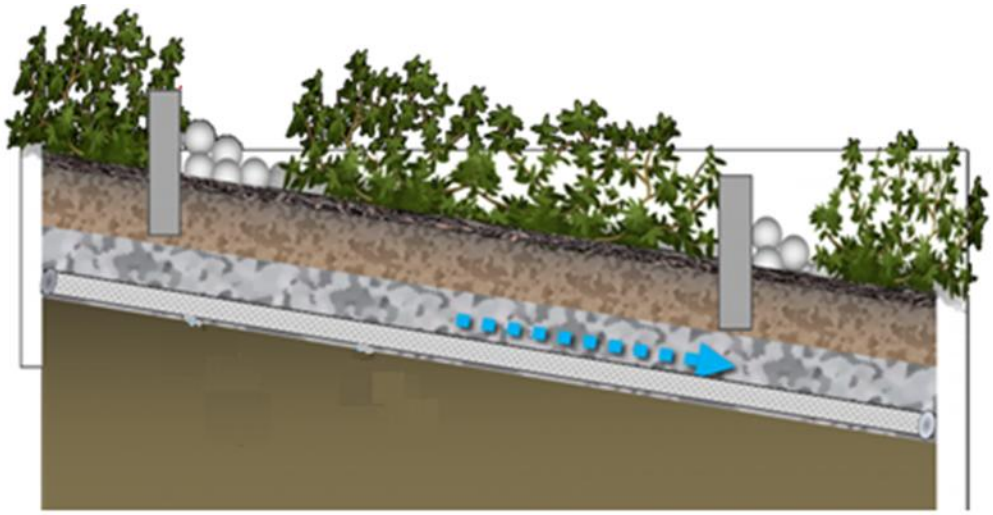


Figure 23. Schematic Longitudinal Section of a Bioswale with Water Flow Path

6.2.5 Subsurface Collection and Storage: Modular Honeycomb Reservoir and Permeable Surface Paving

At the lowest elevation zone of this innovative hydro system, a centralized subsurface collection and storage unit is deployed. By utilizing the site's absolute hydraulic low point, the system enables highly efficient, gravity-fed accumulation of treated stormwater. The reservoir is strategically sited near utility-accessible areas and carefully positioned to avoid interference with critical tree root zones, thereby minimizing excavation impacts and preserving existing mature vegetation.

Technical Specifications and Structural Geometry

- Material & Core Structure: The core of the reservoir is constructed from an array of ultra-light, high-strength honeycomb blocks (comb blocks). Manufactured from 100% recyclable Polypropylene (PP), these units guarantee immense structural durability. The material is UV-stable, highly resistant to acids and alkalis, and strictly groundwater-neutral, holding approvals for unrestricted irrigation water applications.

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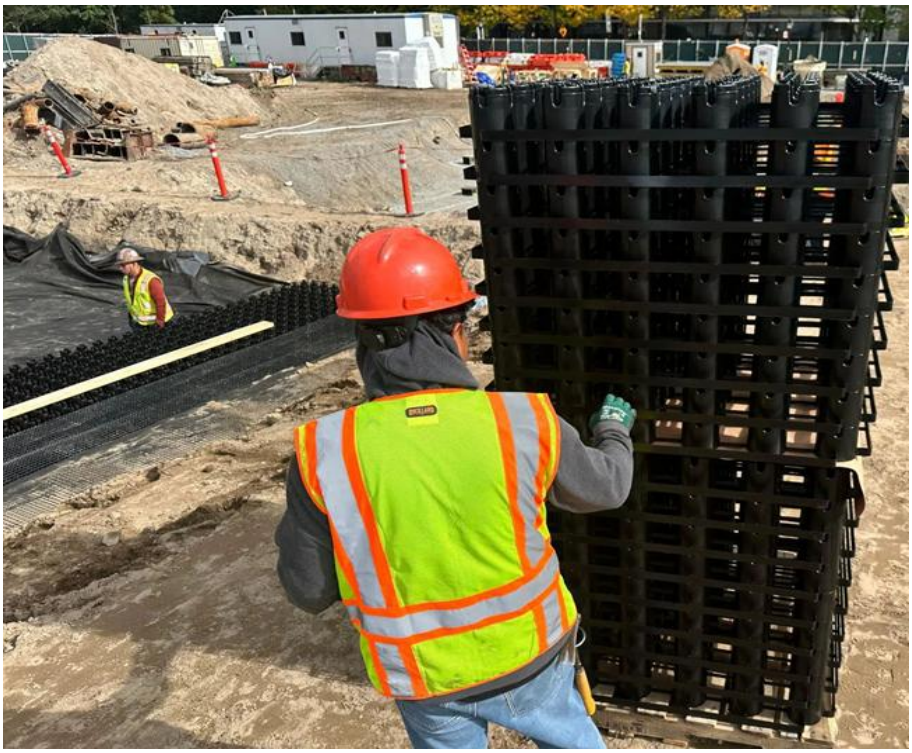


Figure 24. Honeycomb modular subsurface storage system (PP blocks)

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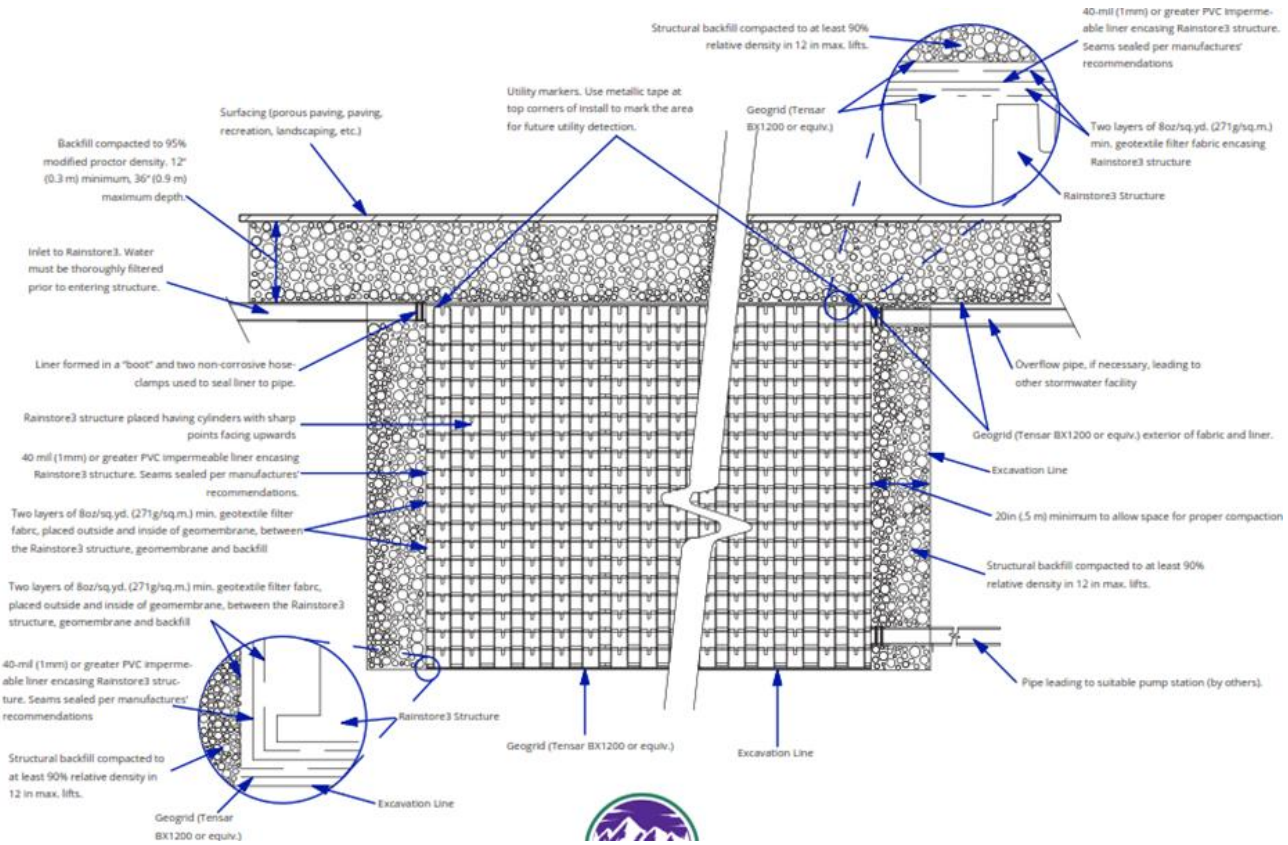


Figure 25. Detailed cross section of a Honeycomb modular subsurface storage system

- Hydraulic Void & Flow Dynamics: The internal architecture of the honeycomb structure permits unimpeded, three-dimensional hydraulic flow. The raw PP blocks boast shows an exceptional net storage volume of over 95%.

- Spatial Dimensioning: The subsurface array spans a targeted surface coverage of approximately 45 m². The excavation requires a total depth of 2.0 meters, accommodating a highly efficient active storage (effective depth) of 1.7 meters utilizing the stacked honeycomb modules. The system's engineered dimensioning applies a volumetric occupancy coefficient of 0.80 to account for internal dynamics and system fittings. This configuration yields a total operational storage capacity of approximately 60 m³.

- Encapsulation & Load Bearing: The stacked modules are installed seamlessly without the need for mechanical connection elements. To function as a watertight reservoir, the entire block matrix is enveloped in a heavy-duty impermeable foil jacket (geomembrane), which is subsequently wrapped in protective non-woven geotextile layers. The robust design of the blocks ensures

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exceptional bearing capacity, capable of supporting heavy surface traffic loads without structural deformation.

Surface Permeable Paving and Stakeholder Co-creation: Directly above the subsurface storage array, the final surface finish will consist of a fully permeable paving system. This ensures rapid, unimpeded infiltration of surface runoff into the underlying systems while maintaining pedestrian functionality. The exact final paving material will not be pre-determined; instead, it will be selected through active stakeholder co-creation activities, ensuring the solution perfectly aligns with local social, aesthetic, and functional preferences. The available technical options include:

- Stabilized Ceramic Flooring: An entirely ecological and bioclimatic material offering a natural, earthen aesthetic. It provides a stable, highly water-permeable, and pedestrian-friendly finish that avoids the use of conventional concrete while maintaining exceptional longevity.



Figure 26. Stabilized Ceramic Flooring

- Cellular Grid Pavers (Recycled Interlocking System): A sustainable, eco-neutral paving solution manufactured from recycled interlocking grids (33 x 33 cm modules). This highly durable and flexible system supports three distinct infill options depending on the required use: a soil/turf mix for reinforced drivable green spaces, hardy succulents (sedum/moss) for ultra-low-maintenance greenery, or decorative aggregate (gravel) for high-traffic, heavy-duty permeable zones.

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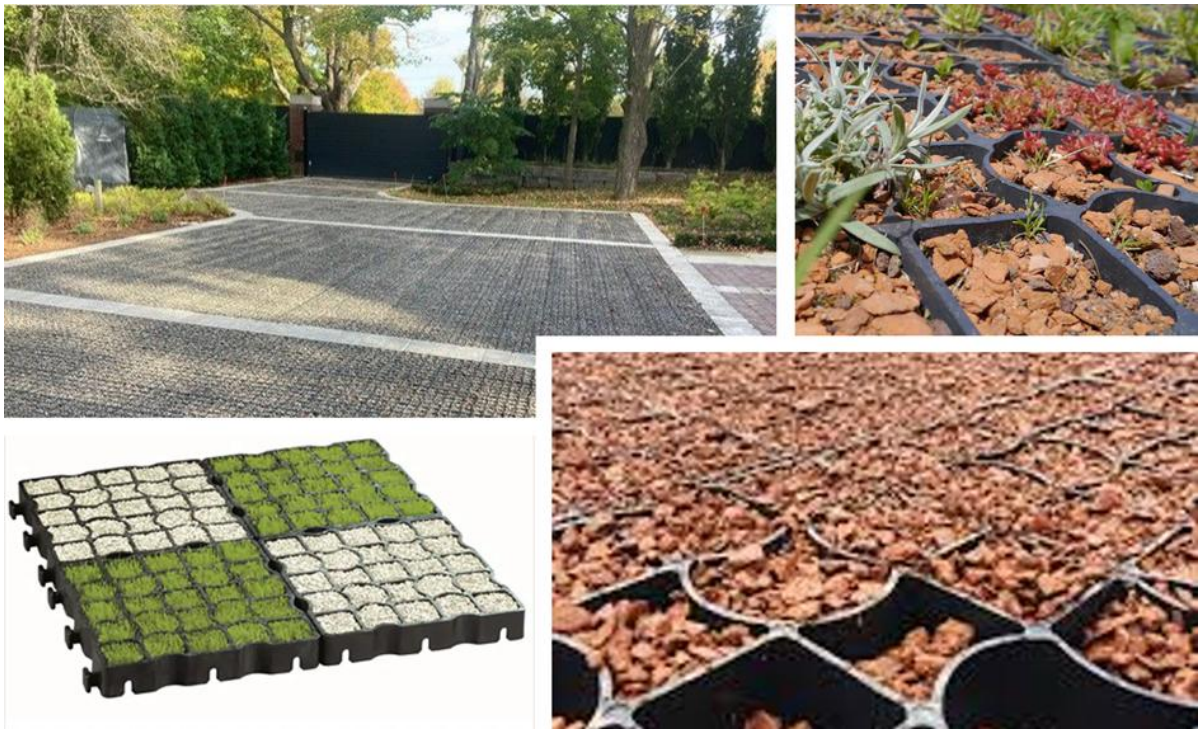


Figure 27. Cellular Grid Pavers (Recycled Interlocking System)

- Concrete Grid Pavers: A robust, traditional permeable paver option offering high structural stability and localized infiltration through integrated void spaces.



Figure 28. Concrete Grid Pavers

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Active Reuse and Failsafe Mechanisms:

- Active Subsurface Drip Irrigation: The stored 70 m³ volume serves as the central hub for an active reuse strategy. An integrated subsurface drip irrigation network extends from this reservoir to supply the surrounding tree clusters and planting beds, meticulously routed to avoid paved infrastructure.

- Overflow Pathways (Hydraulic Failsafe): To guarantee complete hydraulic safety during extreme, high-intensity precipitation events, an integrated subsurface overflow pipeline network is established. This failsafe mechanism automatically redirects any excess water volume beyond the design capacity back into the municipal drainage network (EYDAP), entirely mitigating surface flood risks.

6.2.6 Slope Drainage Control and Subsurface Diversion System

The main internal pedestrian pathway of the park exhibits a steep topographical gradient, generating high-velocity surface runoff during precipitation events. This unchecked flow consequently induces severe soil erosion in the downstream landscape. To effectively mitigate this issue, a specialized transverse interception trench is engineered across the pathway, functioning as a primary capture, detention, and infiltration node.

Technical Dimensioning and Material Configuration:

- Spatial Geometry & Excavation: The transverse trench encompasses a surface footprint of 5.5 m² with a precisely excavated depth of 40 cm.
- Subsurface Profile & Infiltration Matrix: The basal layer of the trench (accounting for 30 cm of the total depth) is backfilled with 1.7 m³ of highly permeable coarse gravel. This robust granular matrix serves as a localized, high-capacity reservoir, allowing for the rapid deceleration, temporary detention, and immediate infiltration of the intercepted runoff.
- Surface Paving (Permeable Finish): To ensure structural stability for pedestrian traffic without compromising hydraulic efficiency, the final top layer (the remaining 10 cm) is finished with Cellular Grid Pavers (Recycled Interlocking System). The void spaces of this eco-neutral modular grid are filled with fine gravel/aggregate, guaranteeing maximum surface permeability and a seamless aesthetic integration with the surrounding pathway.
- Hydraulic Conveyance and Failsafe: Once the intercepted runoff percolates through the granular matrix, the collected water is gravity-fed directly into an adjacent control manhole. This structure acts as the central hydraulic collection and regulation point. From this manhole, an integrated subsurface pipeline system conveys any excess water safely downstream, discharging it entirely outside the park boundaries into the municipal stormwater drainage network (EYDAP). This ensures complete erosion control and hydraulic safety, preventing any localized flooding across the park's topography.

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Figure 29. Example of vertical drainage path

6.2.7 Telemetry and smart monitoring

An integrated automation system will be implemented to ensure efficient monitoring and management of water resources and irrigation operations. The quality and quantity of harvested rainwater will be monitored remotely in real time through state-of-the-art IoT sensors, to enable data acquisition and system optimisation.

Furthermore, a weather station set in the site could be installed to collect real time accurate and site specific meteorological data, including precipitation, temperature, humidity, solar radiation, and wind parameters. These data will be utilised to optimise the irrigation and sustainability of the system.

Based on the collected environmental and soil data, a fully automated drip irrigation system will be designed to be deployed. The system will comprise of remote control units, electrically actuated valves, soil moisture sensors, and self-regulating emitters. Irrigation parameters will be adjusted according to the requirements of the vegetation and actual climatic conditions.

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7. Urban integration and landscape - Vegetation and new plants

7.1 Integration into the urban fabric

The design of the proposed solution emerged following a series of stakeholder interviews and interactions, which are presented in detail in Chapter 10. A central concern throughout the process was the need to respect and preserve the existing uses of the park—an urban green space historically claimed, shaped, and defended by local residents, the cultural association, and the surrounding neighborhood.



Figure 30. Picture taken from documentary: "History of the KAPAPS Park - 2017, Actions of the Association"

Given this long history of community advocacy, the current design of the park -and its everyday uses- are deeply intertwined with local identity and collective memory. As a result, residents are particularly cautious toward any proposed changes. The integration of Nature-Based Solutions must therefore be carefully designed to avoid disrupting existing activities. The grassy areas, for example, are essential for picnics, cultural events, informal play, and dog walking. Introducing extensive ornamental vegetation could reduce the park's usable open space.

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7.2 Landscape and spatial design considerations

With these considerations in mind, the rain garden was positioned in the northern section of the park, adjacent to the street—an area with limited current use in collective events, but well-suited for receiving stormwater. Its dimensions were selected to preserve sufficient open space, and its boundary is proposed as a 50-cm stone wall constructed with grey stones similar to those already present in the park.

From the rain garden, the bioswale follows the natural slope of the terrain, an area primarily used by dog owners. To maintain accessibility, the bioswale will be crossable at two points and planted with vegetation and large stones, avoiding loose pebbles that may be displaced.

The bioswale continues along an existing depression in the park's internal road, crossing it via an ecoraster or other permeable structure placed above modular underground tanks. These tanks will capture excess runoff that currently erodes the compacted-earth road, carving channels during heavy rainfall. Retaining and infiltrating water at this point will enhance both the park's resilience and its water management capacity.

The bioswale goes on a swale in the park's road, and then crosses this road with an ecoraster or permeable structure on underground modular tanks to absorb the excess water that may come through the compressed earth road. That water was carving the road, making a swale of its own in heavy rain, taking down structural materials. Storing and stopping the excessive rain, permitting it to be absorbed at the top of the road will be beneficial for the durability of the park as much as for water retention.

The water storage area is designed to be integrated under a paved area, which will become more permeable with ecoraster or similar materials. This approach avoids altering existing planted zones and maintains the park's familiar material palette and spatial organization, ensuring that the intervention remains compatible with current uses.

7.3 Planting strategy and green infrastructure

Vegetation plays a critical role in the overall performance of the system. Based on the vegetation design to be implemented, irrigation shall be enhanced, soil structure shall be improved, and infiltration capacity is expected to be increased. Root systems contribute to the formation of macropores within the soil, to improve permeability and to enable water movement towards deeper layers. At the same time, plant evapotranspiration supports the natural regulation of soil moisture, reducing waterlogging and maintaining optimal conditions for continued infiltration. Additionally, the use of drought-tolerant and native species reduces irrigation demand while ensuring system resilience under the particular Mediterranean climatic conditions.

The sloppy landscape would need underhill of the trees of small retention stones and mulch that would help keep the moisture close to the trees longer and reduce their need for water.

Some of the plants that can be used in the bioswale system for filtration are described below:

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Moisture and drought resilient perennials (core zone) Grasses & Grass-like Plants for filtration



Carex divulsa is a versatile plant that can be used as a ground cover on slopes, in meadows, and in large plantings. The plant is drought resilient once established but appears better with regular moisture. It tolerates a wide range of conditions, including heat and humidity, moist to boggy soils, clay, or sandy soils, and can naturalize in shaded areas under trees.



Juncus inflexus, commonly known as hard rush, is a perennial plant native to Europe, Asia, and Africa. It is a rhizomatous tufted perennial that typically grows 0.5 to 1 meter tall, with stiff, glaucous stems and small reddish-brown flowers. This plant thrives in wet places such as springs, marshes, and damp meadows, preferring heavy, base-rich or neutral soils. It is unpalatable to cattle and is eaten by rabbits, especially when grazing pressure is high. Juncus inflexus is also drought-tolerant and can be found in wet, boggy, sunny locations, making it a versatile choice for gardeners looking to add a unique and resilient plant to their landscape.



Papyrus is a versatile aquatic plant with historical, cultural, and ornamental significance. Its tall, tufted stems and rapid growth make it visually striking, while its historical uses highlight its importance in human civilization. Proper care involves ample water, sunlight, and warm conditions, and it can be propagated easily through rhizome division or seeds. Its environmental and aesthetic value makes it a popular choice for water gardens and ornamental plantings.



Iris pseudacorus, commonly known as yellow flag or yellow iris, is a vigorous, water-loving perennial with striking yellow flowers, ideal for wetland gardens but potentially invasive. Iris pseudacorus is toxic to pets and humans if ingested, causing mild gastrointestinal upset. Gloves and protective equipment are recommended when handling the plant. While generally non-life-threatening, veterinary advice should be sought if pets consume significant amounts. This species thrives in wet, humus-rich, acidic soils and is commonly found at the margins of ponds, streams, wetlands, and fens. It tolerates submersion, low pH, and anoxic soils, and can survive periods of drought due to its rhizomatous roots. It prefers full sun or partial shade.

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For a bioswale in a Mediterranean climate plants that can tolerate periodic flooding in winter and long dry periods in summer are needed. The most suitable species are those with high ecological flexibility and the ability to survive fluctuating soil moisture.

Transitional zone plants (ideal for bioswales) for alternating wet–dry conditions in bioswales



Festuca arundinacea, or tall fescue, is a perennial, cool-season grass valued for turf, forage, and erosion control, notable for its deep roots, drought tolerance, and clump-forming growth habit. It is known for its wide and hard leaves, rich, deep root system, and ability to keep its color all year round. The grass is extremely resistant to diseases and can withstand stepping on. It grows to a maximum height of 4-5 cm and is durable in various conditions. For optimal growth, the soil should be kept moist, and the cutting height should not exceed 3-3.5 cm after the first pruning.



Pennisetum alopecuroides, commonly known as fountain grass, is a graceful, clump-forming ornamental grass prized for its arching foliage and bottlebrush-like flower spikes. It is a warm-season perennial grass native to Asia and Australia, forming rounded clumps typically 70cm tall and wide, though some cultivars can reach up to 1.5m in height and spread. Pennisetum, although quite drought-resistant once established, needs regular watering during the first few weeks after planting. For plants that have taken root satisfactorily, water the pennisetum once a week in spring and autumn and twice a week in summer.



Achillea millefolium is a herbaceous perennial belonging to the Asteraceae family. It typically grows to a height of 0.2 to 1 meter and features fern-like leaves that are deeply dissected. The plant produces small, flat-topped clusters of flowers that can be white, pink, or yellow, blooming from March to October. Yarrow prefers well-drained soil and can tolerate poor conditions. Avoid overly rich or moist soils to prevent floppy growth. Full sun is ideal for optimal flowering and growth. Once established, yarrow is drought-tolerant and requires minimal watering.



Verbena bonariensis, commonly known as purpletop vervain, is a perennial herbaceous plant with upright, slender, square stems and small, lance-shaped, rough-textured, toothed dark green leaves. The plant typically grows 100–180 cm tall in a single growing season, with flowers on long stems that appear to float above the foliage. Its violet-purple, tubular flowers bloom from mid-summer to late autumn, forming compact clusters at the ends of stems. Verbena bonariensis prefers a sunny location with moderately fertile, well-drained soil. It tolerates drought, wind, and urban pollution, making it suitable for a variety of garden settings.

Also, aromatic and xerophitic plants can be used as they are resilient with low water demand.

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Mediterranean drought -tolerant Shrubs



Rosmarinus officinalis thrives in well-drained, sandy or stony soils with full sun exposure and is drought-tolerant. It can be grown as an upright, bushy shrub or trailing variety for ornamental purposes. Light pruning after flowering encourages a second bloom, and the plant is relatively resistant to pests, though it may be susceptible to powdery mildew in humid climates.



Lavandula, commonly known as lavender, is a genus of flowering plants in the mint family, known for its aromatic properties and ornamental value. These plants can be herbaceous perennials or small shrubs, thriving in well-drained soils and sunny conditions. They are known for their resilience to drought and poor soil. Lavender thrives in full sun and well-drained soil, preferring slightly alkaline conditions. Lavender is relatively low-maintenance, requiring minimal watering once established.



Thymus vulgaris, commonly known as common thyme or garden thyme, is a woody, aromatic perennial herb widely used in cooking, medicine, and ornamental gardening. Thymus vulgaris thrives in full sun and well-drained, sandy or rocky soils with a neutral to alkaline pH. It is frost and drought-tolerant, making it a low-maintenance herb suitable for herb gardens, rock gardens, borders, or as groundcover.



Salvia officinalis, or common sage, is a perennial, aromatic subshrub valued for culinary, medicinal, and ornamental purposes. Salvia officinalis is a perennial, evergreen subshrub. The plant typically grows to about 60 cm tall and wide, forming a compact, bushy clump. It thrives in sun-drenched, rocky hillsides and prefers well-drained, medium to dry soils, tolerating drought and poor soil conditions but not wet or poorly drained soils.

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8. Performance Assessment

The performance assessment of the proposed NBS system at KAPAPS Park evaluates its effectiveness in addressing key hydrological and environmental challenges under current and future climate conditions. The assessment focuses on three core dimensions: flood mitigation capacity, aquifer recharge potential, and overflow and stormwater management. These aspects are critical for determining the system's contribution to urban resilience, water circularity, and climate adaptation within densely built urban environments.

Indicative literature demonstrates that NBS such as rain gardens, bioswales, green corridors, and other low-impact development (LID) systems can substantially improve urban hydrological performance. Reported runoff reductions for rain gardens and similar bioretention systems typically range from 18–30% under standard design conditions (Widomski and Musz-Pomorska, 2025), while broader review indicate that reductions may reach 30-60% at the catchment scale and even higher at the site level, depending on design configuration and rainfall characteristics (Ahiablame et al., 2012; Fletcher et al., 2015).

With regard to the retention and capture efficiency, field-based studies indicate that well-designed rain gardens can fully manage up to 70% of rainfall events without overflow, particularly under low-to-moderate storm conditions (Burszta-Adamiak et. al., 2023). Similarly, bioswales have been shown to retain approximately 40% of incoming stormwater volumes on average, with significantly higher efficiencies reported in optimized or small-scale systems (Nandan H. Shetty, et. al., 2019).

Overall, the literature confirms that integrated NBS systems provide a robust and flexible approach to stormwater management of the cities that result in runoff reduction, peak flow mitigation, increased infiltration, and potential water reuse. Their performance, however, is dependent on the local conditions, such as soil characteristics, size and flexibility of the system, vegetation species, and rainfall patterns.

8.1 Flood mitigation capacity

The proposed NBS interventions at KAPAPS Park are designed to be a distributed circular system that will operate through a sequential configuration of components, composed of an initial rain garden for interception and pretreatment, a bioswale for conveyance, secondary treatment and infiltration, and a final subsurface water storage system for reuse for irrigation purposes of the park.

The system intends to intercept the runoff generated from the impervious surfaces such as roads and sidewalks. By diverting stormwater in a controlled retention pathway within the park, the system reduces the flows as well as the pressure on the existing stormwater drainage network, which is currently fragmented and does not cover most of the areas of the surrounding streets.

The primary flood mitigation mechanisms include:

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- **Temporary storage (detention)**: The rain garden basins provide short and longer term storage during rainfall events, reducing immediate downstream discharge volumes and delaying runoff propagation.
- **Peak flow attenuation**: Controlled release through infiltration and regulated overflow reduces peak discharge intensity, which is particularly critical during short-duration, high-intensity rainfall events typical of the Athens Mediterranean climate.
- **Runoff volume reduction**: A proportion of the captured runoff is either infiltrated into the subsurface or reused for irrigation, thereby reducing total effective runoff leaving the system.

Based on documented performance values from similar NBS applications in urban environments, runoff reductions in the range of 30–50% can be expected under moderate rainfall events (2–5 year return period). For higher intensity storms, while full retention is not feasible, the system still provides significant reduction of peak discharge rates and delay effects, contributing to reduced downstream flooding risk, where significant floods have been observed.



Figure 31. Example of rain garden

Overall, the integration of multiple NBS components transforms KAPAPS Park into a multifunctional flood regulation buffer, improving local hydraulic performance while enhancing the resilience of adjacent urban infrastructure. In addition, the system operates as a demonstration prototype, supporting replication and upscaling across similar high-density urban environments in Athens and the wider Attica region.

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8.2 Aquifer recharge potential

The proposed NBS system in the KAPAPS Park contributes to groundwater recharge by partially restoring natural infiltration processes that are otherwise suppressed in highly impervious urban environments. Nature-based systems enhance infiltration and evapotranspiration processes, contributing to partial groundwater recharge and restoration of the local hydrological balance (Widomski and Musz-Pomorska, 2025). While this represents modest aquifer recharge at a regional scale, it is highly valuable at the site and neighborhood level, especially in water-scarce environments such as Athens.

The bioswale and permeable soil layers within the rain gardens are specifically designed to facilitate infiltration through:

- Engineered soil substrates with high permeability
- Gravel drainage layers that promote vertical percolation
- Vegetation systems that enhance irrigation efficiency, improve soil structure, and increase infiltration capacity

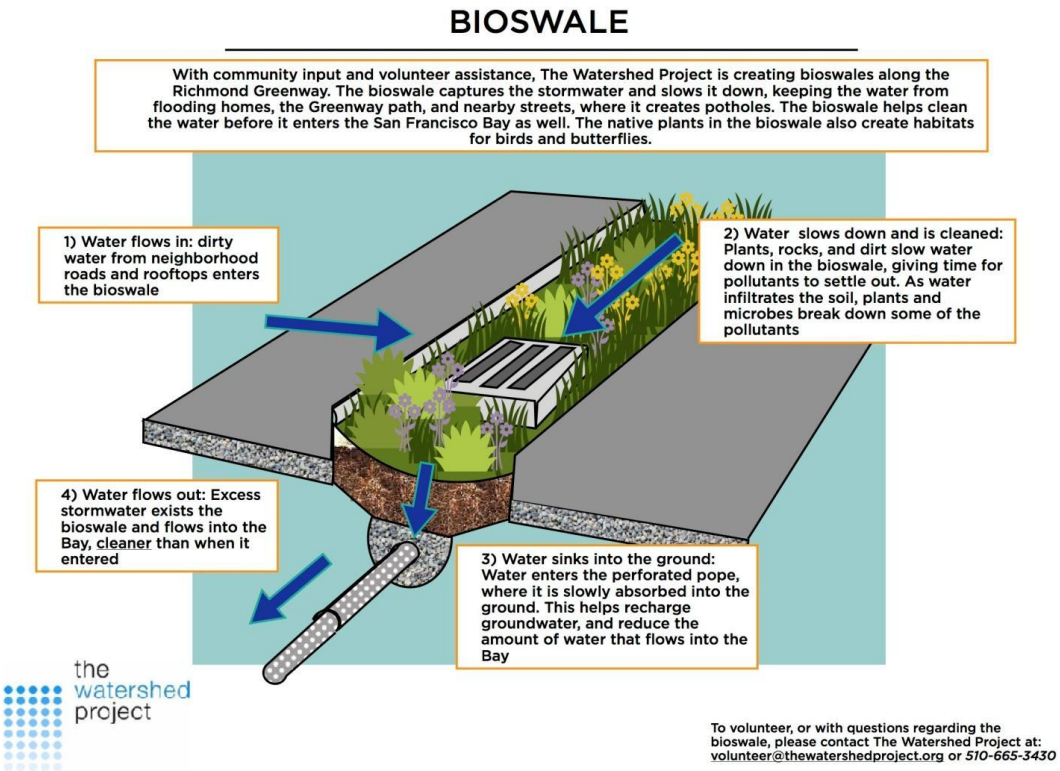


Figure 32. Example of bioswale

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Part of the incoming stormwater is directed into the subsurface through the design of the NBS system, and thereafter a gradual infiltration into the deeper soil layers is performed and, where conditions permit, the local aquifer is recharged.

Although the urban setting and the local geological conditions may constrain large-scale aquifer recharge, the system still provides significant benefits. Even partial infiltration contributes restore the natural water balance and improves soil moisture and vegetation, while reducing irrigation demand, particularly during prolonged dry periods typical of the Attica climate. In addition, increased infiltration reduces surface runoff volumes, and thus flooding events are prevented

8.3 Overflow and stormwater management

The NBS system is designed to retain, delay, treat, store and reuse rainwater, and also to manage effectively excess flows through controlled overflow systems during extreme rainfall events. Due to the variability and intensity of precipitation, the proposed system integrates a robust overflow mechanism to ensure safety, reliability, and sustainability of the system.

Stormwater is initially captured and pretreated before entering the first rain garden, where primary retention occurs. It is then conveyed through the bioswale, which facilitates further treatment and infiltration, before reaching the final water storage and recovery basin. This arrangement allows for the gradual management of runoff, while also ensures the performance and water quality.

To ensure the safe operation of the NBS system during heavy rainfall events, both the rain garden and the subsurface storage basin are equipped with controlled overflow outlets that activate when the storage capacity of each component is exceeded. In such cases, excess water is directed toward the existing drainage network at Trifyllias street through a new pipe that will be installed specifically for this purpose. In addition, a bypass component will be provisioned to divert flows away from the park during extreme events (e.g. a 10-year return period).

This approach ensures efficient performance of the NBS system by maximising retention, infiltration, and potential water reuse, while also maintaining a safe and reliable operation of the system during extreme conditions. In addition, this design takes into account future climate scenarios of rainfall variability and intensity, so as to support long-term urban resilience and sustainability of the intervention.

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9. Monitoring, control and operation

9.1 Monitoring Framework

The monitoring system to be installed in the framework of the NBS interventions at KAPAPS Park is designed to assess both the operation and performance of the system and to prevent any unexpected event. The primary objective is to ensure that the system manages effectively rainwater, facilitates infiltration, and supports vegetation.

The monitoring scheme focuses on measuring key parameters such as water flow in targeted spots (inlet, outlet of the basins), infiltration rate, soil moisture, as well as some quality parameters after treatment to assess water quality (pH, conductivity, turbidity). In addition, ecological indicators such as plant health, species establishment, and biodiversity presence are assessed to evaluate the long-term resilience of the system.

Data collection is performed by an online system but also field observations and periodic inspections are important to prevent any unexpected matter and to have a holistic qualitative and quantitative assessment of system performance.

9.2 Control systems and automations

The NBS system relies primarily on natural processes, control and automation systems can the enhance performance make the system more autonomous. In the KAPAPS pilot, control mechanisms may include water level regulation and overflow control points.

Low-energy sensors can be installed to monitor soil moisture and water levels within bioswales or retention areas, where applicable. These sensors can support decision-making regarding maintenance actions especially during extreme rainfall events.

9.3 System maintenance and operational considerations

The integration of NBS requires a paradigm shift from traditional aesthetic landscaping to the functional maintenance of green infrastructure. While bioretention practices may initially demand more labor during the establishment phase compared to traditional landscaped islands, the overall maintenance requirements significantly decrease over time. Furthermore, if planted with appropriate vegetation, these systems can ultimately consume fewer maintenance resources than conventional urban green spaces.

9.3.1 Pretreatment Infrastructure (Curb Inlets & EN 858 Separator)

Effective pretreatment is critical because it dramatically reduces the overall maintenance burden and prevents the downstream bioretention soil beds from clogging over time.

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- Inlet Inspection: Curb inlets must be inspected after the first major rain of the season, and subsequently on a monthly basis during the rainy season.
- Sediment Removal: Maintenance crews must routinely check for and remove accumulated sediment at the inlets to ensure unobstructed inflow.
- Separator Evacuation: The underground LDPE tanks (sludge trap and oil separator) require periodic vacuuming to remove accumulated inert solids and hydrocarbons, preventing catastrophic bypass into the bioswale.

9.3.2 Bioretention Elements (Hybrid-Rain Garden & Bioswale)

- Vegetation Management (Pruning & Weeding): Pruning must be executed 1 to 2 times per year to control vigorous growth and maintain the system's hydraulic capacity and flow rates. Miscellaneous upkeep, including spot weeding, trash collection, and plant health checks, should be performed monthly.
- Plant Replacement: Dead plant removal and replacement should be conducted annually. It is expected that up to 10% of the plants may die within the first year, though survival rates will increase as the system matures. Removing dead plants is also critical to eliminate nutrients that would otherwise leach back into the treated water.
- Irrigation & Fertilization: For the first 1 to 2 months of establishment, vegetation requires watering every 2 to 3 days; thereafter, watering is only needed sporadically during extreme drought. Fertilization must be strictly limited to a one-time spot application during the first year of vegetation establishment to prevent nutrient runoff.
- Hydraulic Media Restoration: Surface soil layers are highly susceptible to clogging over time in areas with excessive sediment loading. If stormwater ponding persists on the surface for more than 48 hours, it indicates severe sediment accumulation, and the top few inches of the filter media must be excavated and replaced to restore infiltration performance.
- Overflow & Outlet Clearance: Outlets must be inspected monthly during the rainy season to check for erosion and to proactively remove any mulch, debris, or sediment obstructing the overflow devices.

9.3.3 Subsurface Storage (Honeycomb) & Permeable Paving

- Cellular Grid Pavers: Maintenance primarily involves periodic mechanical or manual sweeping to remove fine silt and debris from the aggregate infill, preventing the sealing of the permeable voids.

- Honeycomb Reservoir: The subsurface storage array is virtually maintenance-free, provided that the upstream pretreatment (separator) and the biofiltration layers (rain garden/bioswale) are rigorously maintained to prevent fine silt from migrating into the geomembrane-lined chambers.

In the context of KAPAPS Park, maintenance is aligned with municipal park management routines, ensuring integration with existing operational frameworks. The system is designed to minimize

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maintenance requirements through the use of native, drought- and flood-tolerant vegetation and by relying on natural hydrological processes.

Overall, the monitoring, control, and operation strategy ensures that the NBS system functions efficiently under variable climatic conditions while maintaining ecological integrity. The approach combines simple technological support with nature-based processes, resulting in a robust, low-maintenance and adaptive urban water management system.

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10. Stakeholder engagement and co-creation

10.1 Introduction

To ensure that circular water solutions are context-sensitive, technically robust, and socially accepted, the analysis adopts a structured stakeholder engagement framework. This includes targeted interviews and interactive site meetings as well as participatory workshops aimed at fostering dialogue, strengthening collaboration and co-creating shared value among stakeholders. Such an approach promotes inclusive governance and supports joint decision-making processes at the regional level.

The scale of the project is relatively small, but still, the general stakes might be substantial as it is a pilot project for Nature Based Solution applications in the city. In that sense, a sudden negative reaction against the project might have important risks for the municipality, and exacerbate some tensions that already exist in the municipality but also between different stakeholders. For that reason, the engagement should be meaningful with an informed process and active participation by stakeholders.

According to "the Meaningful Stakeholder Engagement" by the Multilateral financial Institutions Group on Environmental and Social Standards (Kvam, R., 2019), the main principles of the engagement should be:

1. Start the process as early as possible, and create an ongoing process
2. Involve different categories of stakeholders
3. Make it equitable and non-discriminatory
4. It should be transparent and based on factual information
5. Give enough information to the stakeholders prior to their engagement
6. Consultation should be respectful and free of intimidation and coercion
7. Consultation process should be realistic and timewise
8. The process should be documented

10.2 Stakeholder mapping

The neighborhood called Ampelokipi belongs to the 7th Municipal Community of Athens, with elected president and community representatives, and has 3 Associations. The Ano Ampolokipi Cultural Association, which is a very active body and is located next to the park, an Athletic and Cultural Association, and another one further south called Center Ampelokipi Cultural Association.

The Ano Ampelokipi Cultural Association, founded in 1959, played a decisive role in advocating for the needs of the newly built district. Through sustained mobilization, the association contributed to the development of essential infrastructure such as roads, schools, and parks, while also promoting cultural activities and broader initiatives aimed at improving residents' quality of life.

The creation of the park itself was the outcome of decades of collective struggle. Demonstrations, petitions, legal actions, tree plantings, and public events were organized to demand the transformation

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of a 10-hectare vacant area into a public green space and to secure the adaptive reuse of the existing buildings.

Repeated interventions by the association and other local groups prevented the area from being developed for incompatible uses. Over the years, the municipality proposed various construction projects—including housing blocks, a parking facility, and a school—yet residents consistently mobilized to protect one of the few remaining green spaces in the district. Key milestones include the demolition of the buildings on Tryfyllias Street in 2006 to expand the green area, and the formal designation of the site as green space in the municipal plan in 2003.

The association continues to organize numerous cultural and community-building activities within the park, reinforcing social cohesion and collective stewardship. Its stated aims emphasize resident unity around shared concerns, good neighborly relations, and active civic engagement. Among its ongoing claims are the use of the public halls at Lakonos 9 and the establishment of a “friendship club” to support elderly residents.

The old buildings on the East side were given as a use to different organizations by the municipal authorities:

- To the cooperative Myrtillo, a self-sustaining business and educational Social Cooperative Enterprise of Inclusion, where all employees are jointly responsible for its sustainability. Currently 90% of the staff belongs to vulnerable groups.
- The Association for Childhood and Parenthood “our big home"
- Municipal libraries for children and toddlers
- Psychological support of the Athens Municipal Nursery

All those organisations are in immediate contact with the park and are more affected by floods, but also by any change in the park.

As for the City of Athens, the primary stakeholders involved in the project are the Vice Mayor of the Environment and Green Spaces, the Vice Mayor of Technical Services and Municipal Property and Digital Governance, along with their Departments. These roles are central to decision-making regarding urban infrastructure, environmental planning, and the integration of climate-resilient strategies within municipal policy. Their involvement is critical to ensure alignment, secure the necessary approvals, and facilitate the implementation of the proposed interventions.

At the level of local governance, stakeholders from the 7th Municipal Community play a key role in representing the interests of the neighbourhood. This group includes the President of the Municipal Community, as well as two to three elected councillors. To ensure political balance and inclusive representation, these councillors should include at least one representative from the governing party and one or more from opposition groups. Their participation is essential for maintaining transparency, political legitimacy, and responsiveness to local concerns.

In addition to institutional actors, local civil society organisations are key intermediaries in engaging the wider community. The athletic association and cultural associations with active youth departments are particularly relevant, as they provide structured access to younger population groups. These organisations can serve as representatives of local youth interests, ensuring that their perspectives and needs are integrated into the planning and design process.

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Finally, the media is also a key stakeholder group. Press representatives may be invited to cover key stages of the design and implementation process of the interventions at the KAPAPS Park. This can contribute to transparency, increase public awareness, and support the broader dissemination and the public engagement with the concept and the benefits of the interventions.

In the design phase, the stakeholder mapping is registered in Annex I.

10.3 Engagement processes

A series of targeted engagement activities have been carried out to support the design and implementation of the proposed NBS interventions at the KAPAPS Park. These activities combined technical coordination with participatory processes, aiming to ensure both feasibility and local acceptance. Below, a summary of the main engagement activities is provided in Table 3.

Table 2. Summary of the main engagement activities

Engagement Activity	Description
Small-group meetings	Meetings held with the competent vice mayor, the cultural association, and the cooperative. Preliminary drawings were presented, the design concept was explained, and stakeholders were interviewed about park problems, uses, and opportunities.
Stakeholder interviews	Conducted to understand needs, concerns, and expectations regarding the proposed interventions.
Upcoming workshop	A broader workshop will be organised to include additional stakeholders identified through the stakeholder-mapping process.

Small-Group meetings and technical coordination

A number of small-group meetings were organised involving both technical experts and key local stakeholders. On the technical side, regular coordination meetings were held with the design teams to initiate the design, review progress, align specifications, and ensure that the proposed solutions are technically feasible and consistent with project objectives.

In parallel, multiple meetings were conducted with representatives of the Directorate of Green Spaces and Urban Fauna of the City of Athens, including the Head of the Directorate, the responsible person for the parks of the particular Municipal Community, as well as other members and representatives of the particular Directorate. Additional local stakeholders were also actively involved, such as the Cultural Association of Ano Ampelokipi, the owner of the café Myrtillo, as well as representatives of local enterprises and facilities. As a milestone of the process, a more integrated meeting was organised by the

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Vice Mayor for Environment and Green Spaces, with the active participation of the local Cultural Association of Ano Ampelokipi, and the engineering team responsible for the system's design. During this meeting (Figure 33) several key aspects were discussed and important matters were identified to be included in the final design. It was also agreed to hold a more open community workshop, aimed at presenting the NBS pilot to its end users and further engaging the local community.

During these meetings, preliminary design drawings were presented and the overall concept of the interventions was explained. Stakeholders were invited to share their perspectives on current park conditions, everyday uses, and existing challenges, as well as to identify opportunities for improvement.



Figure 33. Stakeholder engagement meeting - sharing current design status and receiving feedback

Overall, the feedback received was positive, with stakeholders expressing general support for the objectives of the project. Furthermore, several constructive recommendations were proposed, particularly regarding the siting and location of specific interventions. These inputs have been taken into account and have already been integrated in the design, to ensure a broadly accepted and sustainable solution.

Stakeholder Interviews

In addition to the group meetings, several targeted stakeholder interviews were conducted to gain deeper insight of the needs, concerns, and expectations of different end user of the park. These interviews focused on discussions of specific issues, including accessibility, usability of space, and potential disruptions during the construction phase. A general comment was to ensure that the construction of the interventions would be limited in terms of duration in the field so that all the works would be coordinated from before.

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Participatory Workshop

As a next step, a more open participatory workshop was organised at the local level to further expand stakeholder engagement and address any concern. This workshop involved a wider range of participants, including residents and additional community members that were invited by the local Cultural Association of Ano Ampelokipi.



Figure 34. Stakeholder engagement workshop - sharing updated design and receiving feedback

The objective of the workshop was to present the updated design of the proposed NBS interventions, to validate the changes made based on earlier feedback and discussions, and to facilitate an open dialog among stakeholders. It also served as an opportunity to strengthen community acceptance for the project and ensure that the final interventions reflect local needs and expectations.

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11. Regulatory framework and permitting

The implementation of Nature-Based Solutions within urban public space requires strict compliance with the national regulatory framework governing construction, land intervention, and municipal infrastructure works. Given that the proposed interventions combine landscape modifications with technical infrastructure (e.g., drainage systems, bioswales, rain gardens, and underground storage tanks), the project falls within a hybrid category of civil and environmental works. As such, multiple legal instruments and permitting pathways apply, alongside approvals from relevant municipal departments.

11.1 Applicable legal and regulatory framework

The regulatory basis for the proposed interventions is primarily defined by three key legislative instruments:

- **Law 4495/2017** – Control and protection of the built environment. This law establishes the overall framework for construction control in Greece. It categorises building and technical works according to their scale and complexity, and defines the permitting procedures required for each category. Of particular relevance is the provision for **Small-Scale Construction Permits - (EEMK)**, which apply to minor works that do not significantly alter building volume or structural integrity but still require regulatory approval. The law also outlines exemptions for very limited interventions like stairs, ramps, buttresses and terraces in uncovered areas of plots and fields and ground shaping up to 0.80 m. from the natural ground for the purpose of improving its natural relief, using natural loose materials, such as soil and masonry without mortar, without altering its general natural geomorphology, the natural slope of rainwater runoff and the starting stations for measuring altitudes.
- **Ministerial Decision Y.A. FEK 1843/B` 13.5.2020 – Definition of Small-Scale Works**. This decision provides a detailed catalogue of documents required by the Small-Scale Construction Permit.
- **New Building Regulation (NOK – Law 4067/2012)**. The NOK defines fundamental concepts such as “technical installations”, “landscape interventions” and “underground constructions”. This distinction is critical for the classification of project components. For instance, rain gardens and bioswales are generally considered landscape interventions, while underground water storage systems may be classified as technical infrastructure. The law therefore plays a decisive role in determining whether a Small-Scale Permit is sufficient or whether a full Building Permit is required.

11.2 Required permits and approvals

Based on the nature of the respective interventions different permitting pathways apply depending on the type of work.

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Landscape and surface interventions

Works such as earthworks, bioswales, rain gardens, permeable channels, and surface drainage modifications are generally classified as landscape interventions. Such interventions are relatively low-impact in structural terms, and do not require formal approval due to the small changes in soil levels, drainage patterns, and public space configuration.

Underground infrastructure (water tanks or retention systems)

Underground tanks or storage systems are classified as technical infrastructure under the NOK framework. Their permitting requirements depend on factors such as size, depth, structural load. A **full Building Permit** may be required where structural calculations, reinforced excavation works are to be done, but even with only a precast water tank.

In all cases, the following municipal approvals are required:

- **Municipal Green Spaces and Urban Fauna Directorate:** responsible for assessing impacts on vegetation, landscape design, and ecological integration.
- **Municipal Technical Works Directorate:** responsible for evaluating structural feasibility, drainage design, and construction safety.
- Additional coordination may be required with other municipal departments depending on site-specific constraints.

Building Permit – Requirements

The permit is required because the works include:

- Earthworks
- Landscape restructuring and planting
- Installation of drainage layers, infiltration systems, and permeable substrates
- Minor civil works associated with water management infrastructure

The documentation package typically includes:

- Topographic survey of the intervention area - compilation of an updated topographic plan
- Landscape design plan
- Technical description of the interventions
- Cross-sections and construction details
- Excavation plans
- Health and Safety Plan
- Approval and technical opinion from the Directorate of Green Spaces and Urban Fauna

This documentation ensures that the intervention is technically sound, environmentally compatible, and compliant with municipal planning objectives.

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Additional approvals and governance requirements

Depending on the scale and visibility of the intervention, further institutional approvals may be required:

- Municipal Green Spaces and Urban Fauna Directorate approval: for landscape integration, planting design, and ecological compatibility
- Municipal Technical Works Directorate approval: for structural and engineering validation
- Municipal Council approval: required when the intervention:
  - ✓ Alters the functional layout of a public park
  - ✓ Introduces new permanent infrastructure elements
  - ✓ Modifies circulation patterns or public use zones

Construction supervision

During implementation, construction activities must be supervised to ensure compliance with approved designs and regulatory conditions. Supervision is typically carried out by:

- Municipal engineers, or
- Appointed external technical supervisors under municipal oversight

This ensures adherence to approved plans, quality control of materials and execution, and compliance with safety and environmental standards throughout the construction phase.

Overall, the regulatory framework ensures that the proposed Nature-Based Solutions are implemented in a controlled, legally compliant, and technically robust manner, balancing environmental innovation with public safety and urban governance requirements.

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12. Replicability and upscaling potential

The Nature-Based Solutions (NBS) interventions implemented at KAPAPS Park are conceived not as a site-specific landscape upgrade, but as a modular and transferable urban water management system. Their design logic—based on distributed bioswales, vegetated infiltration zones, and gravity-driven stormwater routing—supports both replication in similar urban contexts and upscaling at the district or city scale. This chapter evaluates the conditions under which the system can be transferred to other areas and the key parameters that govern its adaptability.

12.1 Potential for replication in other urban areas

The KAPAPS NBS system is particularly suitable for replication in dense Mediterranean cities such as Athens, where stormwater management challenges are closely linked to high surface impermeability, limited drainage capacity, and strong seasonal rainfall variability. The intervention strategy is based on small-scale, distributed landscape units rather than centralized infrastructure, making it inherently adaptable to a wide range of urban typologies.

Replication potential is highest in:

- Public parks and green spaces undergoing regeneration
- Schoolyards and institutional open spaces with available soil surface
- Roadside verges and linear urban corridors
- Underutilised or residual urban land with partial permeability

The system's modularity allows bioswale units to be inserted independently or in series, depending on available space and hydrological requirements. Each module operates as a self-contained micro-drainage cell, capable of intercepting runoff, temporarily storing water, and promoting infiltration before overflow discharge to the conventional drainage network.

A key advantage of this approach is that it does not require full-scale redesign of existing urban drainage infrastructure. Instead, it operates as a complementary layer, reducing peak runoff loads and enhancing local water retention capacity.

12.2 Transferability conditions

A key aspect of the design of the NBS system is that it has been conceptualised as a highly adaptable system, flexible, extendable and transferable to other urban contexts.

First, these include the climatic and hydrological conditions of a site, which means that the design is suitable and can be adopted by any site of Mediterranean climates characterised by high intensity rainfall events and prolonged dry periods. Transferability is therefore most effective in regions with similar precipitation patterns. In wetter climates, adjustments to storage and overflow capacity may be needed,

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whereas in arid climates, greater emphasis must be given toward infiltration and more resilient vegetation.

Second, the soil conditions of the site are a critical parameter for the system performance. The particular bioswale design assumes moderate infiltration capacity that prevents prolonged waterlogging. In cases of low permeability soils, some amendments in the soil layers may be required to ensure functional infiltration. Conversely, in highly permeable soils, additional retention measures may be necessary to maintain sufficient infiltration rates.

Third, spatial and urban morphology constraints must also be considered, as the NBS system relies on adequate gradients to facilitate gravity flow and requires sufficient linear space to develop a functional flow for the treatment processes. Even narrow corridors can be utilised, provided that there is continuity and enough slope to ensure appropriate retention time. However, very steep or flat terrain may limit full replication without adaptations on the design.

Finally, the matter of maintenance activities is a critical factor for transferability. The system is designed to be integrated into the municipal urban green management departments. Successful replication depends on aligning responsibilities between operators of the system and urban green space departments.

12.3 Upscaling potential

The potential of upscaling and replicating the particular NBS system of the KAPAPS Park is strong as the entire design has been conceptualised to be generic, flexible and adaptable based on the spaces that would be available in each site. This concept can be expanded and upscaled in the particular park to collect more volumes of rainwater and increase the capacity of storage and cover more irrigation needs or it can be adapted and implemented into a different park with similar needs and characteristics in terms of surface runoff.

At a more regional scale, this can result in a “sponge city” effect, where again the main concept is that rainfall is intercepted, the surface runoff delayed, and partially infiltrated, or even stored to be reused for irrigation. The general upscaling potential focus on:

- Reduction of peak discharge volumes that enter drainage systems
- Low risk of localised flooding during storm events
- Improved groundwater recharge potential
- Increased urban green vegetation irrigated by the NBS system

Upscaling is not dependent on replicating exactly the same design but rather a consistent design concept of a configuration that can be adapted to similar situations: interception at source, distributed storage, controlled overflow, and reusing rainwater for non-potable uses. This allows the system to be adapted across diverse urban conditions with the necessary adjustments.

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Furthermore, the implementation of such systems can provide a foundation for distributed urban water management solutions at a larger scale, that support the gradual transition from conventional linear water management practices to more integrated, resilient, and circular approaches.

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13. Conclusions

This deliverable presents the detailed design for the implementation and assessment of a particular Nature-Based Solutions (NBS) system for water recovery, reuse and flood mitigation within the urban context of Attica, with a specific focus on the pilot application at the KAPAPS Park in Athens. This study practically contributes to the transition towards a circular and resilient water management approach that addresses both current and future challenges linked with water scarcity and urban floods.

A key conclusion of this work is that water management in dense urban environments such as Athens requires a paradigm shift from conventional, linear approaches toward integrated and circular systems. As highlighted in this report, a significant portion of rainfall in the city is currently lost as surface runoff, contributing to increased flood risk. Furthermore, this source of water is a missed opportunity for local water reuse for non-potable uses. The proposed NBS interventions demonstrate that it is both technically feasible and environmentally and economically beneficial to capture, retain, treat, and reuse stormwater at the local scale and reduce dependency on potable water resources.

The analysis confirmed that water NBS systems such as rain gardens, bioswales, permeable surfaces, and subsurface storage systems, can mimic natural hydrological processes, reduce runoff volumes and peak flows, enhance infiltration and aquifer recharge, and and improve water quality through natural treatment mechanisms. These systems also enable the reuse of collected rainwater for non-potable applications, such as irrigation of urban green spaces, which is particularly critical in Mediterranean climates with prolonged dry periods and high seasonal water demand.

The case study of KAPAPS Park illustrates how such interventions can be successfully integrated into existing urban spaces despite the complexity of surrounding uses and operations and be a part of the entire ecosystem. Beyond their hydrological performance, the proposed solutions contribute also to other aspects such as flood mitigation, enhanced vegetation health, and improvements to the quality of the public space. Therefore, the particular NBS system acts not only as water management measures but also as a valuable demonstration project that promotes public engagement towards climate adaptation.

An important innovative element of the study is the integration of the “fit-for-purpose” approach, in which the water quality requirements are matched to specific water uses. By assessing the water quality parameters of collected rainwater, the study highlights the potential to safely substitute potable water with reclaimed sources for applications such as irrigation. This approach is fully aligned with European and national regulatory frameworks and represents a key paradigm for scaling up water reuse practices in urban environments.

The study has also investigated the capacity of the proposed NBS system to contribute to flood mitigation and local water availability. However, it underscores certain limitations of the NBS interventions. First, they depend on site-specific conditions (such as soil infiltration rate and available space), and they might have reduced performance under extreme rainfall events. These findings highlight the importance of integrating NBS within a broader strategic plan to ensure a more holistic and upscaled approach.

Another critical aspect addressed in this study is the role of monitoring during the operation phase, and the maintenance challenges of the NBS system. The sustainability of NBS depends not only on their design but also on their proper management, including regular maintenance as well as monitoring of the system performance to avoid any unexpected event. Establishing clear operational frameworks and responsibilities is therefore essential to ensure a long-term sustained operation.

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Stakeholders' engagement was also identified as a key component for the successful implementation of the NBS interventions. As indicated in the stakeholder analysis, the involvement of local authorities, water utilities, experts, the local community and end users is crucial for aligning the technical solutions with the actual needs and constraints. This process is important for public acceptance to ensure long term sustainability of the interventions. The THESEUS project, through co-creation and engaging activities, has demonstrated the value of developing interaction with the interested parties and the end users.

From a regulatory perspective, the analysis highlights the actual requirements and the existing gaps within the current legal framework. While European directives and national regulations provide a solid basis for water reuse and sustainable water management, further clarification and simplification of permitting procedures may be required for deploying NBS system at an urban environment.

The deliverable also emphasises the strong potential for replicability and upscaling of the proposed solutions. The flexible and transferrable nature of NBS allows them to be adapted to a wide range of urban contexts, from small neighbourhood interventions to city level plans. Lessons learned from the KAPAPS pilot can inform similar applications across Athens and other Mediterranean cities facing similar climatic and urban challenges. In this regard, NBS can play a key role in formulating future urban plans that promote decentralised circular water management systems.

Following the comprehensive analysis of implementing NBS in the urban environment, certain limitations have been identified, primarily related to data availability and uncertainties from the design to the implementation phase. In particular, gaps in maps and plans may affect the accuracy of the siting of the interventions as during the excavation phase some unexpected events may occur.

In conclusion, this deliverable demonstrates that Nature-Based Solutions offer a viable, integrated and circular approach to address the complex challenges of urban water management in Attica. By combining water recovery, reuse, flood mitigation, and environmental enhancement, NBS contribute to the creation of a more sustainable and resilient urban environment. Their successful implementation, however, requires a holistic approach that brings together technical expertise, regulatory alignment and stakeholder engagement.

Ultimately, the transition towards circular water management is not only a technical challenge but also a strategic and societal one. By embedding NBS into urban design and planning processes, cities like Athens can move towards a more adaptive and resource efficient future with the aim of improving the quality of life for their residents.

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Annexes

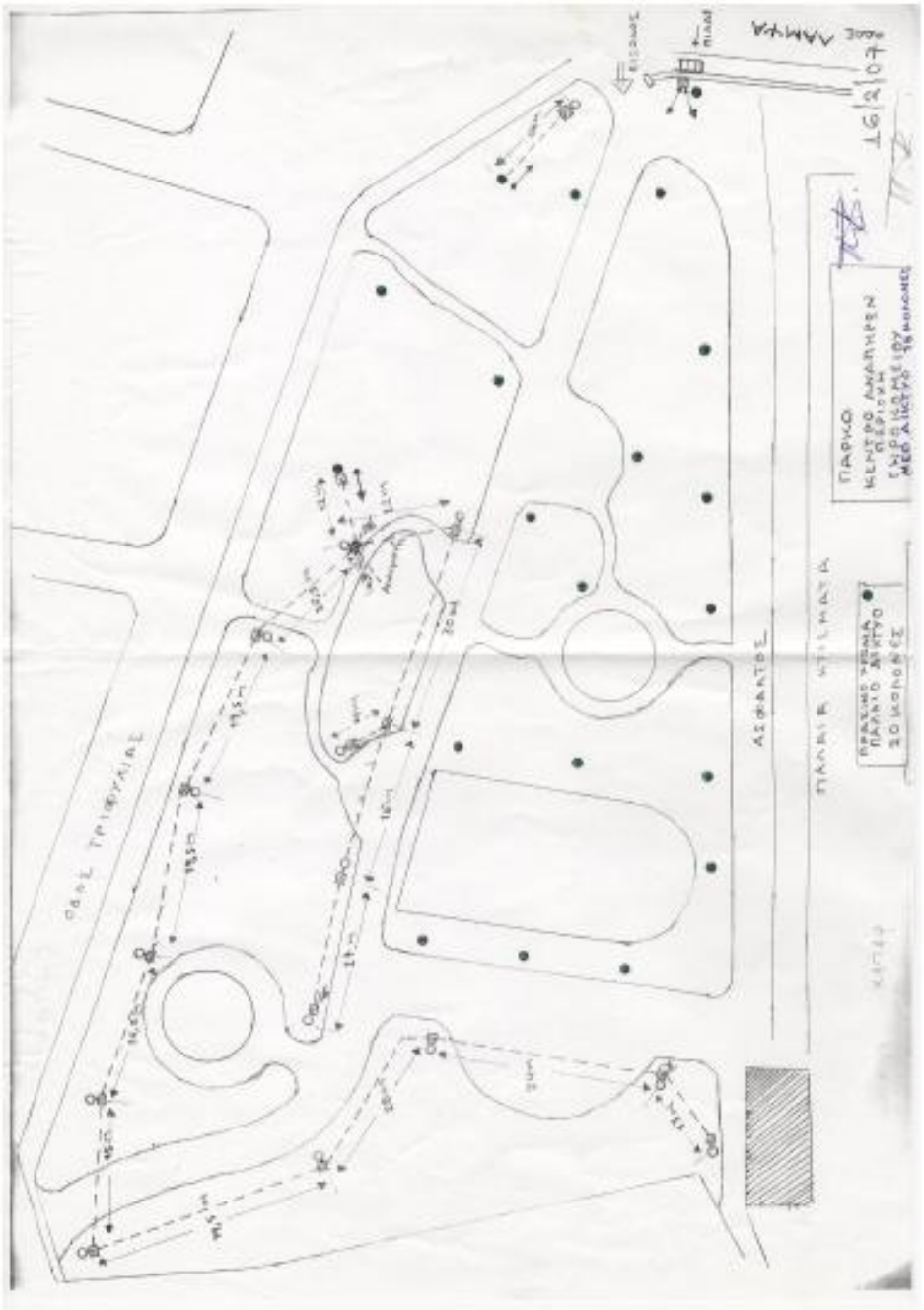
Annex I Stakeholders mapping

Categories	Clubs
Youth organizations	Athletic Cultural Club 'OI AMPELOKIPOI'
Civil society leaders	Cultural Association of Ano Ampelokipi
Civil society leaders	Cultural Environmental Association of the Center of Ampelokipi
	Businesses
Businesses	COOP Myrtillo
	Municipality's organizations
Organization	Association 'Childhood and Parenthood, our big home'
Municipality organizations	Infant - Toddler Library of the Municipality of Athens
Municipality organizations	Children's Library of the Municipality of Athens
Municipality organizations	Athens Municipal Nursery - Psychological Support Department
Municipality organizations	7 D.K. LAMPSA A (Kindergarten) Head Dimtsia Sofia'
Municipality organizations	7 D.K. LAMPSA B (Infant) Head Rigopoulou Athanasia'
Municipality organizations	Friendship Club of Ampelokipi
	7th MUNICIPAL COMMUNITY OF THE MUNICIPALITY OF ATHENS
City leadership	Zacharopoulou Athanasia (President)
City leadership	Avgerinos Emmanouil (Athens Now)
opposition	Gourgiotou Georgia (Open City)
opposition	Raptakis Vasilios (Athens Popular Unity)
opposition	Pappas Athanasios (Free Athenians)
	Municipality of Athens
City leadership	Vice Mayor of Environment and Green Spaces Georgios Apostolopoulos
City leadership	Deputy Mayor of Technical Services Panagiotis Charlaftis
City leadership	Deputy Mayor of Urban Revitalization and Resilience (Maro) Evangelidou
Internal champions within city government	Nikos Chrysogelos, Mandated Municipal Councilor for the Climate Covenant, responsible for supervising and coordinating the actions of the Department of Resilience and Sustainability of the Directorate of Strategic Planning, Resilience, Innovation, and Documentation

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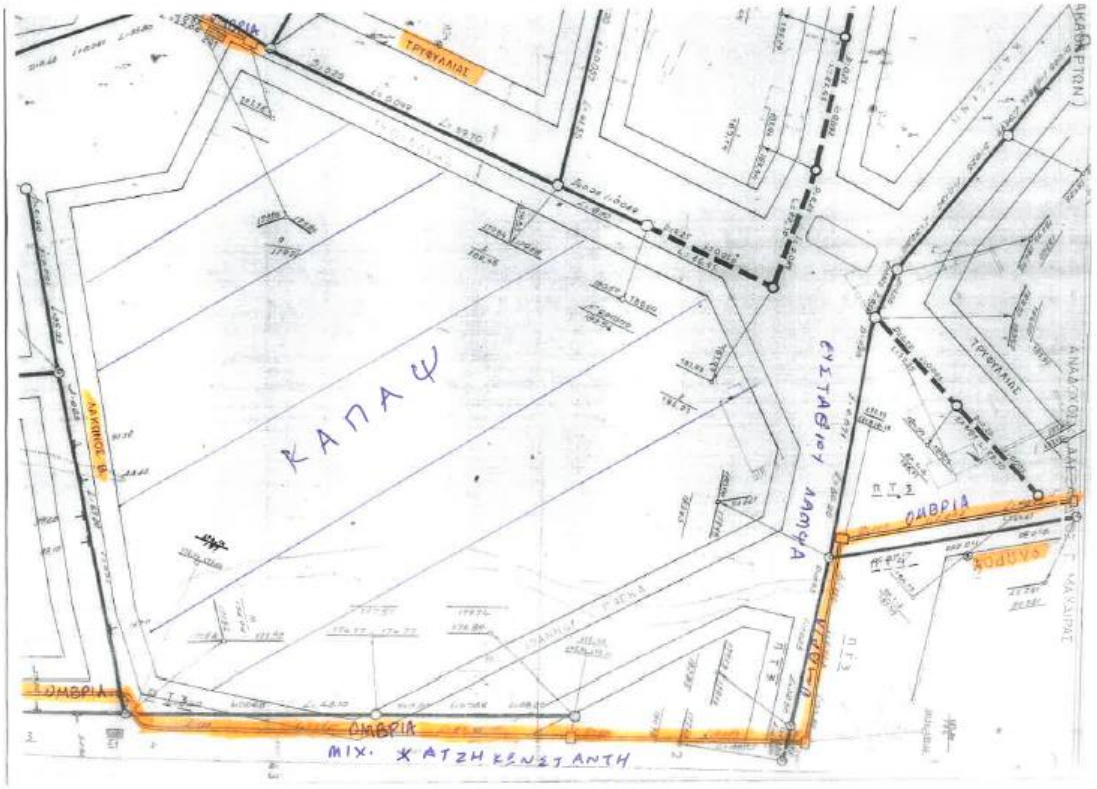
Annex II Electrological Plan



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Annex III Rainwater sewage network



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