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Stormwater management by nature-based techniques in "La Mandria" Park. Proposals and outcomes.

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Abstract

This thesis investigates natural-based stormwater management in Parco La Mandria, focusing on mitigating the impact of recurring flood events, notably in 1994 and 2000, which were exacerbated by the Stura Di Lanzo and Ceronda rivers. The research adopts a comprehensive mixed-methods approach, integrating observational techniques, secondary data analysis, and Geographic Information System (GIS) mapping. Data were sourced from municipal records, a project conducted by a private company, and geoportal maps to ensure a robust and multi-faceted analysis. Furthermore, the evaluation of the sewer system's capacity was conducted using precipitation data, specifically Design Rainfall (DR) and Recorded Rainfall (RR). This assessment was crucial for creating efficient water pathways from the sewer system. Additionally, this effort aligns with the incorporation of the United Nations Sustainable Development Goals (SDGs). Three specific areas within the identified flood-risk zones, as determined by flood-risk maps from GEOPORTALE, were selected for detailed study. These areas were chosen based on their varying land uses and their susceptibility to flooding, providing a diverse set of conditions to test the effectiveness of different stormwater management strategies. The study evaluated three distinct scenarios: the existing natural and current conditions, the application of Low Impact Development (LID) controls, and an optimized version of the LID scenario, which was refined based on financial feasibility and practical implementation considerations. The primary objective was to increase permeable surfaces, thereby enhancing the area's capacity to absorb and infiltrate stormwater, and ultimately reducing surface runoff and mitigating flood risks. Results from the study indicated a significant improvement in stormwater infiltration and a corresponding reduction in runoff across the selected areas. In the industrial area, the implementation of LID controls led to an increase in infiltration by 46.89 mm, with a total runoff measured at 63.85 mm. The Fiat testing track area exhibited exceptional performance of LID controls, with infiltration rates surpassing runoff rates, recording 86.89 mm of infiltration compared to 36.14 mm of runoff. Conversely, the residential area faced limitations due to existing land use and restrictions imposed by private property, resulting in a more modest increase in infiltration (34.85 mm) and higher runoff (107.64 mm).

These findings underscore the significant potential of natural-based solutions for effective flood risk mitigation. They highlight the necessity for tailored approaches that consider the specific land use and contextual constraints of each area. The study emphasizes the importance of integrating financial and functional considerations into the design and implementation of

stormwater management strategies to enhance urban resilience and sustainably manage stormwater in flood-prone regions.
Keywords: stormwater management model, Low impact development, natural-based solution, flood risk mitigation, Sustainable Development Goals, geography information system, permeable surfaces.

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Contents

Glossary of terms

Storm Water Management Modelling	SWMM
Low Impact Development	LID
Curve Number	CN
Design Rainfall	DR
Geographic Information System	GIS
Digital Terrain Model	DTM
Open-Source Map	OSM
Parco la Mandria	PLM
Environmental Protection Agency	EPA
Sustainable Development Goals	SDGs
Liter Per Second	LPD
Green Infrastructure	GI
Natural based	NB
Hectares	ha
Square meter	m^2
Urban Heat Island Effect	UHIE
Rain Garden	RG
Bio-retention cells	BRCs
Roof Garden	RG
Permeable Pavement	PP
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
Stormwater Management	The management and utilization of stormwater runoff aim to mitigate flooding, enhance water quality, and safeguard ecosystems.
Ecosystem services	Advantages offered by natural environments include clean water, improved air quality, and recreational opportunities.

Chapter one

Introduction

Introduction

The first chapter of this thesis provides an in-depth analysis of the context in which stormwater management by nature-based techniques is relevant to "La Mandria" Park. It begins by describing the park's ecological characteristics, including its hydrological patterns, vegetation, and wildlife. This analysis sets the foundation for understanding the specific challenges and vulnerabilities faced by the park in terms of stormwater management.

One of the most important environmental problems that metropolitan areas today are dealing with is stormwater runoff. The amount and quality of stormwater runoff have historically been managed using traditional stormwater management systems including underground storage tanks and pipes, which have proven to be costly and frequently ineffectual. Furthermore, there are no additional environmental advantages or services offered by these conventional methods.

The negative effects of urbanization and climate change on the environment and human settlements are greatly reduced thanks to stormwater management. There is an urgent need for creative and sustainable solutions to deal with the problems brought on by growing stormwater runoff as metropolitan areas continue to grow. The ability of nature-based techniques to integrate biological systems with urban infrastructure has attracted a lot of interest in this area.

Objectives of study

This thesis focuses on stormwater management through nature-based techniques in the context of "La Mandria" Park, a renowned natural reserve located in [Viale Carlo Emanuele II, 256, 10078 Venaria Reale TO]. These techniques offer numerous environmental benefits, such as improving water quality, increasing biodiversity, and reducing the urban heat island effect. The park's unique natural setting, encompassing diverse ecosystems and a rich biodiversity, provides a compelling opportunity to explore and implement nature-based solutions to mitigate stormwater-related issues.

Stormwater management involves the regulation and utilization of surface runoff resulting from precipitation events, including rain and snow. Effective management of stormwater is crucial in both urban and natural settings to mitigate the risks of flooding, erosion, and water pollution. The fundamental objective of stormwater management is to replicate the natural hydrological cycle, where rainwater infiltrates the soil, is absorbed by vegetation, and gradually recharges groundwater reserves. However, this natural process is frequently disrupted in urban areas due to the widespread presence of impervious surfaces such as roads, rooftops, and parking lots, which hinder water infiltration into the ground.

Therefore, the purpose of this thesis is to evaluate the effectiveness of nature-based stormwater management techniques in an urban area. Specifically, the study will analyze the performance of these techniques in terms of their ability to manage stormwater runoff and improve water quality. The study will also compare the effectiveness of nature-based techniques to the current situation without the intervention of different methods.

Urban planners, engineers, and policymakers who are interested in putting sustainable stormwater management strategies into practice will find the study's conclusions useful. The study will also add to the expanding body of knowledge about natural methods and their potential to solve urban stormwater management problems.

The problem statement section of this chapter articulates the specific issues that require the detection of nature-based techniques for stormwater management in "La Mandria" Park. These issues may include a variety of environmental and ecological problems caused by the implementation of conventional stormwater management strategies.

stormwater that accumulates on impermeable surfaces like streets, parking lots, and roofs causes stormwater runoff, which is then directed into stormwater drainage systems. The runoff may pick up pollutants like oil, fertilizer, and germs as it passes through these systems, which might be detrimental to the environment and public health.

Traditional stormwater management techniques, such as detention basins and underground storage tanks, were developed to manage the quantity of runoff by capturing and slowly releasing it into the environment. However, these techniques are often expensive and require significant maintenance, and they do not address the quality of the runoff or provide any additional environmental benefits.

Nature-based stormwater management techniques, on the other hand, mimic natural processes to manage and treat stormwater runoff. These techniques can include green roofs, rain gardens, bioswales, and other green infrastructure practices that allow water to infiltrate into the ground or be absorbed by vegetation.

Nature-based techniques offer a multitude of environmental benefits besides their capacity to manage stormwater runoff. One illustrative instance is the employment of green roofs and walls to mitigate the urban heat island phenomenon. This phenomenon refers to the significant elevation in temperature of cities compared to their surrounding rural areas, resulting from the accumulation of buildings and pavements. Vegetation, including plants and trees, has the inherent capacity to capture and store atmospheric carbon dioxide and various types of pollutants, thereby potentiating the enhancement of air quality.

Furthermore, this section explores the theoretical framework that makes the research approach outlined in this proposal. It explores the principles and theories of nature-centered solutions, emphasizing their potential advantages in managing stormwater. The theoretical framework also integrates ideas from landscape architecture, hydrology, urban ecology, and sustainability, offering a comprehensive methodology for evaluating and designing nature-based strategies.

This study will provide valuable insights into the effectiveness of nature-based stormwater management techniques in an urban environment. By evaluating their ability to manage stormwater runoff and improve water quality, you can contribute to the growing body of research on sustainable stormwater management practices. Finding stormwater management through nature-based techniques in "La Mandria" park by evaluating the ability to manage stormwater runoff and improve water quality, aims to enhance our comprehension of sustainable stormwater management methods, promote ecological adaptability, and encourage the incorporation of nature-based solutions in park administration and urban development, benefiting both the environment and society.

Chapter two

Literature review

Background and Rationale

The purpose of this chapter is to present a thorough summary of the current knowledge and research concerning the utilization of nature-based techniques in stormwater management within "La Mandria" Park. This section critically assesses relevant studies, publications, and projects that investigate the implementation of nature-based solutions for controlling stormwater in both urban settings and natural reserves. By integrating and examining the existing literature, this chapter will establish a solid knowledge base that will guide the development and assessment of nature-based techniques in the following chapters.

As climate change is on the rise, cities are urged to take action against the increasing impacts of climate-related disasters by introducing transformation towards sustainability and resilience, both aiming to systematically understand dynamic processes and future needs in cities. More specifically, urban resilience focuses on climate adaptation and emphasizes the urgency of taking action by cities (Hoelscher and Frantzeskaki, 2021). Nature-based solutions are one of those actions that have potential to contribute to practicable climate adaptation. For example, these include green infrastructure, urban ecosystem services, and water sensitive urban design. While all of them emphasize multifunctionality and target urban challenges, the potential benefits and effectiveness of these solutions have not been discovered fully (Lin et al., 2021; Frantzeskaki and McPhearson, 2022).

Overview of stormwater management

In recent years, stormwater management has become an increasingly multidimensional and multidisciplinary issue. Moreover, stormwater presents very distinct qualitative and quantitative characteristics from domestic sewage. It is recognized as the most important source of heavy metals, whereas wastewater constitutes the main source of organic and nitrogenous pollution (Bavor et al. 2001; Eriksson et al. 2007; Barbosa et al. 2012).

In many countries, separate sewer network systems are predominant, and most rainwater networks discharge rainwater directly to receiving waters, without any purification, which is a serious threat to the quality of such water. This is particularly dangerous for small watercourses flowing through cities for which rapid discharge from rainwater drainage systems exceeds the hydraulic capacities, and the introduced pollution load is a serious threat. Further, until the 1990s, it was believed that the best solution to the rainwater problem in cities should be drainage, i.e., efficiently collecting and discharging stormwater to receiving waters (Orala, H. V., Carvalho, P., ... (2020) (A review of nature-based solutions for urban water management in European circular cities: a critical assessment based on case studies and literature)

However, progressing urbanization is inevitably connected to replacing the natural land cover with impermeable surfaces, which leads to increased surface runoff. Additionally, climate change is leading to more volatile rainfall patterns with an increasing number of extreme events, thereby causing frequent overloading of the drainage systems. As a result, floods are occurring, especially in central city districts with a high level of impervious surfaces. Such events, referred to as pluvial flash floods, are followed by long dry spells. For example, over the last 18 years in Gdań sk, Poland, more than four rainfall events with a 100-year return period (i.e., over 100 mm/day) have occurred. On 14/15 July 2016, 160 mm of rain fell within 14 hours, exceeding the total rainfall of two months. On the other hand, as mentioned above, long periods without precipitation are also causing functional problems for cities. Thus, the lack of stored rainwater increases the need for watering urban green areas with irrigation systems. Such approaches require both natural resources and financial support, thereby leading to their unsustainability (Wojciechowska et al. 2015). Despite the risks that water can pose in urban spaces, it is an integral part of the city and a vital resource for the residents. From the human health perspective, it is necessary to integrate water in the urban layout. Therefore, a modern approach to the urban planning of the so-called WSUD assumes the use of the most natural technological solutions, the so-called eco-engineering. We count green roofs, bioretention systems, 'rainforests' and hydrophyte systems that combine the function of purification and retention and provide many ecosystem services (ES), including biodiversity and returning rainwater to the local water cycle by evapotranspiration. The natural ground cover would only have 10% runoff with 40% via evapotranspiration and 50% through infiltration while the impervious cover would have 55% runoff with 30% evapotranspiration and 15% infiltration (US EPA 2003).

Nature-based stormwater management techniques

Nature-based stormwater management techniques leverage the natural processes of ecosystems to manage water runoff and mitigate the adverse impacts of urbanization. These techniques, often referred to as green infrastructure or Low Impact Development (LID) strategies, include green roofs, permeable pavements, rain gardens, constructed wetlands, and bioswales. Green roofs, for instance, consist of vegetation layers installed on rooftops that absorb rainfall, reduce runoff volume, and provide insulation benefits. Studies have shown that green roofs can retain up to 75% of rainfall during summer months and 40% during winter, significantly reducing the burden on urban drainage systems (Getter & Rowe, 2006). Permeable pavements, designed to allow water infiltration through surfaces that traditionally do not permit water penetration, help reduce surface runoff and promote groundwater recharge. Research indicates that permeable pavements can decrease surface runoff by up to 50%, contributing to the mitigation of urban flooding and improving water quality (Brattebo & Booth, 2003).

Rain gardens and bioswales are other effective nature-based solutions that use native vegetation to absorb, filter, and store stormwater. Rain gardens are shallow, vegetated basins that capture and infiltrate runoff from impervious surfaces, such as rooftops and parking lots. They have been found to reduce runoff volume by up to 30% and significantly improve the quality of infiltrated water by removing pollutants through soil filtration and plant uptake (Dietz & Clausen, 2005). Bioswales, which are linear, vegetated channels designed to convey stormwater, similarly enhance infiltration and pollutant removal. A study by Davis et al. (2009) demonstrated that bioswales could achieve removal efficiencies of 90% for sediment, 80% for phosphorus, and 70% for nitrogen, showcasing their effectiveness in improving urban water quality. Constructed wetlands, which mimic the functions of natural wetlands, provide additional benefits such as habitat creation, carbon sequestration, and aesthetic enhancements. Collectively, these nature-based stormwater management techniques not only mitigate flooding and improve water quality but also contribute to urban biodiversity, climate resilience, and community well-being.

Benefits of Nature-Based Water Management

Nature-based water management offers numerous benefits compared to conventional stormwater management practices. One key advantage is flood mitigation. Green infrastructure elements, such as green roofs, rain gardens, and constructed wetlands, can absorb and store rainwater, reducing peak flows and preventing flash floods (Fletcher et al., 2019). These techniques also enhance water quality by filtering pollutants through the natural processes of soil infiltration, plant uptake, and microbial degradation (Marsalek et al., 2019). Moreover, nature-based approaches contribute to groundwater replenishment, as they facilitate the percolation of water into aquifers, ensuring long-term water availability (Fletcher et al., 2019). Additionally, these techniques provide habitat for diverse plant and animal species, enhance urban aesthetics, and offer recreational spaces for communities, thus improving the overall quality of urban environments (Liu et al., 2018).

Traditional stormwater management techniques

Traditional stormwater management techniques primarily rely on engineered solutions such as storm sewers, detention basins, and concrete channels to control and direct runoff away from urban areas. These methods are designed to quickly convey stormwater to prevent flooding, but they often fail to address water quality and ecological impacts. Storm sewers and concrete channels, for example, expedite the flow of runoff into rivers and streams, frequently leading to increased erosion, habitat destruction, and downstream flooding. Moreover, these systems do not provide filtration, resulting in the direct discharge of pollutants, such as heavy metals, oils, and sediments, into natural water bodies. Detention basins, while effective at temporarily holding runoff to reduce peak discharge rates, often lack the capacity to treat water quality adequately. Additionally, these traditional infrastructures can be costly to construct and maintain, and they offer limited flexibility in adapting to changing climatic conditions. In contrast, nature-based stormwater management techniques offer a more holistic approach, enhancing water quality through natural filtration and promoting groundwater recharge, while also providing additional environmental and social benefits such as biodiversity enhancement, recreational opportunities, and aesthetic improvements. By integrating green infrastructure into urban planning, cities can achieve more sustainable and resilient stormwater management outcomes.

Flood protection and water management

Drawing upon the historical flood events that transpired in Parco la Mandria in Torino in the years 1994 and 2000, it becomes evident that the implementation of flood protection techniques and water management tools is of paramount importance in mitigating potential risks and safeguarding against future hazards. The significance of flood protection measures extends beyond the immediate preservation of the park's infrastructure; it also encompasses the preservation of the park's natural elements. This section underscores the pivotal role that flood protection plays in ensuring the integrity of both the park's physical infrastructure and its diverse ecological components. By comprehensively addressing flood protection, the subsequent impact on various facets of the park can be explored and assessed.

Ecosystems, depending on their management, can either contribute to the problem or provide effective NBS for flood risk reduction or climate change mitigation and adaptation (Cohen-Shacham et al.2016). At the same time, the implementation of NBS depends on the state and capacity of ecosystems to provide particular regulating services (flood, erosion, climate). Their spatial dimensions provide a basis for land use management and urban planning decisions in accordance with an ecosystem-based approach for flood risk management and other aspects of urban environmental management (Szopiń ska et al. 2019).

Planning infrastructures to manage flood risk is related to connectivity (Parson et al. 2015), circularity (Kirchherr et al. 2017; Comino et al. 2018; Keesstra et al. 2018) and finding a balance between natural and urban elements (Gaines 2016). Moreover, in a fast developing city, the loss of circularity is often associated with the altered hydrological cycle, implying that water is not a natural, valuable resource, but rather a threat to the urban environment, when it flows at rates different from those of natural paths, from/toward locations that are functional to the development of human activity rather than to the environmental dynamics, through man-managed (often fast) connections, with quality standards far from those provided by natural water bodies (EPA 2005).

Consequently, the loss of circularity in the altered natural water cycle is derived from the reduction of soil infiltration capacity and resulting in fast surface runoff. The fact that the natural water cycle is replaced by the urban water cycle threatens soil, channelized urban drainage systems, receiving water bodies, and downstream cities. Furthermore, the wash-off of pollutants from anthropogenic catchments poses a threat to the receiving water bodies and their biomes. The loss of infiltration and uncontrolled leakage from sewage threaten groundwater and connected surface water bodies. Subsequently, resources, politics, and awareness affect the socio-environmental dynamics and determine whether the socio-hydrological system will undergo irreversible decline or be self-sustainable (Ursino 2019).

NBS, in this context, is meant to partially recover the pre-development water fluxes and water quality, thus reducing the flood risk (WWAP 2018). Therefore, the use of NBS in this context is strongly related to the well-known concept of sustainable urban drainage, known in the literature with different keywords, such as sustainable drainage systems (SuDS), WSUD, or low impact development (LID), as reviewed by Fletcher et al. (2015). All these concepts aim to restore the water cycle within an urban catchment, from post-development back to the pre-development state (Fletcher et al. 2013). Thus, based on site-specific characteristics and the aim of implementation (to recover the original functionality of the urban catchment or address specific issues linked to water management and risk control), NBS alone may not be able to re-establish complete circularity of the natural water cycle but rather provide multiple services to the community (e.g., mitigate flood and drought risk, affect local climate conditions, increase amenity and biodiversity). Further, based on the scale at which NBS are integrated into the so-called GI, different benefits can arise (Golden & Hoghooghi 2018).

Stormwater Management Requirements

Onsite Stormwater Management Required

Onsite stormwater management is required to the maximum extent feasible unless stormwater management is provided in a regional facility as part of a larger plan or project. The term “onsite” refers to the limits of the project site and is not a distinction between property and the right-of-way. For example, a residential development proposal could manage the runoff from the building onsite (on private property) via dry wells and the runoff from the frontage improvements onsite (in the public right-of-way) through a vegetated planter. While development proposals on the property may be bound by the parcel or taxlot geometry, the term “onsite” can be used to describe meeting the Infiltration and Discharge Hierarchy for any type of project. (Stormwater Management Manual of Portland,2020)

Facility Selection: Vegetation and Infiltration

The selection of optimal practices and tools holds considerable significance when implementing our model within the park, as it allows us to fulfill the assigned purpose effectively. Therefore, acquiring a comprehensive understanding of the functioning of each facility becomes a crucial prerequisite. By gaining insights into the operations and mechanisms of these facilities, we can ensure their seamless integration with the proposed model, ultimately enhancing its efficacy in achieving the desired objectives. The importance of this endeavor stems from the necessity to make informed decisions regarding the choice and application of appropriate practices and tools within the park's context.

The City’s stormwater management approach prioritizes vegetation and infiltration to meet stormwater requirements and to maximize environmental, system and urban design benefits. Designers must evaluate and use vegetated and infiltration facilities to the maximum extent practicable.

Vegetation and infiltration provide numerous environmental benefits. Vegetation and infiltration facilities in the built environment minimize the effects of development on natural resources and the City’s built storm systems. They are also more resilient than other stormwater management methods (e.g., structural detention or manufactured treatment) to changes in hydrology anticipated due to climate change. Vegetation provides habitat for wildlife and scenic, aesthetic, and health benefits for humans. Infiltration of stormwater provides hydrologic benefits, better mimicking natural hydrologic processes, recharging groundwater, providing summer base-flows in streams, and reducing downstream flooding. The combination of soil, plants, and biological activity in vegetated facilities removes stormwater volume through retention and evapotranspiration and filters and degrades pollutants, keeping them out of the City's systems and the natural environment.

Infiltration Characteristics for Enhanced Stormwater Management

In the context of natural-based stormwater management at Parco La Mandria, infiltration requirements within the Storm Water Management Model (SWMM) are paramount for accurately simulating and designing effective green infrastructure solutions. SWMM employs various infiltration methods, such as Curve Number (CN) methods, to represent the infiltration processes in urban and natural landscapes. The Curve Number method, derived from empirical data, provides a straightforward approach to estimating runoff and infiltration based on land use, soil type, and antecedent moisture conditions, making it an ideal choice for large-scale hydrologic assessments.

Incorporating accurate infiltration parameters in SWMM is critical for the success of natural-based stormwater management strategies at Parco La Mandria. These parameters must reflect the park's diverse soil types and vegetation cover to ensure reliable simulation results. Field measurements, such as soil hydraulic conductivity tests and infiltration rate studies, should be conducted to gather site-specific data. Additionally, historical rainfall and runoff data can be used to calibrate and validate the model, ensuring it accurately represents the natural hydrologic processes. By integrating precise infiltration data into SWMM, the model can better predict the effectiveness of green infrastructure interventions, such as bioswales, permeable pavements, and rain gardens, in mitigating stormwater runoff, reducing flood risks, and enhancing groundwater recharge within the park's ecosystem.

Surface infiltration facilities

Surface infiltration facilities are designed to infiltrate water through the upper layers of the soil. The most common vegetated surface infiltration facilities are basins, planters, and rain gardens. Permeable pavement is also considered a surface.
Surface infiltration facilities are usually incorporated into the site landscape design and are. often planted with vegetation.

Level 1 Sizing Requirements (Surface Infiltration)

- **Water quantity:** Surface infiltration facilities designed for full disposal must infiltrate Portland's 10-year, 24-hour design storm (3.4 inches).
- **Water quality:** Surface infiltration facilities provide water quality treatment by filtering the water quality storm through the upper layers of soil.

Level 1 Groundwater Separation Requirements (Surface Infiltration)

New surface infiltration facilities are required to have a minimum separation.

distance of 5 ft between the bottom of the facility and the seasonal high groundwater level unless otherwise approved by BES. (stormwater management manual of Portland,2020)

Definitions

SWMM

Storm water management model (SWMM) software is frequently used to simulate runoff from storms and evaluate how well different stormwater management techniques function. A hydrologic and hydraulic model for the study region will be created using SWMM, taking into account the current drainage system and the suggested LID controls. To properly predict the hydrological response to various storm events, the model will take into account rainfall data, soil characteristics, plant traits, and topographical information.

SWMM (Storm Water Management Model) is a software tool utilized in the field of water management for modeling and simulating the behavior of stormwater runoff, drainage systems, and water quality. Developed by the United States Environmental Protection Agency (EPA), SWMM is widely recognized and extensively used for assessing the performance of various stormwater management strategies.

SWMM operates by dividing an area of interest into a network of interconnected nodes and links that represent different components of the drainage system. These components typically include pipes, channels, storage units, and various types of land surfaces such as impervious areas, pervious areas, and green spaces. The software enables users to define these elements, specify their characteristics (e.g., dimensions, slopes, roughness), and assign hydrological properties to them.

The modeling process in SWMM involves the simulation of rainfall events and subsequent hydrological processes, such as infiltration, runoff generation, and routing through the drainage network. Users can input historical or synthetic rainfall data, and the software applies hydrologic algorithms to estimate the resulting runoff volumes and flow rates. It also considers the interactions between different land uses, pollutant loads, and water quality processes.

SWMM offers a range of analysis capabilities for water management purposes. It allows users to assess the performance of existing drainage systems under various conditions, evaluate the effectiveness of different stormwater management practices (e.g., detention basins, green infrastructure), and investigate the impact of land use changes or climate scenarios on stormwater runoff and water quality. Moreover, SWMM supports the examination of key performance indicators, such as peak flows, time of concentration, flood volumes, pollutant loads, and concentration profiles. These outputs can aid in decision-making processes related to urban planning, infrastructure design, and policy development for sustainable water management.

By employing SWMM in this case study, it can utilize its robust modeling capabilities to analyze and evaluate the effectiveness of specific water management strategies, investigate the impacts of different factors on stormwater runoff and water quality, and make informed recommendations for sustainable urban water management practices.

in this study, first data was garbed from GIS including Curve Number, and flood risk areas, then exported to SWMM to acquire an understanding of the contemporary condition delineated in the case study and devise strategies for addressing and surmounting the identified challenge. The main outputs extracted from this software were different scenarios that were defined based on involving regional components of permeable pavements, rain gardens, bio-retention cells, and green roofs.

sub-catchments

Sub-catchments are segments of land where the terrain and drainage features funnel surface water to a single exit point. These sub-watersheds are categorized into permeable and impermeable zones. In the permeable zones, surface water can seep into the topsoil, enhancing groundwater recharge. Conversely, in the impermeable zones, infiltration is obstructed. The impermeable zones are further subdivided into areas with depression storage, where water can temporarily accumulate, and areas without such storage features. Water runoff from one zone within a sub-watershed can be directed to another zone, or both zones may discharge water directly to the sub-watershed's outlet.

Expanding on this concept, sub catchments play a critical role in managing water flow and quality within a larger watershed. The distinction between permeable and impermeable areas is crucial for urban planning and environmental management. Permeable areas, often consisting of natural landscapes like forests and grasslands, help mitigate flooding and sustain stream flows during dry periods by allowing water to infiltrate and recharge groundwater supplies. On the other hand, impermeable areas, which include paved surfaces and rooftops, increase surface runoff, leading to higher risks of erosion, flooding, and pollution. Understanding the dynamics of water movement within sub catchments is essential for designing effective stormwater management systems. These systems aim to mimic natural hydrologic processes, reducing the adverse impacts of urbanization on water cycles. Techniques such as creating green spaces, installing permeable pavements, and constructing detention basins are employed to enhance water infiltration and reduce surface runoff.

Each sub catchment is equipped with an outfall designed to convey the water collected from both surface runoff and Low Impact Development (LID) utilities. This infrastructure effectively channels the accumulated stormwater, directing it toward the sewage system for proper management and treatment. The integration of these outfall mechanisms is crucial for ensuring that excess water from precipitation events is efficiently transported, thereby preventing flooding and promoting sustainable water management practices. By linking surface and LID-derived water flows to the sewage network, the system supports the overall hydrological balance and enhances the resilience of the urban environment against stormwater-related challenges.

LID controls

Stormwater runoff and urban flooding are an increasing threat in built environments around the world. In addition to property damage, extreme precipitation events can cause sewer overflows, which increase sewage treatment costs and threaten water quality (Goonetilleke, Thomas, Ginn, & Gilbert, 2005; Londono ˜ Cadavid & Ando, 2013). Existing traditional (gray) stormwater infrastructure is often aging and under-dimensioned to accommodate predicted increased frequency and intensity of extreme precipitation events as a consequence of climate change (Eckart, McPhee, & Bolisetti, 2017). Many cities have turned to low impact development (LID) to control volumes and pollutant loads of smaller storm events (Luan et al., 2019). Setting clear policies and expectations for establishing LID in new building projects is relatively straightforward, but in an urban environment, most areas are characterized by a patchwork of small, built properties managed by diverse owners. For example, Oslo, Norway, has implemented a "blue-green factor" regulation for setting minimum requirements for LID in new building projects (Oslo kommune, 2018), but lacks tools for incentivizing adoption of LID on existing built properties. Integrating any new infrastructure – even green infrastructure – into established urban areas can be costly and disruptive (Schifman et al., 2017). Policies to increase the adoption of LID in established urban areas include raising awareness and economic instruments. Adoption of LID based solely on awareness (advertising) campaigns is quite low. For example, one study in Missouri, USA demonstrated that advertising resulted in less than 10% of households adopting rain gardens (Shin & McCann, 2018). Two economic instruments explored in the literature and to some extent in practice, include reverse auctions (RA) and stormwater fees (SWF) (Kea, Dymond, & Campbell, 2016; Tasca, Assunçao, ˜ & Finotti, 2018; Zhao, Fonseca, & Zeerak, 2019). In a reverse auction (also known as a procurement auction), property owners bid to finance part of the cost of establishing LID on their property. The municipality selects owners willing to pay the largest fraction of the cost and establishes the LID on their property, with the private landowner sharing the cost of installation (Thurston, Taylor, Shuster, Roy, & Morrison, 2010).

Low impact development (LID) for stormwater includes a suite of approaches to managing stormwater that attempts to incorporate natural features and processes (such as infiltration and evapotranspiration) into stormwater management systems (Eckart et al., 2017). LID can offer many benefits in addition to stormwater management, including filtering polluted water, reducing urban heat island effects, and aesthetics, and providing plant and wildlife habitat (Eckart et al., 2017; Elliott et al., 2020; Schifman et al., 2017). Typical examples of LID are small-scale, distributed infrastructure such as green roofs, downspout disconnection, and rain gardens. Rain gardens, the focus of our research, are one of the most common LIDs implemented on private property. A rain garden is a man-made depression in the ground that uses plants to infiltrate stormwater and delay peak flows (Dietz, 2007).

Water quality

The degradation of water quality within our study area has emerged as a pressing concern, necessitating immediate attention towards its improvement and maintenance. To address this issue effectively, it is imperative to comprehend the fundamental concept of water quality and explore the strategies and approaches available for achieving this objective. By acquiring a comprehensive understanding of water quality and its underlying factors, we can implement targeted measures and interventions aimed at enhancing and preserving the integrity of water resources within the study area. The significance of this endeavor lies in its potential to ameliorate the deteriorating water quality, safeguard ecological systems, and ensure the provision of safe and sustainable water resources for both human and environmental needs.

One of the main environmental concerns with stormwater runoff is its impact on water quality. You can gather data on the levels of pollutants in stormwater runoff in your study area and compare the effectiveness of nature-based techniques to traditional stormwater management methods in reducing these pollutants.

Water quality is one of the most important environmental concerns associated with stormwater runoff. When precipitation falls onto impervious surfaces like rooftops, parking lots, and streets, it picks up pollutants such as oil, fertilizer, bacteria, and heavy metals. This polluted runoff is then channeled into stormwater drainage systems and ultimately discharged into nearby bodies of water, where it can harm aquatic ecosystems and human health.

Nature-based stormwater management techniques offer a potential solution to this problem. By mimicking natural processes, such as infiltration and plant uptake, these techniques can capture and treat stormwater runoff on-site, reducing the amount of polluted runoff that is discharged into the environment.

Studies have shown that nature-based stormwater management techniques can be highly effective in improving water quality. For example, a study conducted by the Environmental Protection Agency (EPA) found that rain gardens were able to remove up to 90% of the total suspended solids (TSS) in stormwater runoff. Another study found that bioswales were able to remove up to 95% of the TSS and up to 90% of the total nitrogen (TN) in stormwater runoff.

It is important to note, however, that the effectiveness of nature-based stormwater management techniques can vary depending on a number of factors, including the design of the system, the type of vegetation used, and the characteristics of the site. For example, a study conducted in Minnesota found that rain gardens were more effective at removing pollutants when they were located in sandy soils rather than clay soils.

When evaluating the effectiveness of nature-based stormwater management techniques in improving water quality, it is important to consider not only the removal of pollutants but also the potential for long-term impacts on aquatic ecosystems. For example, if the treated stormwater runoff is discharged into a stream or other body of water, it is important to ensure that the water quality improvements are sustained over time and do not have any unintended negative impacts on aquatic life.

Overall, water quality is a critical environmental concern associated with stormwater runoff, and nature-based stormwater management techniques offer a promising solution. By evaluating the effectiveness of these techniques in removing pollutants from stormwater runoff, your thesis can contribute to the growing body of research on sustainable stormwater management practices. For

Biodiversity

In addition to the aforementioned factors, another critical aspect that warrants consideration within the park pertains to biodiversity, particularly in relation to water bodies and the associated risks of flooding and runoff. Thus, it becomes imperative to incorporate strategies aimed at enhancing the park's drainage systems and adopting effective water management techniques. By addressing these concerns, the preservation and promotion of biodiversity within the park can be facilitated, while simultaneously mitigating potential adverse impacts stemming from flooding and runoff events. The integration of improved drainage systems and water management techniques serves as a proactive approach toward managing and conserving the park's ecological balance, fostering a sustainable environment for both aquatic and terrestrial species.

Nature-based techniques can also have a positive impact on biodiversity in urban areas. You can gather data on the types of plant and animal species that are supported by these techniques and compare them to traditional stormwater management methods.

Biodiversity is another important aspect to consider when evaluating the effectiveness of nature-based stormwater management techniques. These techniques have the potential to provide habitat for a wide range of plant and animal species, improving biodiversity in urban areas and supporting ecosystem services such as pollination and pest control.

Here are some potential data points that can be consider:

Plant species richness: Nature-based stormwater management techniques such as rain gardens and green roofs can support a diverse range of plant species, providing habitat for native flora and potentially reducing the spread of invasive species. You can gather data on the number and types of plant species supported by these techniques and compare them to traditional stormwater management methods.

Bird and insect diversity: Nature-based stormwater management techniques can also support a diverse range of bird and insect species. Birds may use rain gardens and green roofs for nesting or foraging, while pollinators such as bees and butterflies can benefit from the flowers and other vegetation. You can gather data on the types and numbers of bird and insect species supported by these techniques and compare them to traditional stormwater management methods.

Habitat connectivity: In addition to supporting individual species, nature-based stormwater management techniques can also contribute to habitat connectivity in urban areas. By providing corridors of habitat, these techniques can help to connect fragmented green spaces and support movement of wildlife through the urban landscape. You can gather data on the degree of habitat connectivity provided by these techniques and evaluate their potential to contribute to urban biodiversity conservation.

Soil health: Soil health is another important factor to consider when evaluating the potential for nature-based stormwater management techniques to support biodiversity. Healthy soils can support a wide range of plants and microbial life, contributing to ecosystem services such as nutrient cycling and carbon sequestration. You can gather data on the health of soils in areas where nature-based techniques have been implemented and compare them to traditional stormwater management methods.

Green infrastructure

The European Commission defines green infrastructure as ‘‘a strategically planned network of high quality natural and seminatural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings (‘‘Green infrastructure and flood management — European Environment Agency.” https://www.eea.europa.eu/publications/green-infrastructure-andflood-management (accessed Jul. 07, 2021).

Parco La Mandria holds significant ecological and historical value, meriting its status as a protected park under the UNESCO designation. The park's inherent significance lies in its biological diversity and historical importance, both of which necessitate stringent preservation efforts. However, the green infrastructures within the park face imminent threats that imperil their integrity. Thus, it is imperative to prioritize the protection and conservation of Parco La Mandria, recognizing its invaluable contributions to the broader ecological landscape and historical heritage.

Green Infrastructure not only manages stormwater runoff and purifies stormwater on-site but also provides a broad range of economic, social, and ecological benefits, it is seen as an important aspect for mitigating climate change impacts, reducing the load on conventional systems, and making cities resilient. These natural-based strategies can be convenient for both new development and retrofitting applications. (EPA, ‘‘Green infrastructure and climate change collaborating to improve community resiliency,” p. 26; 2016.) (Xia H, Zhang Y, (Eds.). The 2nd international symposium on rail transit comprehensive development (ISRTCD) Proceedings. Berlin, Heidelberg: Springer Berlin Heidelberg; 2014. 10.1007/978-3-642-37589-7.) They can also be applied on multiple scales from small source control practices up to large infiltration systems and watershed levels. (U.S. EPA, ‘‘Greening CSO Plans: Planning and Modeling Green Infrastructure for Combined Sewer Overflow (CSO) Control,” p. 38; 2014.)

Green infrastructure practices in arid climates facing extreme rainfall events and urban flash floods, can provide effective and sustainable solutions for stormwater management, provide urban green spaces while conserving water resources. (Hassan BT, Yassine M, Amin D. Comparison of urbanization, climate change, and drainage design impacts on urban flashfloods in an arid region: case study, New Cairo, Egypt. Water 2022; vol. 14, no. 15, Art. no. 15. 10.3390/ w14152430)

With the impact of climate change and rapid urbanization on existing drainage infrastructure and the continuous shifts in precipitation, there is a need for the integration of sustainable stormwater management systems that can adapt to these changes and mitigate flood risk to increase cities' resilience. Green infrastructure is a more viable solution that can solve problems of insufficient infrastructure capacities, avoid the cost of repairing infrastructure, and public & private properties damages, and contribute to global demand for sustainable development, risk management, and improvement of the people's living environment. (Pakzad P, Osmond P. Developing a sustainability indicator set for measuring green infrastructure performance. Proc - Soc Behav Sci 2016; 216:68–79. doi: https://doi.org/10.1016/j.sbspro.2015.12.009.), (Adem Esmail B, Suleiman L. Analyzing evidence of sustainable urban water management systems: a review through the lenses of sociotechnical transitions. Sustainability 2020; vol. 12, no. 11, Art. no. 11. 10.3390/su12114481.)

Social equity

The incorporation of social equity considerations in flood management endeavors enables Parco La Mandria to deploy strategic measures that effectively safeguard the park and neighboring communities from the deleterious impacts of flooding. This approach encompasses the recognition and mitigation of vulnerabilities among diverse stakeholders, ensuring fairness, inclusivity, and equitable access to protective measures. By actively addressing the concerns and requirements of all stakeholders, these strategies foster an environment that upholds principles of justice, fairness, and impartiality, thereby reinforcing the principle of social equity within flood management practices.

It is important to consider the potential social equity implications of stormwater management practices. Nature-based techniques can provide multiple benefits to communities, including improved air and water quality, but it is important to ensure that these benefits are distributed fairly. You can gather data on the demographics of the communities where nature-based techniques are implemented and evaluate the social equity implications of these practices.

Environmental sustainability

in 2021 the European Commission launched a Call for Expression of Interest to allow cities to state their interest in becoming climate-neutral by 2030 and to submit information on their current situation, ongoing work, and future plans with regard to climate neutrality. Following the Call, the Commission has chosen 100 of the 377 applicant cities, coming from all 27 Member States as well as 12 additional cities coming from associated countries. These 112 cities are now being invited to develop participatory Climate City Visions, which will include an overall strategy for climate neutrality across all sectors such as energy, buildings, waste management, and transport. As one of the selected cities, Torino is now required to develop an overarching vision that is tailored to suit local and regional contexts and will support its decarbonization through new and existing tools. resources, and expertise. it is important to use methods in this direction so that environmental sustainability which is one of the most important factors in this goal will play a significant role.

Environmental sustainability is a key element of sustainable urban planning. The built environment has a significant impact on the natural environment, and sustainable urban planning seeks to minimize this impact. It is important to incorporate various sustainable design strategies, including energy efficiency, water efficiency, materials selection, IEQ (Indoor Environmental Quality) Green spaces and urban agriculture can also contribute to environmental sustainability by reducing the urban heat island effect and enhancing biodiversity. According to a study by De Vries et al. urban green spaces can help reduce air temperatures and mitigate the effects of climate change. Additionally, urban agriculture can help reduce food miles and promote local food systems, thus reducing the carbon footprint associated with food production and transportation (Vries, 2013).

Social sustainability

Stormwater management practices that prioritize the integration of green infrastructure elements, such as rain gardens, permeable pavements, or urban wetlands, extend their utility beyond flood control to encompass a multitude of advantages. These sustainable approaches contribute to the enhancement of aesthetic qualities, the amelioration of air quality, the provision of urban cooling effects, and the creation of recreational spaces within the built environment. The equitable dissemination of these benefits ensures that individuals across diverse socioeconomic backgrounds can equally access and enjoy an improved quality of life and an array of environmental amenities. By conscientiously integrating social considerations into the planning and implementation of stormwater management strategies within Parco La Mandria, various aspects of social sustainability can be effectively intertwined. This entails the promotion of public health through enhanced water quality and reduced health risks, the equitable allocation of benefits to prevent exacerbation of social disparities, active community engagement to foster collaborative decision-making processes, the mitigation of environmental justice concerns to prevent disproportionate impacts on marginalized communities, and the cultivation of education and awareness initiatives to empower individuals towards sustainable practices. By embedding these social dimensions into stormwater management endeavors, the realization of social sustainability objectives can be synergistically accomplished.

Social sustainability is another critical aspect of sustainable urban planning. A socially sustainable city is one that is equitable and inclusive, where all citizens have access to basic services, such as healthcare, education, and affordable housing. Social sustainability is achieved through the provision of affordable housing, the creation of public spaces that encourage social interaction, and the promotion of diversity and inclusivity (Wang et al., 2021).

Economic sustainability

The utilization of natural-based stormwater management techniques unlike conventional gray infrastructure solutions has the potential to yield cost savings. Such natural systems are commonly associated with reduced maintenance requirements, prolonged longevity, and diminished construction expenditures. Through the adoption of these natural approaches, Parco La Mandria can effectively administer stormwater while mitigating financial outlays, thereby fostering the advancement of economic sustainability. Traditional gray infrastructure solutions often necessitate large-scale construction projects involving extensive networks of pipes, drains, and concrete structures, which can incur substantial upfront costs. Conversely, natural systems, such as green infrastructure elements like rain gardens, bioswales, and permeable surfaces, can be integrated harmoniously with the existing park landscape, requiring less invasive and costly construction. The use of vegetation and natural materials not only reduces construction expenses but also adds aesthetic value, enhancing the overall appeal of Parco La Mandria and potentially attracting more visitors.

Economic sustainability is also a vital aspect of sustainable urban planning. A sustainable city should be economically viable, with a thriving local economy that provides job opportunities and supports entrepreneurship. Sustainable urban planning can contribute to economic sustainability through the creation of mixed-use developments that combine residential, commercial, and industrial activities. Sustainable urban planning seeks to create cities that are environmentally responsible, economically viable, and socially inclusive. Environmental sustainability, social sustainability, and economic sustainability are key aspects of sustainable urban planning.

Sustainable development goals (SDG)

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

The SDGs build on decades of work by countries and the UN, including the UN Department of Economic and Social Affairs(https://sdgs.un.org/)

The SDGs encompass a wide range of interconnected issues, including poverty eradication, health and well-being, quality education, gender equality, clean energy, sustainable cities and communities, responsible consumption and production, climate action, and biodiversity conservation, among others. These goals recognize the need for a holistic approach that balances social, economic, and environmental dimensions of development. By addressing these challenges collectively, the SDGs aim to create a world that is equitable, inclusive, and environmentally sustainable. Achieving the SDGs requires collaboration and concerted efforts from governments, businesses, civil society, and individuals worldwide, emphasizing the importance of partnerships and collective action to create lasting positive change for people and the planet. (*THE 17 GOALS | Sustainable Development*, 2022)

Goal 6 specifically focuses on ensuring the availability and sustainable management of water and sanitation for all. Natural-based water management can contribute significantly to achieving this goal and can be linked to several other SDGs as well.

SDG6; Ensure availability and sustainable management of water and sanitation for all

Clean Water and Sanitation: Natural-based water management techniques, such as watershed restoration, wetland conservation, and nature-based solutions (NBS), can improve water quality, enhance water availability, and promote sustainable water use. They can help protect water sources, recharge aquifers, and mitigate water pollution, ensuring clean and accessible water for all.

One aspect closely aligned with this goal is natural-based stormwater management, which involves the utilization of natural systems and techniques to effectively handle stormwater runoff and mitigate its associated pollutants. This approach encompasses the implementation of nature-based solutions, green infrastructure, and ecosystem-based approaches, with the primary objective of reducing the adverse impacts of stormwater on both water quality and quantity.

Natural-based stormwater management techniques emphasize the integration of ecological processes and structures into urban and peri-urban landscapes. These techniques encompass a range of measures, including constructed wetlands, bioretention systems, permeable pavements, vegetated swales, and green roofs. Through the utilization of these nature-based solutions, stormwater is intercepted, stored, and treated in a manner that mimics natural hydrological processes. By employing natural systems, stormwater runoff can be effectively managed, leading to several benefits related to SDG 6. Firstly, natural-based stormwater management plays a vital role in improving water quality. As stormwater infiltrates the ground through constructed wetlands and bioretention systems, it undergoes natural filtration processes, facilitating the removal of pollutants and reducing their transport into water bodies. This contributes to the availability of clean and safe water resources for human consumption, sanitation, and other purposes.

Furthermore, natural-based stormwater management techniques contribute to ensuring water availability, a critical component of SDG 6. Measures such as rainwater harvesting and infiltration basins capture and store stormwater, facilitating groundwater recharge and maintaining baseflow in streams and rivers during dry periods. These practices enhance the sustainability of water resources, thus fostering their accessibility and availability for various societal needs.

In addition, natural-based stormwater management aligns with the goal of climate resilience. With the increasing frequency and intensity of storms attributed to climate change, the implementation of green infrastructure and nature-based solutions can mitigate the adverse impacts of stormwater runoff. These approaches attenuate the flow of stormwater, reduce the risk of flooding, and minimize erosion, thereby enhancing the resilience of communities and infrastructure to the effects of extreme weather events.

SDG11; Sustainable cities and communities

SDG 11, also known as Sustainable Development Goal 11, focuses on making cities and human settlements inclusive, safe, resilient, and sustainable. It highlights the importance of creating sustainable urban environments that can accommodate the growing population and ensure access to basic services, adequate housing, and transportation systems. SDG 11 aims to promote inclusive and sustainable urbanization by improving urban planning and management, enhancing the quality of slums and informal settlements, and providing equal access to green and public spaces. Additionally, it emphasizes the need for cities to mitigate their environmental impact, reduce pollution, enhance resilience to disasters, and promote sustainable and efficient use of resources. SDG 11 recognizes the crucial role of cities in achieving sustainable development and calls for integrated policies and strategies to create cities that are livable, environmentally friendly, and socially inclusive. (*Goal 11*, 2022)

SDG13; climate action

It is a critical goal of the United Nations' Sustainable Development Goals because it emphasizes the urgent need to take significant measures to combat climate change and its impacts. This SDG aims to strengthen resilience and adaptive capacity to climate-related hazards, integrate climate change measures into national policies, promote education and awareness on climate change mitigation, and mobilize financial resources to support climate actions. It recognizes that climate change is a global challenge that requires collective efforts from governments, businesses, and individuals to reduce greenhouse gas emissions, promote sustainable practices, and transition to a low-carbon economy. By addressing climate change, SDG 13 contributes to the overall sustainability of the planet and the well-being of present and future generations. (*Goal 13*, 2022)

SDG15; life on land

Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

A flourishing life on land is the foundation for our life on this planet. We are all part of the planet's ecosystem and we have caused severe damage to it through deforestation, loss of natural habitats, and land degradation. Promoting a sustainable use of our ecosystems and preserving biodiversity is not a cause. It is the key to our survival. (United Nations Global Goals n.15)

LID practices, encompassing strategies such as green roofs, permeable pavements, and rain gardens, align with SDG 15's objectives by mimicking natural hydrological processes and mitigating the adverse environmental impacts of conventional stormwater management systems. By promoting infiltration and groundwater recharge, LID controls contribute to biodiversity conservation by preserving habitats and supporting diverse ecosystems. Moreover, they combat land degradation and desertification by minimizing soil erosion and maintaining soil moisture levels essential for sustainable land use. Embracing LID practices within stormwater management frameworks not only fosters ecological resilience but also advances the broader agenda of sustainable development, thus exemplifying a synergistic approach towards achieving environmental sustainability goals outlined in SDG 15.

SDG 17; Partnerships for the Goals

Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.

SDG 17 underscores the imperative of reinvigorating global partnerships to advance sustainable development, with a particular emphasis on fostering collaboration, enhancing capacity, and addressing systemic challenges. In the realm of stormwater management, this goal highlights the critical need for coordinated endeavors involving diverse stakeholders, ranging from governmental bodies and local communities to industrial actors and non-governmental organizations. Initiatives such as Low Impact Development (LID) controls, which are tailored interventions aimed at managing stormwater at its source through methods like permeable pavements, green roofs, and rain gardens, serve as exemplars of SDG 17's ethos by engendering partnerships that span across sectors. By facilitating engagement among policymakers, urban planners, engineers, and residents alike, LID controls not only mitigate the adverse effects of stormwater runoff but also engender comprehensive and inclusive strategies for sustainable development that align with the principles outlined in SDG 17.

Case studies of successful nature-based stormwater management projects

High Line Park, New York City

The High Line Park in New York City serves as a notable example of successful nature-based water management. Built on a historic elevated railway track, the park incorporates various green infrastructure features to manage stormwater runoff effectively. The design includes permeable pavements, bioswales, and rain gardens that capture and infiltrate rainwater, reducing the load on the city's stormwater infrastructure (Anderson et al., 2014). According to the Friends of the High Line (FHL), the organization that manages the park, the High Line represents "…a model for adaptive reuse and sustainable practices for parks and planning projects around the world" (www.thehighline.org/, accessed 24 April 2016). This approach not only addresses flooding issues but also enhances the park's aesthetic appeal and provides valuable green spaces for urban residents and visitors. The success of the High Line Park demonstrates how nature-based water management can transform underutilized urban spaces into vibrant and resilient landscapes while providing multiple ecological and social benefits. Along the High Line, under the paved surface, there is an intricate drainage system that helps to reduce stormwater runoff and helps to keep planting beds healthy.

Figure 2-1 Conversion of the railway to a drainage permeable pavement

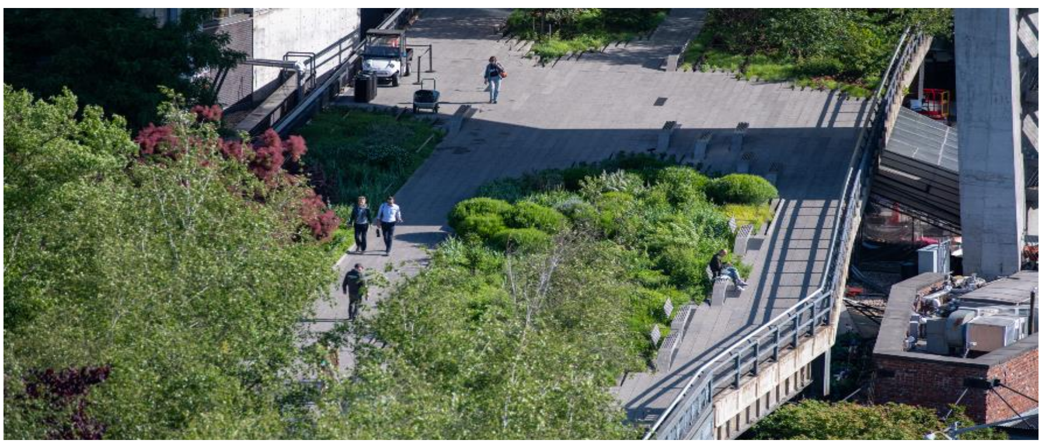


Figure 2-2 Rain Garden applied in high-line park

Chapter three

Methodology and Data

Methodology and data

Background data

The objective of this study is to implement a natural-based stormwater management approach in Parco La Mandria, Torino, in 3 different contexts by utilizing the Storm Water Management Model (SWMM) software. It details the methodologies employed in this research, outlining the steps taken to address the research question. Following the acquisition of raw data, it was imperative to enhance the data to tackle the primary issues concerning Parco La Mandria. The study explores the application of Low Impact Development (LID) controls in three distinct areas within the park: an abandoned track test road, an industrial building, and a residential section to understand the difference between 3 different scenarios which are called respectively: current situation urbanization, LID controls applied and an optimized model that LID controls are considered in the second and third scenario to evaluate the effect of natural based stormwater management on water management and how it could manage runoff by using SWMM water management modeling for Parco La Mandria in Torino. This research adopted a mixed-methods approach, integrating observational techniques, secondary data analysis, and Geographic Information System (GIS) mapping. Data were obtained from multiple sources including municipal records, data from a project conducted by a company, and geoportal maps. Observational techniques provided initial insights into the primary issues. Secondary data analysis was conducted on the municipal records and company project data to identify patterns and trends. GIS mapping was utilized to spatially analyze the data and visualize the geographic distribution of the issues. This comprehensive approach enabled a thorough examination and understanding of the primary issues. Geographic Information System (GIS) and Storm Water Management Model (SWMM) software were utilized to gain valuable insights into their functionalities, features, and potential applications across different scenarios. Based on the obtained information, the decision was made to analyze the case study in three possible scenarios to conduct a thorough investigation and address the issues using the best qualitative solutions.

The main purpose of this model is to provide a comprehensive cognition of the current situation of urban drainage systems and the efficiency potential of using LID controls in three sections in Parco La Mandria. By analyzing the data obtained from this model, it is possible to assess the contribution of natural-based solutions controlling runoff and assess the effectiveness of LID controls in mitigating stormwater runoff and improving the overall sustainability of the park's stormwater management system. This research will contribute valuable insights and recommendations for implementing nature-based solutions for stormwater management in urban green spaces. Which can be done by simulating and assessing the performance of LID controls using SWMM software. This research aims to quantify their impact on stormwater runoff reduction, water quality improvement, and overall sustainability. The research plan is illustrated in the accompanying flowchart.

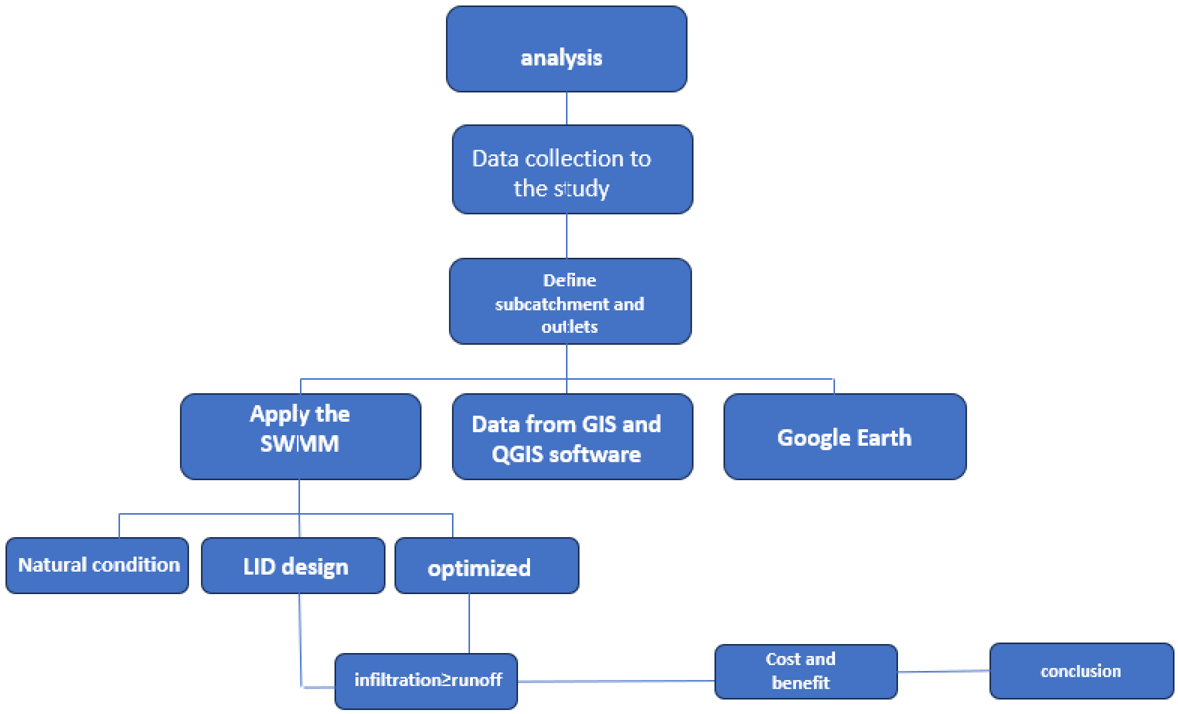


Figure 3-1 flowchart

Case study area

This thesis focuses on three distinct areas within Parco La Mandria, which will be elaborated upon in the subsequent section:

Fiat Abandoned Testing Track Area

The Fiat abandoned testing track, also known as the Fiat test track, is a notable site within Parco La Mandria. Historically used by the Fiat automobile company for vehicle testing, this area now lies unused and has the potential for redevelopment or repurposing for nature-based stormwater management solutions. The testing track features extensive paved surfaces, making it a prime candidate for the implementation of permeable pavements or green infrastructure to manage stormwater runoff effectively. Geographically, it is situated within the boundaries of La Mandria Park, which covers a considerable area that includes a mix of woodlands, meadows, and historical buildings.

Marelli Manufactory

The Marelli manufactory, part of the Magneti Marelli automotive component manufacturing group, is located near Parco La Mandria. This industrial site, with its extensive impervious surfaces, contributes to stormwater runoff issues in the area. Its proximity to the park presents an opportunity to explore integrated stormwater management solutions that can benefit both the industrial site and the surrounding natural environment. The exact coordinates and geographical boundaries of the Marelli site within the context of Parco La Mandria would be essential for detailed planning and implementation of any proposed nature-based techniques.

Robassomero

Robassomero is a municipality located near Parco La Mandria, in the Metropolitan City of Turin, Piedmont region. This area lies to the northwest of Turin and is part of the park's broader landscape. Robassomero's geographical setting includes both residential and agricultural zones, which interact with the hydrology of La Mandria Park. Effective stormwater management in this area is crucial due to its mixed land uses and the potential for runoff to affect both urban and rural environments. The topography, soil types, and existing land cover in Robassomero would be important factors to consider when designing nature-based solutions for stormwater management.

Theoretical frameworks

To protect water quality and mitigate the negative consequences of urbanization, it is important to effectively manage stormwater runoff. In the case of Parco La Mandria, a notable location in Torino with rich natural and cultural significance, it is essential to gain a thorough understanding of the characteristics of its stormwater runoff in order to minimize any potential harm to the environment.

Objectives:

The primary objectives of this analysis are as follows:

- Utilize the SWMM model to simulate stormwater runoff in the aimed part of Parco La Mandria.
- Evaluate runoff in the areas.
- Identify potential flood-prone areas within the park.
- Provide recommendations for improving stormwater management strategies for aimed areas in Parco La Mandria.

- comparing the costs and benefits of the proposed model

Data Collection

Collect relevant data including precipitation data, soil properties, hydraulic network information, and digital elevation models. Obtain this data from local authorities, surveys, or open data sources.

Area and data collection

Location: Parco La Mandria is situated in the northern part of Italy, specifically in the Piedmont region. It is located about 20 kilometers northwest of the city of Turin. Introduction of Parco La Mandria: Background Parco La Mandria is a renowned urban park situated in Torino, Italy, known for its diverse natural ecosystems and cultural heritage. As urbanization intensifies, managing stormwater becomes increasingly important to prevent flooding, reduce pollution, and preserve the ecological integrity of the park. Traditional stormwater management systems often rely on conventional infrastructure, which may have limitations in terms of sustainability and resilience. Therefore, integrating natural-based stormwater management strategies, such as Low Impact Development (LID) controls, presents an innovative approach to mitigate these challenges.

La Mandria Park is a UNESCO "buffer zone" area, in relation to the Castello della Mandria, recognized as a World Heritage Site in 1997 in the context of the Royal Residences of Piedmont, which includes another site present in the perimeter of the protected area, represented by the Reggia di Venaria and its gardens.

In La Mandria Park, there is a Special Area of Conservation (ZSC) of the Natura 2000 network, identified in accordance with the Habitats Directive 92/43/EEC called IT1110079 - La Mandria whose boundaries are shown in the following figure. This area is also recognized as a Special Protection Area (SPA identified in accordance with the "Birds" Directive 79/409/EEC.

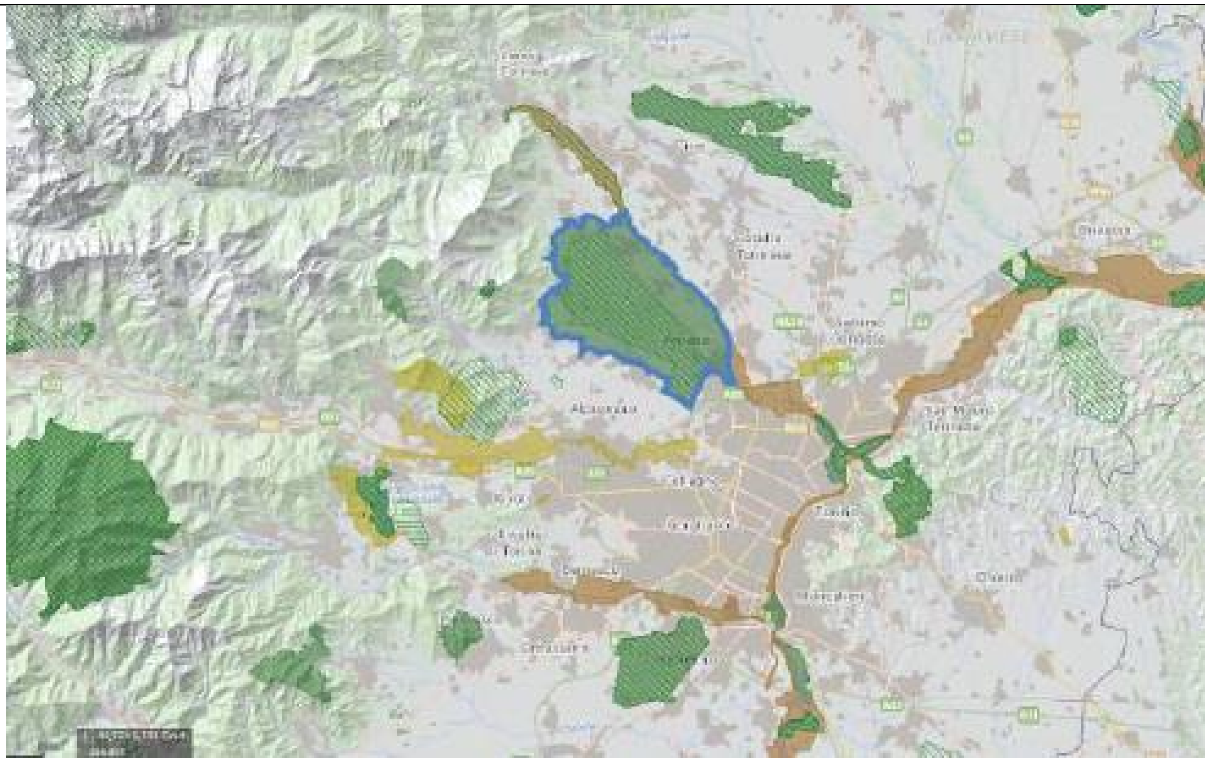


Figure 3-2 Location of La Mandria Park with respect to the vast area ecological

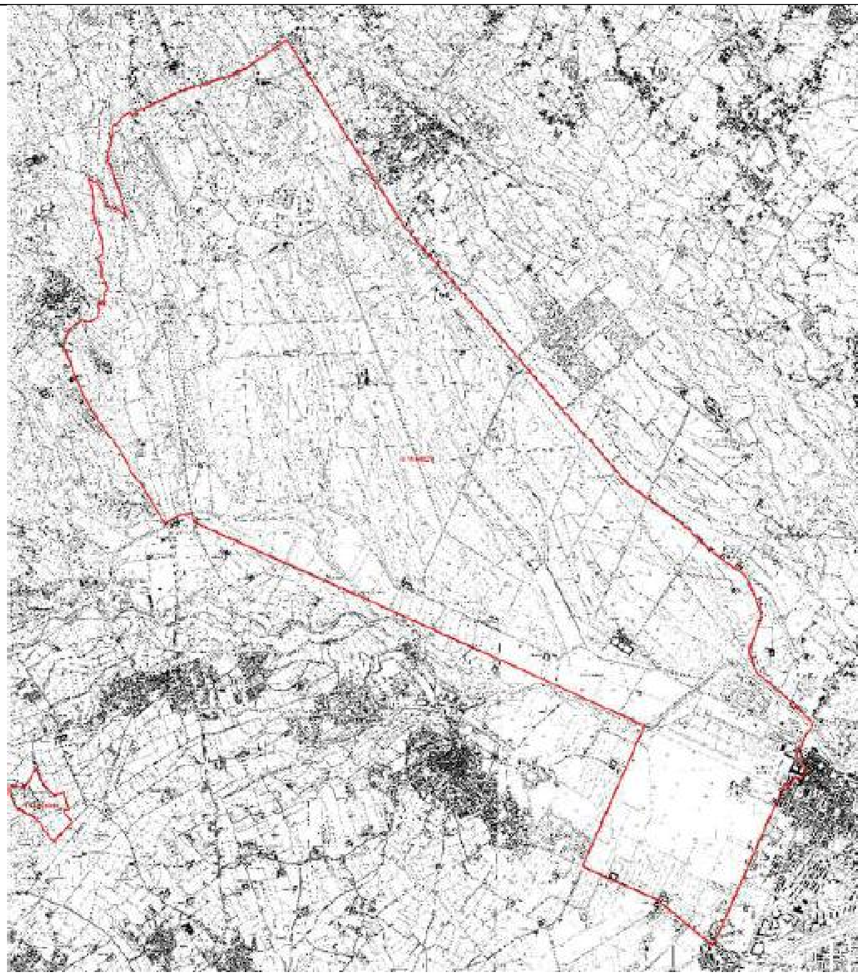


Figure 3-3 the boundary of Parco La Mandria took from established by regional plan of Torino by SMAPROGETTI, VARIANTE III PIANO D'AREA)

Key environmental factors

Geographic Data

The territory of the park is included between the courses of the Ceronda and Stura di Lanzo streams with almost 70000-hectare area, and is characterized by a high level of naturalness and biodiversity: there are numerous habitats present even if the prevailing categories are mainly represented by:

Mowing lawns.

Arable land.

Riverine forests of oak, alder and common ash.

Black locust plantations.

The Park is affected by numerous areas subject to hydrogeological constraints and some areas at very high risk of flooding. Furthermore, the bands of outflow from the flood, flooding and inundation due to catastrophic floods refer to the Stura di Lanzo and Ceronda streams, as well as to the main water bodies of the analyzed context.

Hydrology and Water Resources

In the area, there are two notable rivers named: Stura di Lanzo and Credona configurations that come together near the Venaria Reale Park. This geographical convergence not only amplifies the park's visual appeal but also exerts a fundamental influence on its ecological and hydrological characteristics. Moreover, supplementing the aqueous topography, the park contains an additional collection of large lake-like bodies of water. These aquatic elements together create a complex water system in the park. This leads to a diverse and connected aquatic environment.

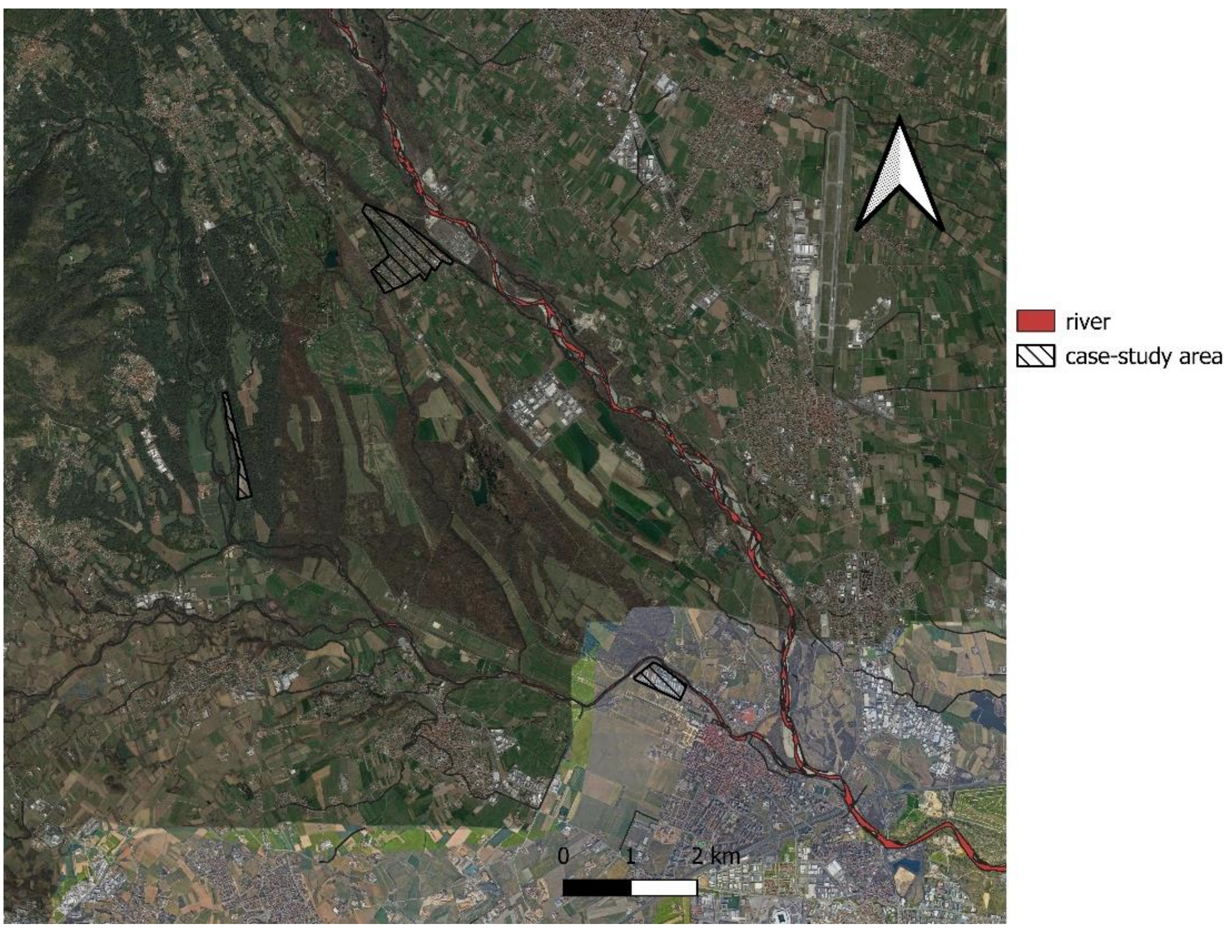


Figure 3-4 Ceronda and Stura di Lanzo streams

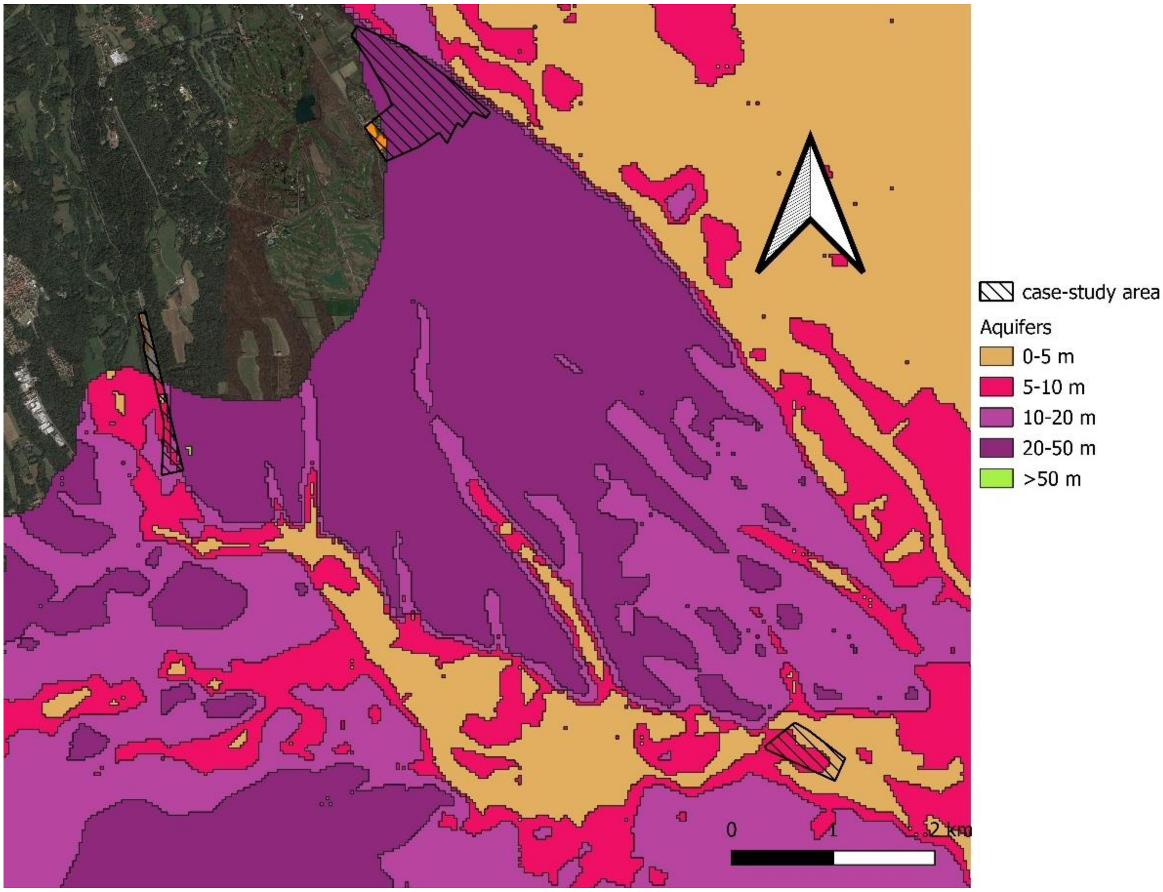


Figure 3-5 Map of existing aquifers in the area

Soil type

The park's soil composition varies throughout its different areas. It primarily consists of fertile soils that support the growth of various vegetation, including grasslands, forests, and agricultural crops. The specific soil types present in the park include loam, clay, and sandy soils.

The territory of the Mandria Park develops mainly on the right edge of the large cone of fluvial-glacial material of the Stura di Lanzo stream, which extends from the mouth of the Valli di Lanzo to the course of the Po, whose relict surface is currently testified by the highest part of the terraces of La Mandria and the neighboring Vaude. The lowering of the base level at the Stura-Po confluence produced by more recent tectonic and climatic modifications has generated an intense erosion phase which has led the bed of the Stura and its tributaries to deepen within the materials of the ancient fluvial-glacial fan. This erosive phase is still ongoing, as evidenced by the fact that the Stura has come to engrave older Villafranchian sediments, buried beneath the Quaternary deposits.

The territory is marked by various orders of terraces with a flat surface, both towards the Stura river and towards the Ceronda stream. These terraces are separated by escarpments, sometimes tens of meters high and are affected by the erosive action of various minor rivers.

The sequence of these terraces defines the morphological and landscape structure of the park and also characterizes the areas from an environmental and anthropic point of view. (SMAPROGETTI, VARIANTE III PIANO D'AREA)

Flood

Most of the areas of the park rest on alluvial fans raised, from which many streams branch off with drainage functions following meteorological events, or with minimum flow rates in winter/spring (due to a slower drainage given by the characteristics of the land which retains a lot of water) and therefore in the summer it would become a very dry area. The work of man has intervened on this natural situation, creating a network of irrigation canals (all originating from derivations of the Stura di Lanzo) and, above all, the Savoys who, having destined almost the entire area for hunting lodges, have modified the territory by creating humid or marshy environments, exploiting both the pre-existing streams and small depressions to form lakes or to continue to keep the lakes always humid even in dry periods.

It's important to note that Parco La Mandria is located in a region that has experienced occasional flood events in the past. The park is situated in the vicinity of the Po River, which is one of the major rivers in Italy. Flooding can occur during periods of intense rainfall or when the river's water levels rise significantly. To mitigate flood risks, local authorities and park management will likely implement flood prevention and management measures, such as regular monitoring, maintenance of drainage systems, and emergency response plans.

From a hydraulic point of view, the Park territory appears vulnerable near the centers of Venaria and Druento. These critical issues were very evident during the last floods which occurred in 1994 and 2000. The floods occurred over large areas and were originated by the regurgitation of the Ceronda flood wave in conjunction with numerous minor tributaries which cause flooding and failure at entry points.

Climatology

The average annual temperature, defined as "annual normal", is 11.9 °C, a value fully in line with the characteristic piedmont climatic zone of the site.

The highest monthly thermal value is reached in July with 22.0°C; the lowest is reached in January with 1.3°C.

Regarding the seasonal averages, the following values were found:

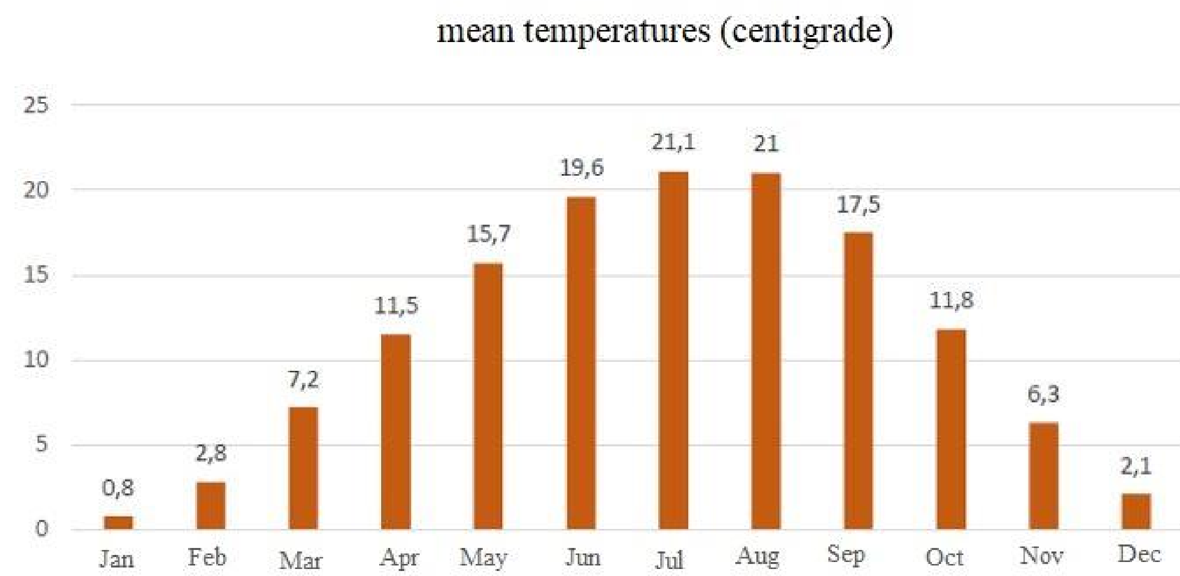


Figure 3-6 Yearly average temperature (SMAPROGETTI, VARIANTE III PIANO D'AREA)

For the area in question, there are about 60 days a year in which temperatures drop below freezing point (frost days per year).

The seasonal rhythm of rainfall in the La Mandria area falls within the western sublittoral rainfall regime typical of Piedmont, with usual equinoctial maxima, where the spring one is higher than the autumn one, and the two minima, which are, the lowest in winter and the second in summer; however, the latter differs considerably more than the reference figure for Turin. That is, for the summer, there is a not very significant difference between the rainfall of these seasons and the two equinoctial peaks, a phenomenon of transition towards the seasonal trend of rainfall in northern Piedmont, where the summer decline is even less accentuated. What has been mentioned excludes that during the summer there are generally periods of aridity, which in any case occur occasionally, can be buffered in a positive sense within certain limits by the granulometry of the soil which tends, except in sloping areas, to stagnate the moisture in the soil.

The average annual rainfall is 1225.80 mm while the rainy days are about 84.1 a year which corresponds in theory to having about one rainy day out of four/five. Of course, the effective distribution of rainy events takes place with a clear prevalence in the autumn and spring periods, so the occurrence of drought periods which can occur above all during the summer months cannot be excluded.

Data analysis allows the area to be included in the rainfall regime subalpine. This is mainly characterized by the presence of two average rainy seasons (spring and autumn) and above all by two dry seasons of which the winter is evidently the most intense.

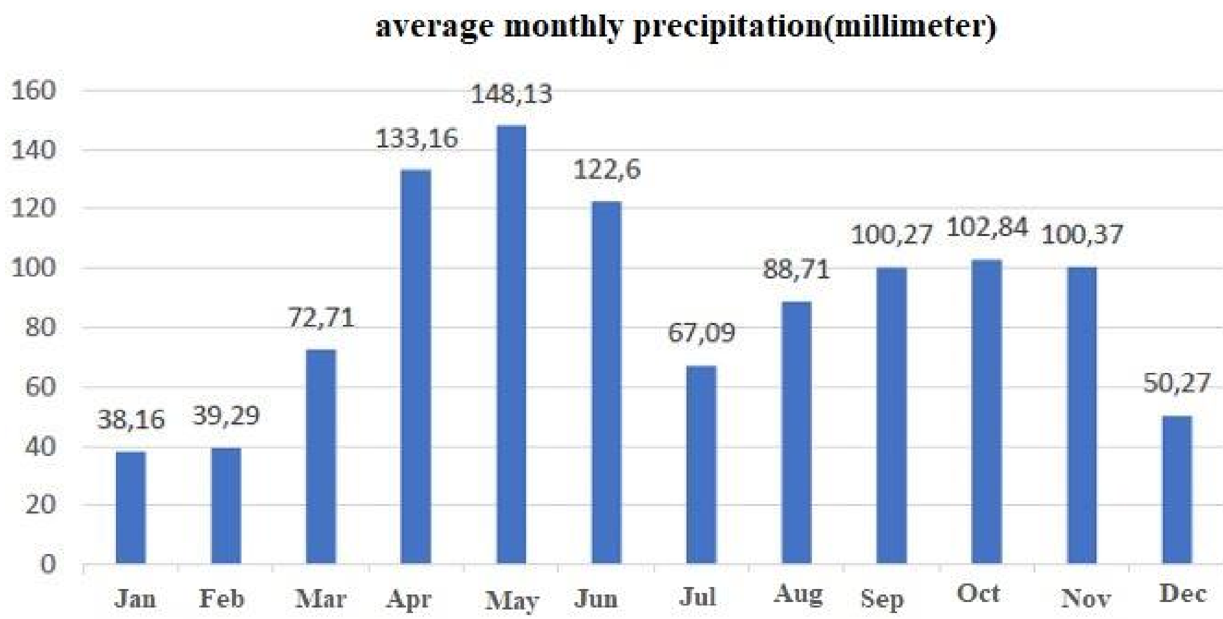


Figure 3-7 Average monthly precipitation in millimeters

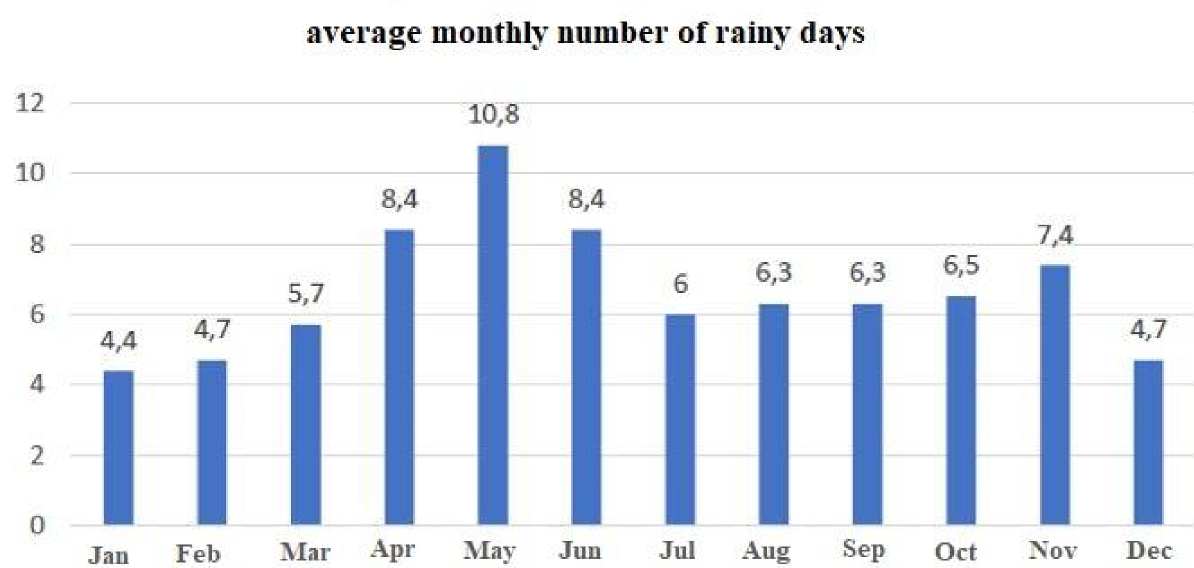


Figure 3-8 Average number of rainy days

The total average annual snowfall is modest and is between 50 and 75 millimeters, with non-continuous ground cover.

After conducting a thorough examination of literature and best practices, a collection of LID controls has been selected for implementation in specific zones of Parco La Mandria. These controls comprise various methods such as bioretention systems, green roofs, permeable pavements, rain gardens, and vegetated swales. Each control possesses distinct qualities and roles that play a part in managing stormwater, including infiltration, evapotranspiration, and the removal of pollutants.

Management tools

The adoption of a policy mandating the removal of buildings situated in flood risk areas within Parco La Mandria is of paramount importance, underpinned by compelling rationales rooted in public safety, environmental preservation, and long-term resilience. Firstly, such a policy prioritizes the protection of human lives and property, mitigating the potential for catastrophic loss and harm associated with flood events. By proactively addressing flood risks through the removal of vulnerable structures, the policy ensures the safeguarding of individuals, families, and communities who frequent or reside within the park. Secondly, the policy aligns with principles of environmental stewardship by minimizing the disruption to natural ecosystems and biodiversity hotspots within Parco La Mandria. By preventing further development in flood-prone areas, the policy preserves vital habitats and ecological corridors, supporting the park's role as a haven for wildlife and native flora. Lastly, the policy fosters resilience in the face of climate change-induced hazards, acknowledging the imperative to adapt to evolving environmental conditions. By embracing a forward-thinking approach to floodplain management, Parco La Mandria can enhance its capacity to withstand and recover from extreme weather events, ensuring its sustainability and vitality for future generations.

Policy

Given the imperative to mitigate flood risks in Parco La Mandria, particularly in areas designated as Level A, B, and C flood risk zones, it is imperative to enact proactive measures to safeguard lives and property. In accordance with this policy, any buildings located within flood-prone subcatchments must undergo thorough assessment and, where necessary, removal to minimize potential hazards. This policy is grounded in the overarching objective of prioritizing public safety and minimizing the vulnerability of communities to flood events. Furthermore, it aligns with broader initiatives aimed at fostering sustainable land use practices and enhancing resilience to climate-induced hazards within the park. The area in question urgently requires targeted interventions to mitigate flooding and enhance permeability, particularly in regions dominated by impermeable surfaces that exacerbate flood risks. It is imperative to identify the zones most susceptible to flooding and implement effective strategies to manage runoff and reduce the incidence of flooding. This thesis primarily focuses on nature-based solutions as a means to achieve these objectives. Specifically, we investigate the efficacy of bioretention cells, rain gardens, permeable pavements, and green roofs within select areas. By integrating these green infrastructure elements, we aim to improve water infiltration, reduce surface runoff, and ultimately enhance the overall resilience of the urban landscape to flood events. This approach not only addresses immediate flooding concerns but also promotes sustainable urban development and environmental stewardship. Through rigorous analysis and strategic implementation of these solutions, we aspire to contribute valuable insights and practical frameworks for urban flood management.

Tools

To effectively implement the aforementioned policy that emphasizes the use of natural processes to improve stormwater management, focusing on enhancing water quality, controlling water quantity, improving amenities and biodiversity, and facilitating the removal of buildings situated in flood-risk areas within Parco La Mandria, a comprehensive management tool is proposed which is not appliable due to land use limitations. This tool encompasses a multi-step approach, beginning with detailed flood risk assessment and mapping to identify vulnerable structures within Level A, B, and C flood zones. Subsequently, stakeholders, including governmental bodies, park authorities, and affected property owners, will be engaged in collaborative decision-making processes to determine the most appropriate course of action for each identified building. This may involve relocation, retrofitting to enhance flood resilience, or in cases where risks cannot be adequately mitigated, demolition and removal. Throughout this process, emphasis will be placed on transparency, community engagement, and adherence to established regulatory frameworks governing land use and floodplain management. By employing this management tool, Parco La Mandria can proactively address flood risks, safeguarding both the natural environment and the well-being of park visitors and residents.

Utilizing Geographic Information Systems (GIS) data, an analysis of historical flood occurrences and the varying degrees of flood susceptibility across different layers within the designated study region has been conducted. Subsequently, this analysis has enabled the identification of areas at risk of flooding. Leveraging this information, prospective interventions are being formulated through the integration of Storm Water Management Model (SWMM) simulations tailored to the unique characteristics of each identified area. This software is used to simulate and analyze the hydrological impacts of different stormwater management practices. In simpler terms, we're using computer maps to see where floods have happened before and where they might happen again. Then, we're coming up with ideas to stop those floods from happening using a computer program called SWMM. A map is provided to clarify the location and risk level of flood in the area which makes it easier to decide about stormwater management. A has the lowest risk; B medium risk of flood and C has the highest risk of flood in the area. According to this map, the industrial area is located in fascia B with a medium risk of flooding and near fascia A with a high risk of flooding, The Fiat testing track is near fascia B which should take into consideration of medium risk for flooding. Fortunately, the residential area is not located in a flood-risk area but still has considerable impermeable surfaces.

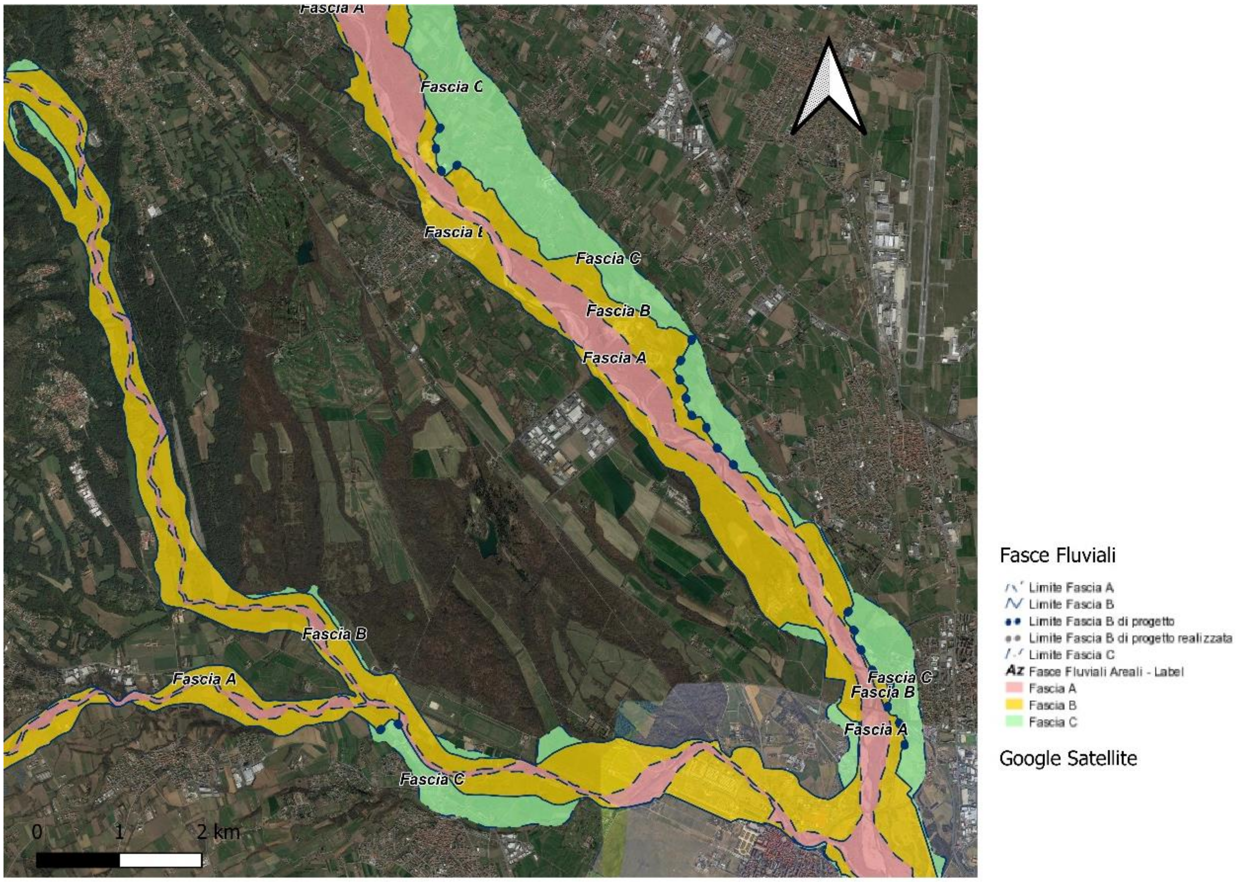


Figure 3-9 Flood risk zones in the case study area

Potentials

Parco La Mandria's Abandoned Track Test Road offers a chance to evaluate the efficiency of Low Impact Development (LID) measures in a deteriorated urban environment. In this location, we will implement LID controls like permeable pavements and bioretention systems to capture, store, and treat rainwater runoff from the road surface. The effectiveness of these controls will be assessed by comparing the conditions before and after the installation of LID measures, focusing on the reduction of runoff volume and removal of pollutants.

The unused structure located in Parco La Mandria presents an exceptional opportunity to utilize Low Impact Development (LID) measures for controlling stormwater runoff originating from rooftops and nearby impermeable surfaces. To address this, we will employ green roofs, rain gardens, and infiltration trenches to capture and treat the runoff, thereby enhancing infiltration and evapotranspiration processes. The effects of these measures on reducing runoff volume, improving water quality, and regulating temperature will be thoroughly examined.

A small, untouched section within Parco La Mandria will function as a reference area, reflecting the current state of stormwater management. In this natural portion, we will evaluate the hydrological processes and vegetation cover to establish a baseline for comparing with the areas implementing LID controls. The information gathered from this region will contribute to comprehending the potential advantages of incorporating LID measures in managing stormwater runoff and maintaining the park's ecological equilibrium.

LID controls

To achieve the objectives of this research, four types of Low Impact Development (LID) controls were applied, as explained below:

Green roof

Green roofs have a layer of plant material that absorbs water like a sponge. They capture water when it rains, slowly releasing it through evaporation and plant use. Green roofs can significantly reduce the amount of rainwater that would otherwise run off an impervious roof surface. Green roofs can also help reduce building energy usage and noise levels while increasing the durability and lifespan of the roof compared to conventional roofs.

Green roofs are being increasingly used in urban areas where space constraints limit the use of other stormwater management practices.

Note: Structures must be able to support the loading of green roof materials under fully saturated conditions. In other words, A modified form of bioretention cells comprises a structured arrangement with an upper stratum of soil overlaying a specialized drainage mat material, facilitating the efficient conveyance of surplus percolated precipitation from roofs. This design incorporates vegetative elements that play a crucial role in promoting both infiltration of rainfall into the soil matrix and evapotranspiration processes, thereby facilitating the sustainable management of water resources. This integrated approach not only enhances the hydrological performance of bioretention systems but also underscores their potential to mitigate the adverse impacts of urban stormwater runoff, aligning with broader objectives of sustainable urban water management and ecosystem resilience. Typically, the berm height and soil thickness are sequentially set at 100 mm and 400 mm, respectively.

By providing an extra layer of insulation to a home or building, green roofs slash cooling- and heating-related energy usage and costs. Green roofs sequester rain and carbon pollution as well. Somewhere between 40 and 80 percent of the total volume of rain that falls on green roofs can be retained. .(example of green roofs on carbon pollution: https://www.nrdc.org/sites/default/files/GreenRoofsReport.pdf)

The use of green roofs is intended for application on building rooftops. However, the areas targeted for intervention in this study are predominantly owned by the private sector, which significantly limits the feasibility of implementing green roofs. Consequently, the deployment of this option is not extensive. The only exceptions are a few industrial areas and a couple of public buildings where permission has been granted to utilize this type of green infrastructure. Therefore, the study's application of green roofs is confined to these select locations, reflecting the practical limitations encountered in expanding this strategy more broadly.

The berm heigh applied in this study for green roof have 100mm of surface and 1000mm soil thickness with conductivity of 12mm/h and 3mm of drainage mat.

Rain gardens:

A rain garden is a garden of native shrubs, perennials, and flowers planted in a small depression, which is generally formed on a natural slope. It is designed to temporarily hold and soak in rainwater runoff that flows from roofs, driveways, patios, or lawns. Rain gardens are effective in removing up to 90% of nutrients and chemicals and up to 80% of sediments from the rainwater runoff. Compared to a conventional lawn, rain gardens allow 30% more water to soak into the ground.

A rain garden is not a water garden. Nor is it a pond or a wetland. Conversely, a rain garden is dry most of the time. It typically holds water only during and following a rainfall event. Because rain gardens will drain within 12-48 hours, they prevent the breeding of mosquitoes.

It can be used in a variety of settings from street medians to small yards—typically featuring native shrubs, perennials, and grasses planted in a shallow basin. Actually, it is designed to absorb and trap water from rooftops, street runoff, and sidewalks. Also, it can help to allow rainfall to evapotranspiration or slowly filter into the ground, recharge underground aquifers, keep stormwater from reaching waterways and also provide habitat for wildlife, and can beautify a street or yard

A typical rain garden is 30% more than a conventional lawn.

Planter boxes, a type of rain garden, are often used in the space between a sidewalk and a street. They feature elevated sides and small openings that allow runoff to enter and be absorbed by vegetation and soil.

Why use rain gardens?

- Improves water quality by filtering out pollutants.
- Aesthetically pleasing
- Preserves native vegetation.
- Provides localized stormwater and flood control.
- Attracts beneficial birds, butterflies, and insects.

- Easy to maintain after establishment.

A rain garden should have an area about 20% the size of the roof, patio, or pavement area draining into it. A typical rain garden for a residential home or small building is between 100 and 400 square feet. Regardless of the size, big or small, each rain garden can make an impact.

Rain gardens are shaped longer than they are wide and positioned perpendicular to the slope of the land in order to catch the maximum amount of rainfall. Rain gardens should be placed at least 10 feet away from building foundations and should not be located where water ponds are for an extended period of time.

Groundwater foundation-EPA (United States Environmental Protection Agency) https://groundwater.org/

(https://groundwater.org/rain-gardens/)

Given that the primary objective of this study is to increase the amount of permeable surface area within the specified contexts, rain gardens have been identified as a valuable option. These features are considered for their ability to enhance infiltration in each area, effectively collecting stormwater and mitigating runoff. By incorporating rain gardens, the study aims to improve water management and increase the overall permeability of the targeted sites, contributing to more sustainable and resilient urban environments.

The rain garden applied in the modeling of this study has 200mm on the berm surface and soil thickness with conductivity of 12 mm/h and 75mm for the suction head.

Bioretention cells

Bioretention cells are landscaped depressions that capture and infiltrate stormwater runoff from impervious surfaces. They are used to reduce water pollution and runoff volumes. Bioretention cells have an engineered and constructed sub-grade to ensure adequate percolation of captured runoff.

Bioretention refers to vegetated stormwater practices that temporarily store roof and pavement runoff in depressed planting beds or vertical-walled structures. Depending on native soil infiltration rate and physical constraints, the facility may be designed without an underdrain for full infiltration, with an underdrain for partial infiltration, or with an impermeable liner and underdrain for no infiltration, "filtration only" (i.e., a stormwater planter or biofilter) design. Bioretention can be adapted to fit into many different development contexts and provides a convenient area for snow storage and treatment.

Bioretention systems may be the most well-recognized form of low impact development (LID). They can fit into any style of landscape and utilize all of the stormwater treatment mechanisms: sedimentation, infiltration, filtration, attenuation and evapotranspiration.

Bioretention is an ideal technology for:

Fitting multi-functional vegetation into urban landscapes

Treating runoff collected from nearby impervious surfaces.

The fundamental components of a bioretention cell are:

Inlets which may be curb openings (e.g. modified curbs, spillways), pipes, road or side inlet catch basins, trench drains, or other prefabricated inlet structures.

A surface ponding area defined by landscaped side slopes or hardscape structures and the invert elevation of the overflow outlet structure.

A filter bed containing filter media.

A filter bed surface cover layer (e.g. mulch and stone).

Plants

An overflow outlet to limit surface ponding and safely convey excess flow to a downstream storm sewer or the next BMP in the treatment train.

(https://wiki.sustainabletechnologies.ca/wiki/Bioretention)

Bioretention cells are implemented across all three areas to enhance water infiltration and storage. These facilities are particularly effective in parking lots and other impermeable surfaces, where they facilitate the percolation of water into the soil. In addition to their functional role in managing stormwater, bioretention cells contribute to the aesthetic appeal of the area, creating a visually pleasing environment while simultaneously addressing issues related to water runoff. By integrating these systems, the study aims to promote both environmental sustainability and urban beautification.

Bio-retention cells used in the modeling of this study have 100 mm of berm height surface and 500mm of soil with conductivity of 12mm/h and 75mm of suction head.

Permeable pavements:

A pavement system often used for sidewalks, parking lots, or driveways, that allows rainfall to leak into underlying pollutant-filtering layers before making its way to groundwater aquifers.

it is also an economic option compared with conventional pavement systems in the long term

all in all, using this green infrastructure can considered a green street which takes advantage of a combination of the mentioned solutions to capture, absorb, and filter rainfall where it lands, slashing the amount of runoff that reaches waterways and improving the quality of what does.

Permeable pavements, although less optimized in terms of infiltration capacity and maintenance requirements compared to other utilities, are implemented in specific areas where alternative options are not viable. Despite these limitations, permeable pavements still provide a satisfactory increase in the permeability of the targeted areas. Their use, while limited, contributes to the overall goal of enhancing water infiltration and managing runoff in contexts where other solutions are impractical. This selective application demonstrates the versatility and adaptability of permeable pavements in improving urban water management.

curve number (CN)

In the context of the Storm Water Management Model (SWMM), the curve number (CN) is a parameter used to estimate the amount of runoff generated from a particular land cover or watershed. SWMM is a widely used hydrologic and hydraulic simulation software developed by the U.S. Environmental Protection Agency (EPA) for analyzing stormwater runoff and drainage systems.

The curve number is a dimensionless value ranging from 0 to 100 that represents the soil's ability to retain water. It takes into account various factors such as land use, soil type, and antecedent moisture conditions. The CN is used in the Soil Conservation Service (SCS) method, also known as the Natural Resources Conservation Service (NRCS) method or the SCS-CN method, which is an empirical approach for estimating direct runoff from rainfall.

The CN values are typically assigned to different land cover types based on their hydrologic characteristics. For example, urban areas with impervious surfaces like roads and buildings have higher CN values, indicating lower water infiltration rates and higher runoff generation. On the other hand, natural or agricultural areas with vegetation and more permeable soils have lower CN values, indicating higher infiltration rates and lower runoff. The curve Number is a key parameter in the SWMM, representing the integrated effects of soil characteristics, land use, and antecedent moisture conditions on runoff potential. Its application in hydrologic models helps in the efficient estimation and management of stormwater runoff, crucial for both urban planning and environmental conservation.

In SWMM, the CN value is used in conjunction with rainfall data and other parameters to estimate the runoff volume and flow rates within a watershed or a specific subcatchment. By considering different land cover types and their associated CN values, SWMM helps in analyzing and designing stormwater management systems for effective flood control, pollutant transport, and water resource planning.

The process consists of three sections in three different segments of the park. The curve numbers utilized in this model for each subcatchment are 50, 58, and 71, respectively which 50 is indicating high infiltration and low runoff potential, CN 58 suggesting moderate infiltration and moderate runoff potential and 71 a higher Curve Number indicating lower infiltration and higher runoff potential that have lower infiltration rates, combined with more impervious land uses like urban areas with significant impervious surfaces under wet conditions. These values were derived from (Pastorello, 2019) GIS data,, which are presented in the two maps provided below:

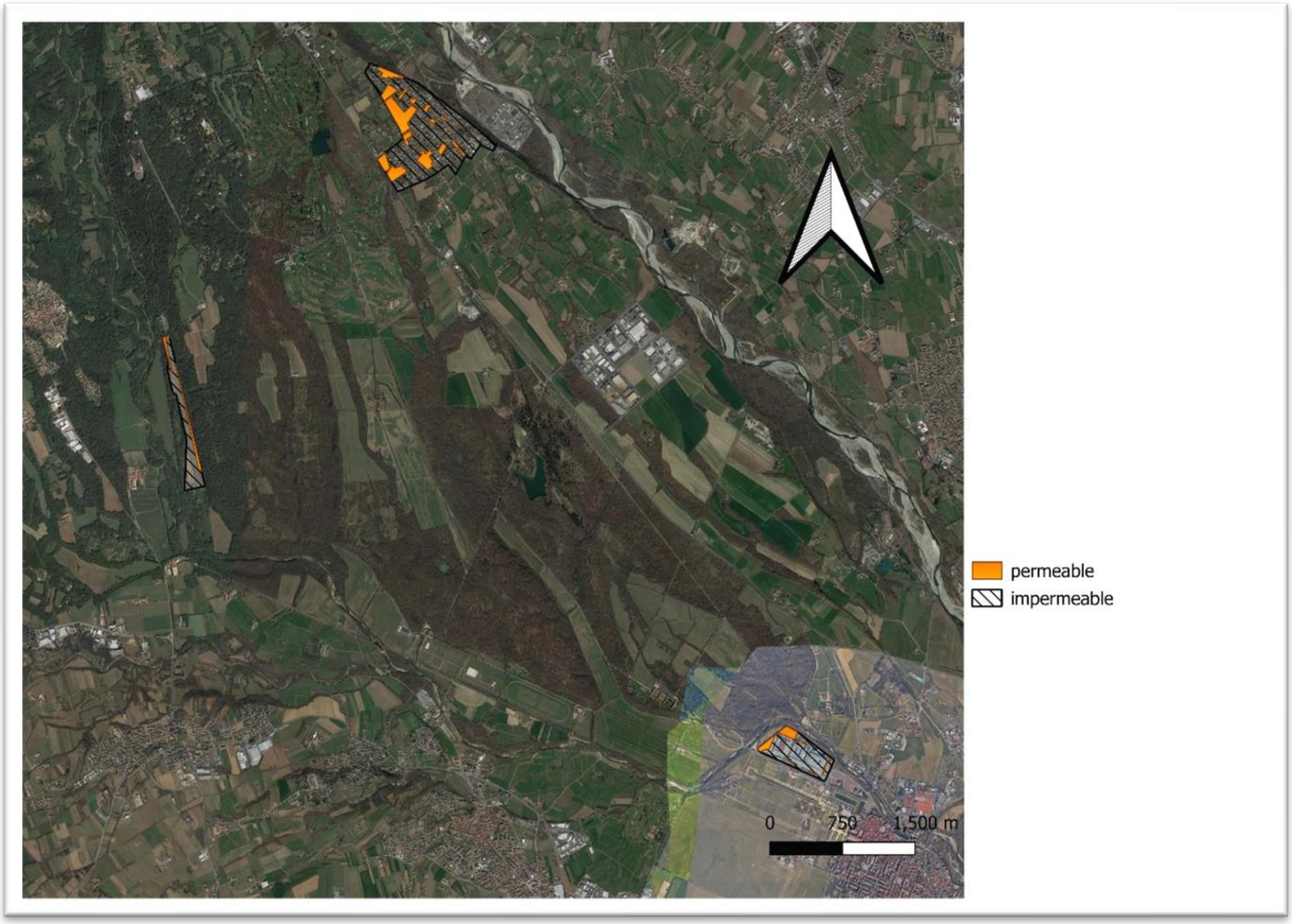


Figure 3-10 Location and permeability of each subcatchment in Parco La Mandria

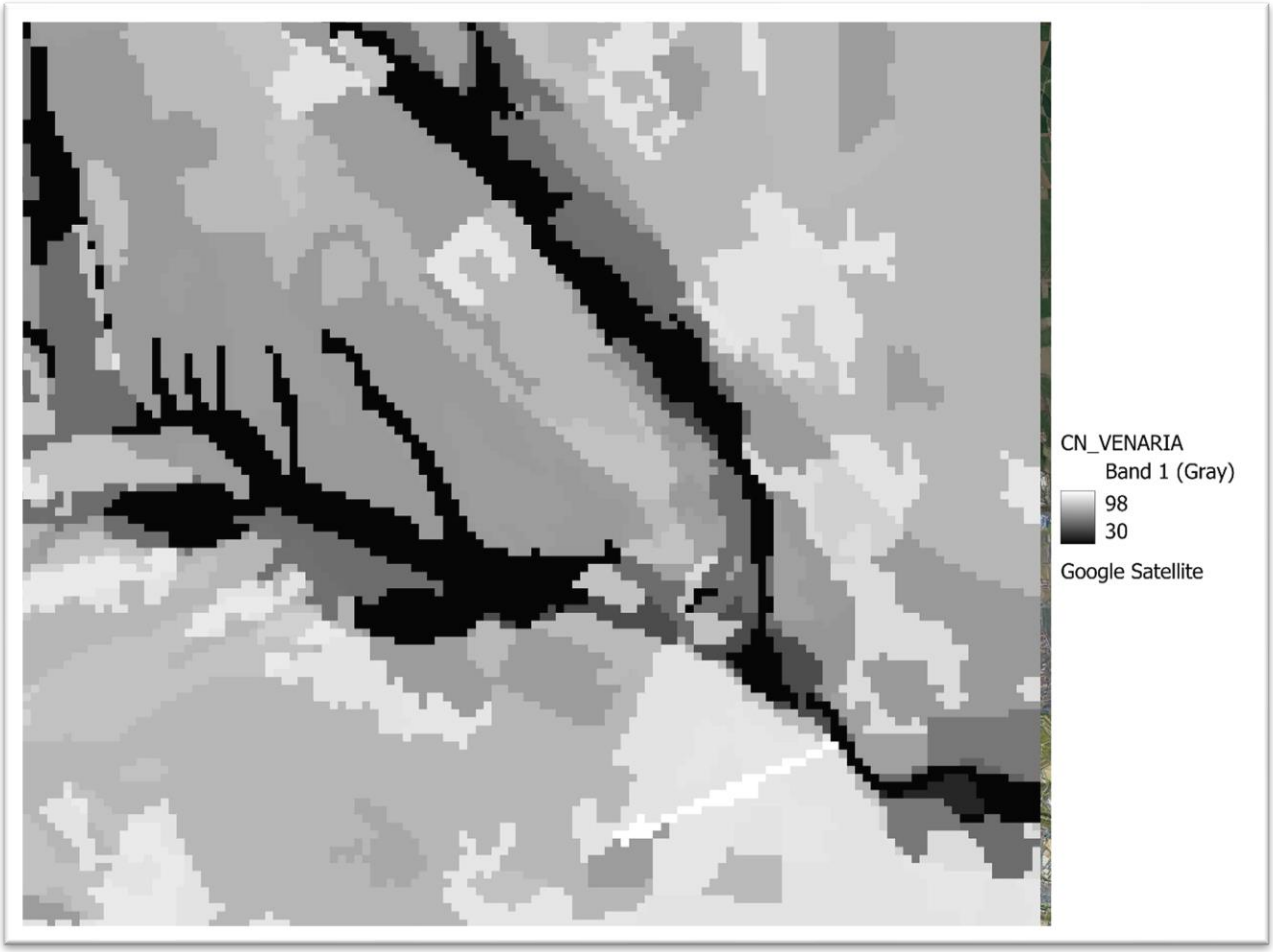


Figure 3-11 Curve number of each subcatchment based on QGIS data

The adoption of a policy mandating the removal of buildings situated in flood-risk areas within Parco La Mandria is of paramount importance, underpinned by compelling rationales rooted in public safety, environmental preservation, and long-term resilience. Firstly, such a policy prioritizes the protection of human lives and property, mitigating the potential for catastrophic loss and harm associated with flood events. By proactively addressing flood risks through the removal of vulnerable structures, the policy ensures the safeguarding of individuals, families, and communities who frequent or reside within the park. Secondly, the policy aligns with principles of environmental stewardship by minimizing the disruption to natural ecosystems and biodiversity hotspots within Parco La Mandria. By preventing further development in flood-prone areas, the policy preserves vital habitats and ecological corridors, supporting the park's role as a haven for wildlife and native flora. Lastly, the policy fosters resilience in the face of climate change-induced hazards, acknowledging the imperative to adapt to evolving environmental conditions. By embracing a forward-thinking approach to floodplain management, Parco La Mandria can enhance its capacity to withstand and recover from extreme weather events, ensuring its sustainability and vitality for future generations.

Given the imperative to mitigate flood risks in Parco La Mandria, particularly in areas designated as Level A, B, and C flood risk zones, it is imperative to enact proactive measures to safeguard lives and property. In accordance with this policy, any buildings located within flood-prone subcatchments must undergo a thorough assessment and, where necessary, removal to minimize potential hazards. This policy is grounded in the overarching objective of prioritizing public safety and minimizing the vulnerability of communities to flood events. Furthermore, it aligns with broader initiatives aimed at fostering sustainable land use practices and enhancing resilience to climate-induced hazards within the park. To effectively implement the aforementioned policy and facilitate the removal of buildings situated in flood-risk areas within Parco La Mandria, a comprehensive management tool is proposed. This tool encompasses a multi-step approach, beginning with detailed flood risk assessment and mapping to identify vulnerable structures within Level A, B, and C flood zones. Subsequently, stakeholders, including governmental bodies, park authorities, and affected property owners, will be engaged in collaborative decision-making processes to determine the most appropriate course of action for each identified building. This may involve relocation, retrofitting to enhance flood resilience, or in cases where risks cannot be adequately mitigated, demolition and removal. Throughout this process, emphasis will be placed on transparency, community engagement, and adherence to established regulatory frameworks governing land use and floodplain management. By employing this management tool, Parco La Mandria can proactively address flood risks, safeguarding both the natural environment and the well-being of park visitors and residents.

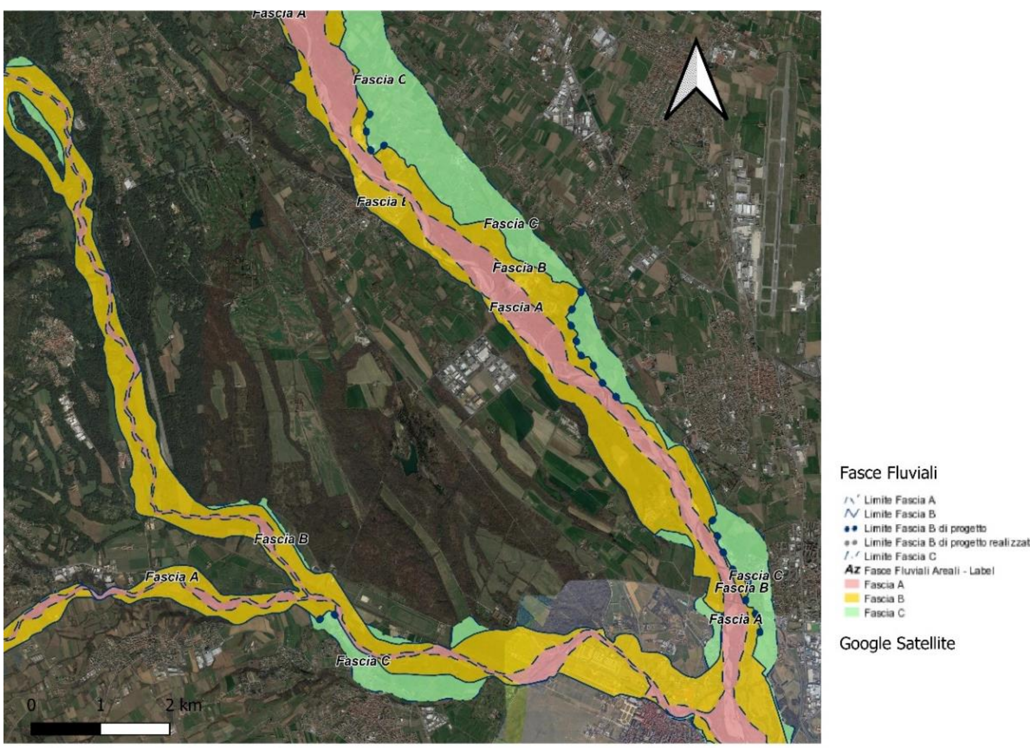


Figure 3-12 Flood risk area in Parco La Mandria

Chapter four

Results

Results

Introduction

In this chapter, detailed results obtained from the software tools GIS and SWMM are presented. The GIS-derived outcomes include Curve Numbers (CN) calculated based on Digital Terrain Model (DTM) data, along with information on location, soil type, flooding risk at various levels, hydraulic canals, and aquifer positions. These GIS-generated data were subsequently used as inputs for the SWMM analysis. Consequently, three different scenarios were defined to evaluate potential alternatives using the SWMM software, addressing surface runoff for each subcatchment. The first scenario assesses the current situation, the second scenario incorporates Low Impact Development (LID) controls, and the third scenario envisions an optimized application of LID controls for each subcatchment. This allows for comparative analysis of the results. The chapter also discusses the approaches used, the results obtained, and the specific factors influencing the outcomes of LID practices.

Design Areas

Industrial area

Current situation

This area has undergone a transformation for industrial purposes. In order to elucidate its evolving status, three distinct scenarios are being evaluated. This area exhibits a high degree of imperviousness, characterized by a dense concentration of buildings that cannot be removed and predominantly asphalt-paved surfaces. Consequently, the primary objective in this subcatchment is to enhance and increase the proportion of pervious surfaces through the implementation of Low Impact Development (LID) controls. The initial assessment delineates the area's natural state and current conditions, while the subsequent analysis involves the implementation of proposed Low Impact Development (LID) controls.in third scenario is an optimized application of LID controls in the same subcatchment. This trifurcation approach aims to facilitate a comprehensive comprehension of the efficacy of these strategies in ameliorating stormwater management and mitigating runoff. In simpler terms, we're looking at what the area was like before and what it's like now that it's being used for factories. Then, we're trying out some ideas to see if they help control the rainwater and prevent it from causing problems.

The curve numbers were derived from Geographic Information System (GIS) data. The assigned curve number for the mentioned area is 50. In the map this area is named subcatchment “1” and a junction, is denoted as ‘’2’’ to account for the specific drainage characteristics of the area. The percentage of imperviousness in this area is considered to be 86 derived from GIS data. Natural conditions exist in this situation.

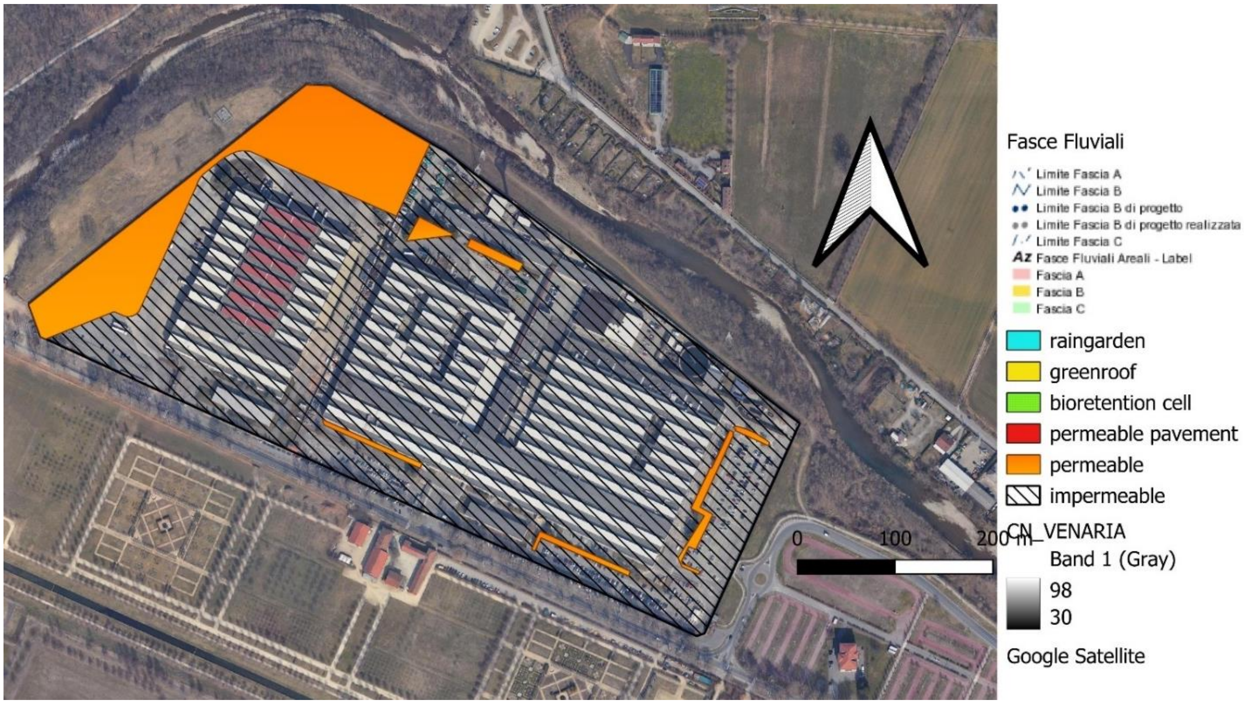


Figure 4-1 Subcatchment 1 industrial area

In the table and the graph below total area and the pervious and impervious areas is illustrated

current	Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]
	20.55	17.71	2.84

Table 4-1 area in the current situation

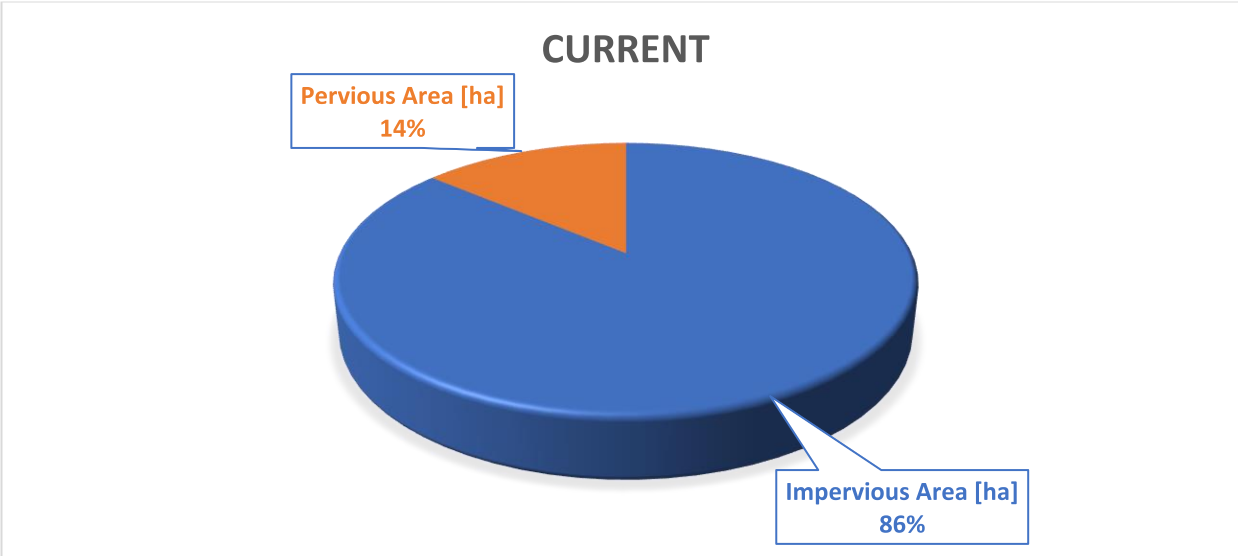


Figure 4-2 Percentage of pervious and impervious area

rainfall

To enhance comprehension of this section, it is essential to provide an introduction to each component of the SWMM software. The accompanying graph depicts the volumes of precipitation, runoff, and flooding across the entire system during a 24-hour rainfall event. As anticipated, the critical hour of the analysis occurs at 8:00 a.m., corresponding to the peak volumes of precipitation, runoff, and infiltration within the system. Notably, it is observed that the system's flooding remains steady even a few hours after the rainfall has ceased, indicating that the water is neither being absorbed nor redirected to other locations.

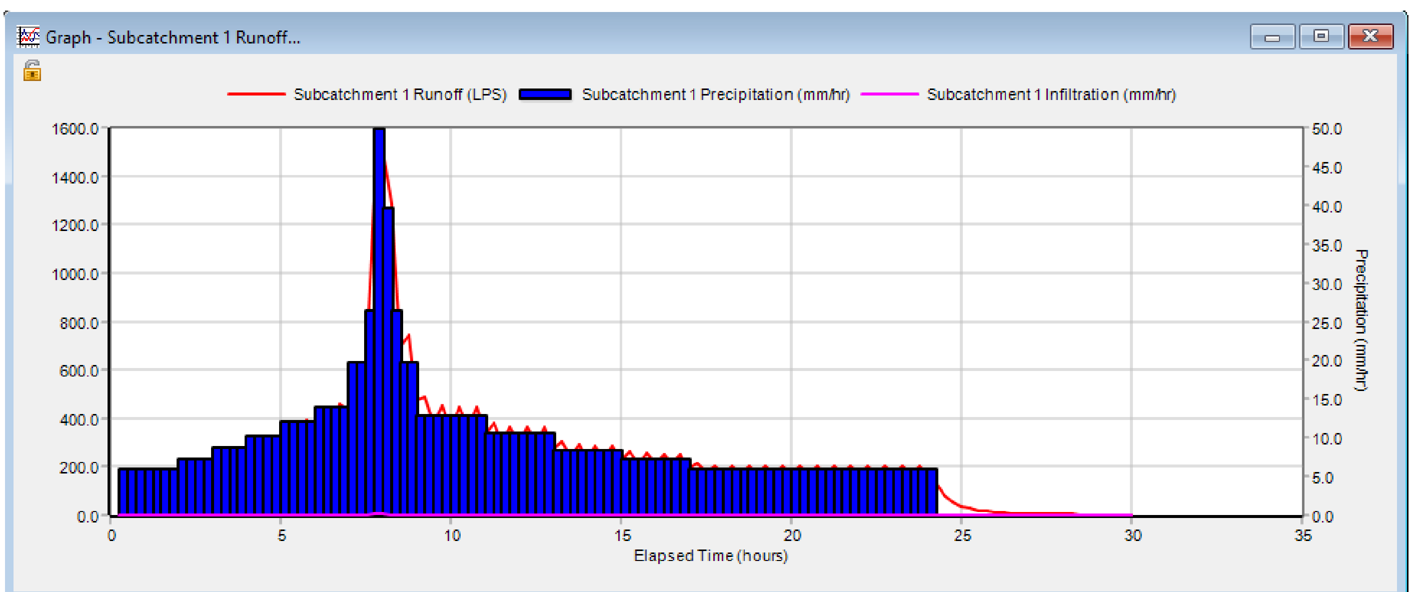


Figure 4-3 subcatchment precipitation, runoff, and infiltration in current situation

Designed scenario
Applying full LID controls in the industrial area (second scenario)

Given the unique environmental and historical significance of Parco La Mandria and its vicinity to the UNESCO heritage site, coupled with the proximity to the manufacturing building, it is imperative to prioritize the preservation of this natural and cultural heritage. The presence of industrial structures in such proximity to significant historical landmarks poses a threat not only to the aesthetic integrity of the area but also to its ecological balance.

Furthermore, the location of the manufacturing building within a flood-risk area exacerbates the potential hazards associated with its presence. The increased frequency and intensity of extreme weather events due to climate change heightens the vulnerability of the site to flooding, which could result in substantial damage to both the industrial facility and the surrounding environment.

In light of these considerations, the removal of the manufacturing building emerges as a prudent policy measure aimed at mitigating environmental risks, safeguarding cultural heritage, and enhancing the resilience of the Parco La Mandria area to future challenges. However, due to legal constraints, proposing the removal of buildings is not permissible. Therefore, the focus is on enhancing the permeability of the subcatchment by prioritizing the restoration of natural landscapes and the preservation of historical assets, policymakers can ensure the long-term sustainability and vitality of this cherished region for generations to come.so In this area applied LID controls are bio-retention-cells and rain gardens and a green roof.

Figure 4-4 Location of LID controls in industrial area

In the table and chart below, the portion of LID control applied, and the change of permeable and impermeable area is illustrated

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]	LID area	green roof area [ha]	Rain Garden Area [ha]	Bio-Retention cell Area [ha]
20.55	11.96	2.84	5.75	4	1.5	0.25

Table 4-2 Area in detail of industrial section

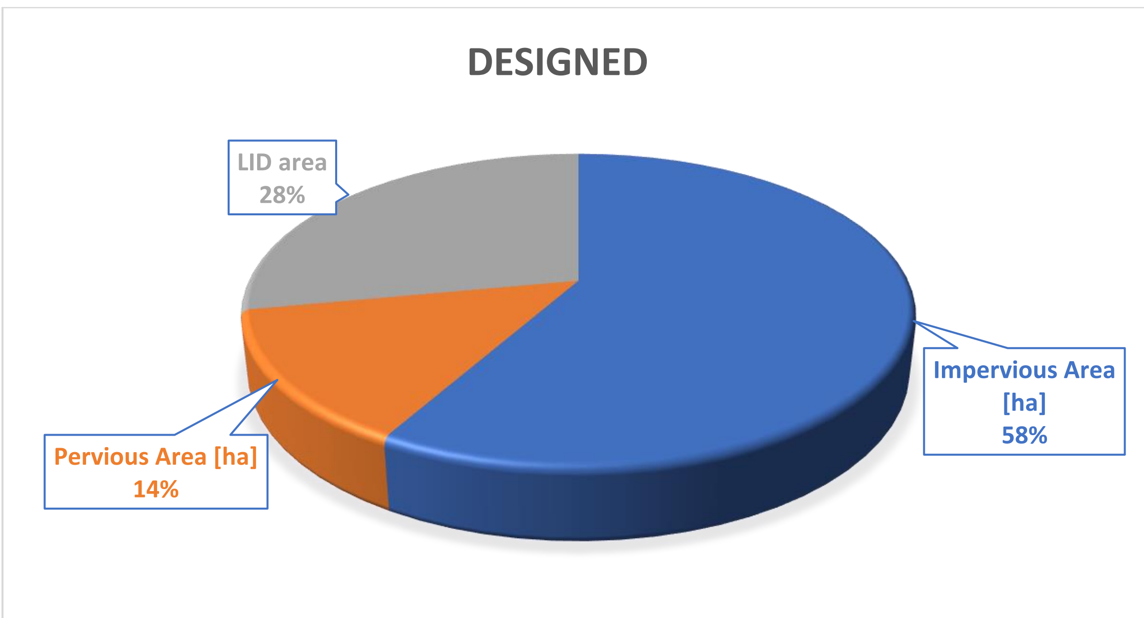


Figure 4-5 Percentage of pervious, impervious, and LID areas in industrial part

Following the implementation of Low Impact Development (LID) controls, the results for precipitation, infiltration, and runoff within this subcatchment are presented. These results demonstrate the effectiveness of the LID measures in managing and mitigating surface water flow.

Figure 4-6 Precipitation, runoff and infiltration in the industrial area

Reduced cost design scenario
Reduced cost LID controls (third scenario)

In this section, the functional properties of utilizing Low Impact Development (LID) controls are critically analyzed. The optimization of utilities is conducted based on their function, efficiency, and cost-effectiveness. This analysis aims to determine whether the optimized use of these utilities can still yield acceptable results. The objective is to evaluate whether the benefits of implementing LID controls justify the associated costs and operational considerations, thereby providing a comprehensive assessment of their viability and effectiveness in sustainable water management. Consequently, green roofs were excluded from consideration due to several limitations specific to the context of this industrial building. Firstly, the presence of various facilities installed on the roof complicates the implementation of green roof technology. The industrial nature of the building poses significant logistical challenges for retrofitting the roof with green infrastructure. Additionally, green roofs primarily address water management for the area they cover and do not substantially contribute to the overall infiltration within the subcatchment. Therefore, alternative LID controls that offer broader and more impactful improvements in infiltration and runoff management for the entire subcatchment were prioritized.

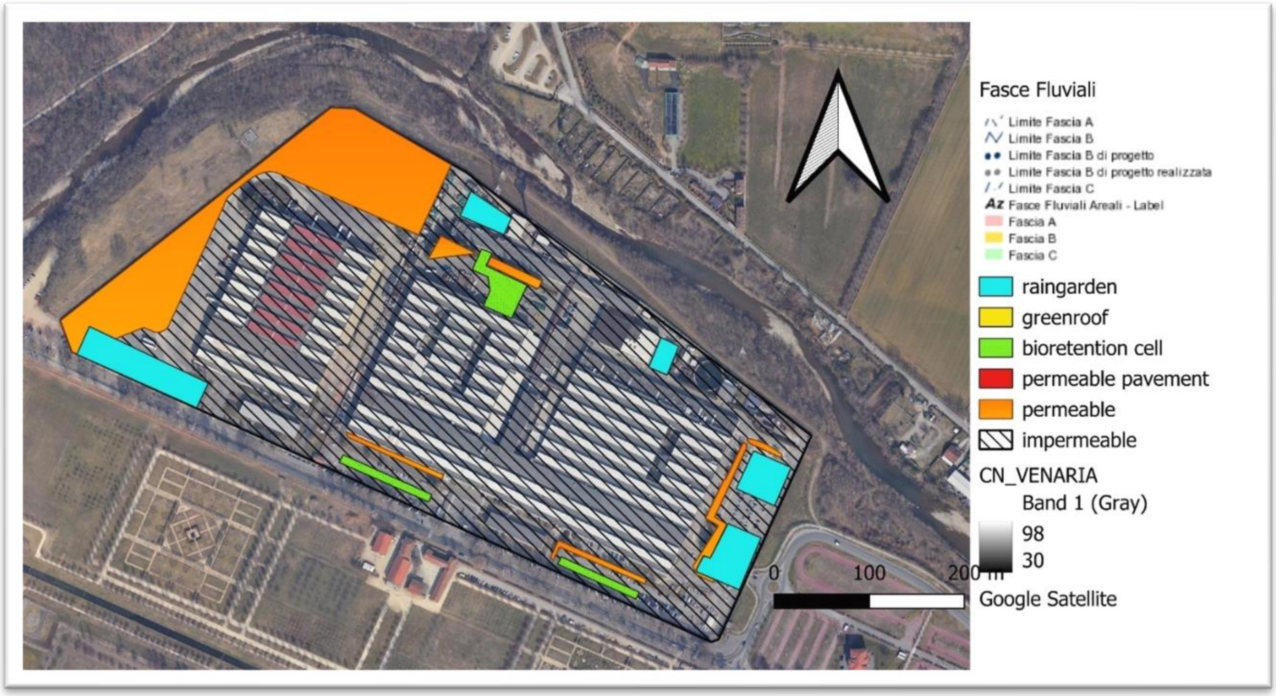


Figure 4-7 Optimized LID controls applied

Below, data regarding the total area, as well as the proportions of permeable and impermeable surfaces, are presented in both a table and a diagram.

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]	LID area	Rain Garden Area [ha]	Bio-Retention cell Area [ha]
20.25	15.96	2.84	1.75	1.5	0.25

Table 4-3 areas in optimized design

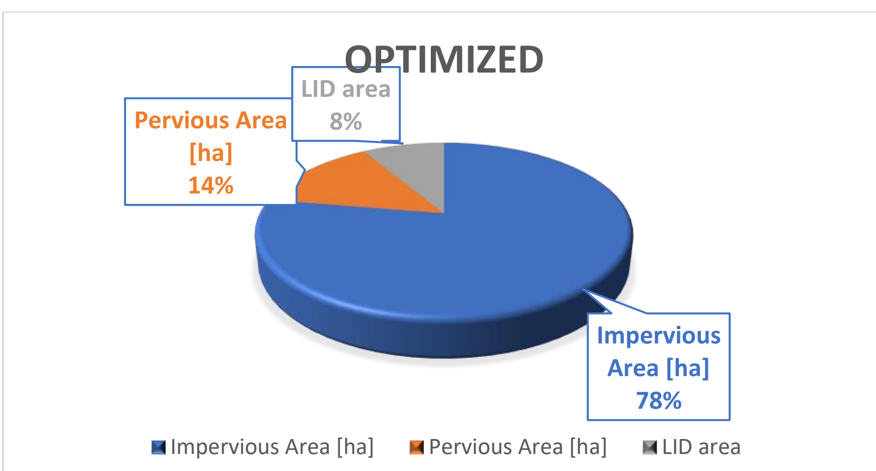


Figure 4-8 Percentage of pervious, impervious, and LID areas in industrial area

Following the implementation of optimized Low Impact Development (LID) controls, the results for precipitation, infiltration, and runoff within this subcatchment are presented. These results demonstrate the effectiveness of the LID measures in managing and mitigating surface water flow.

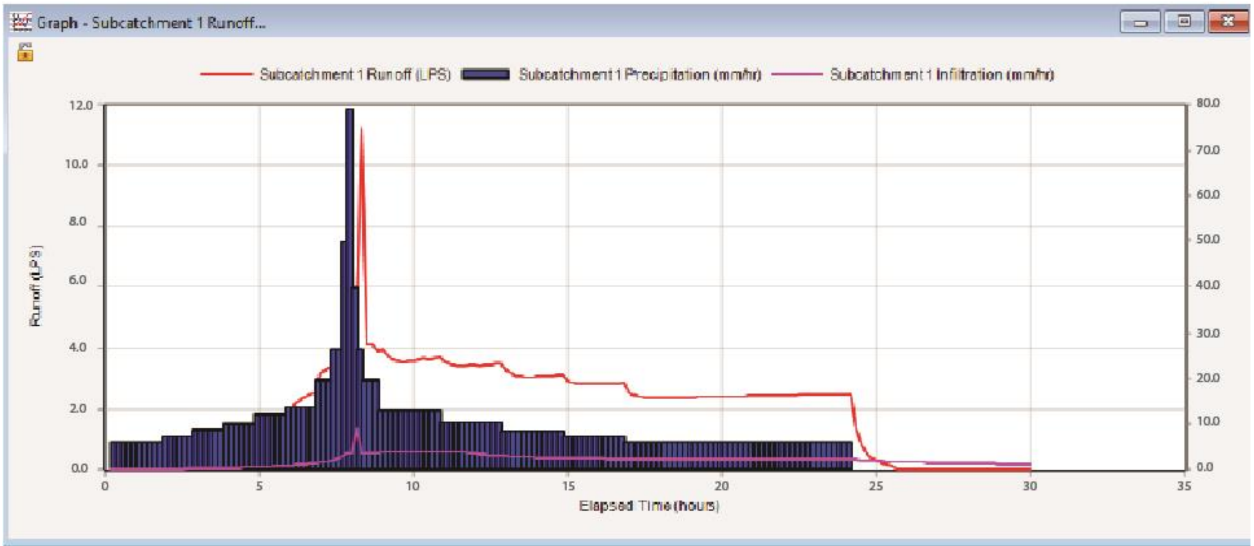


Figure 4-9 Runoff, infiltration, and precipitation in optimized scenario for industrial area

As illustrated in the data, the infiltration capacity remains sufficient, to the extent that, at certain points, no runoff is observed in the area. This indicates the effective performance of the Low Impact Development (LID) controls implemented in this scenario. The results demonstrate that the LID measures are successfully managing stormwater by promoting infiltration and reducing surface runoff, thus validating their efficacy in this specific context.

Ex-fiat testing track

Current situation

This particular site served as a testing ground for Fiat vehicles in the past; however, it currently lies abandoned and unused. This abandonment renders it an ideal candidate for examining the disparities between treated and untreated conditions. According to Geographic Information Systems (GIS) data, the Curve Number (CN) for this area under natural circumstances is recorded as 58, with an observed imperviousness percentage of approximately 88%. Within the Storm Water Management Model (SWMM) framework, this area is designated as subcatchment 3, with junctions identified as 4, aimed at accommodating the unique drainage attributes characteristic of these specific zones. In simpler terms, this place used to be where Fiat tested their cars, but now it's empty. We're studying it to see what happens when we treat it differently. We're using a computer program called SWMM to model how water flows through this area, and we're paying special attention to how it drains because it's different from other places. This subcatchment is enveloped by a verdant landscape, yet the central zone is clad in impermeable asphalt. To address this challenge, a strategic approach was implemented, integrating both permeable pavements and bio-retention cells. These bio-retention cells serve a dual purpose: functioning akin to human-made ponds designed for stormwater management, while also enhancing the visual appeal of the surroundings.

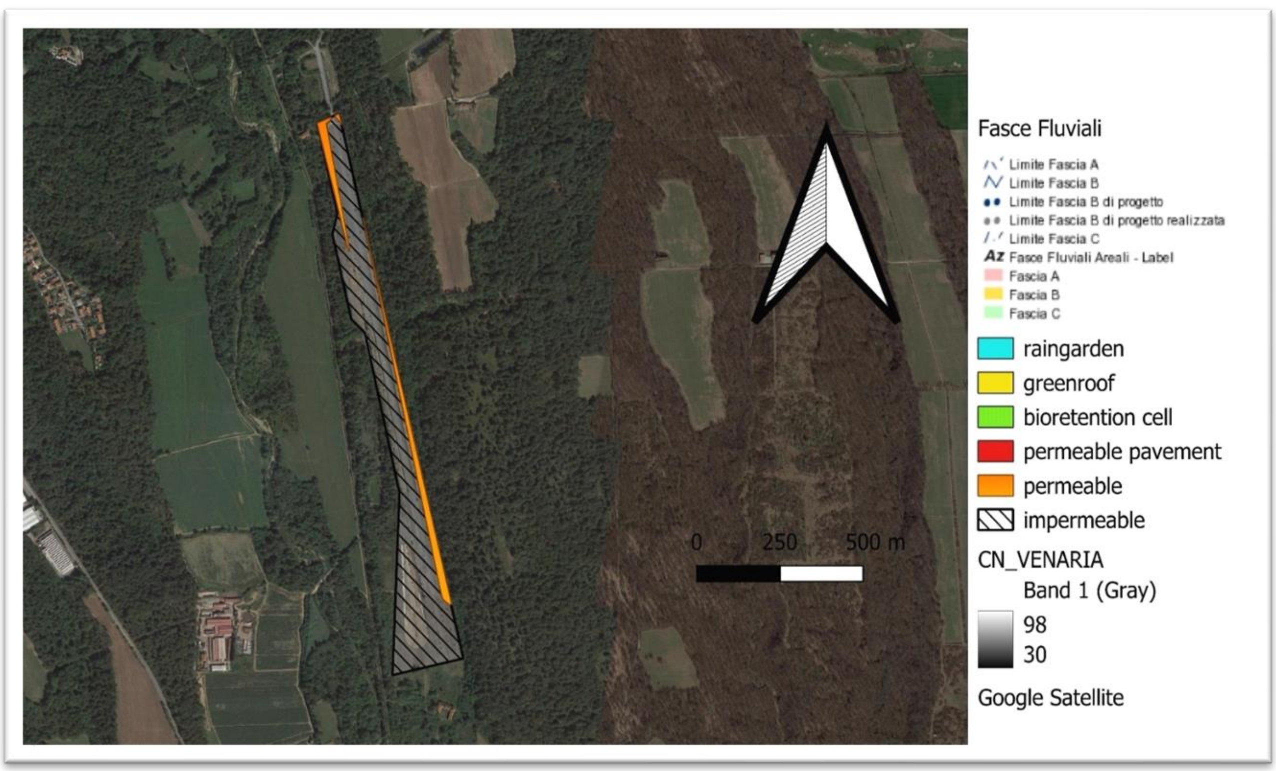
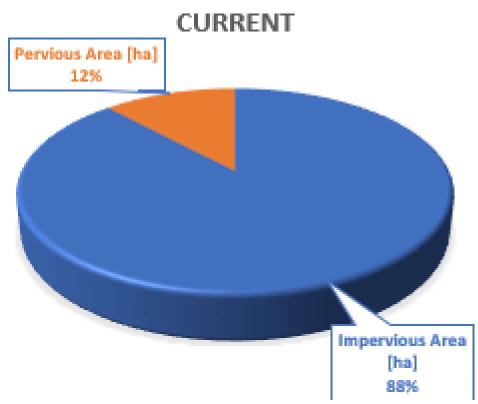


Figure 4-10 Current situation in fiat testing track

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]
16.13	14.21	1.92

Areas In current situation in Fiat testing-track



Percentages of permeable area and impermeable area

The graph illustrates data pertaining to infiltration, runoff, and precipitation specifically for subcatchment 3, highlighting pronounced runoff attributed to a substantial prevalence of impervious surfaces within the area. This observed runoff is directly correlated with the extensive coverage of impermeable materials, which impedes natural infiltration processes.

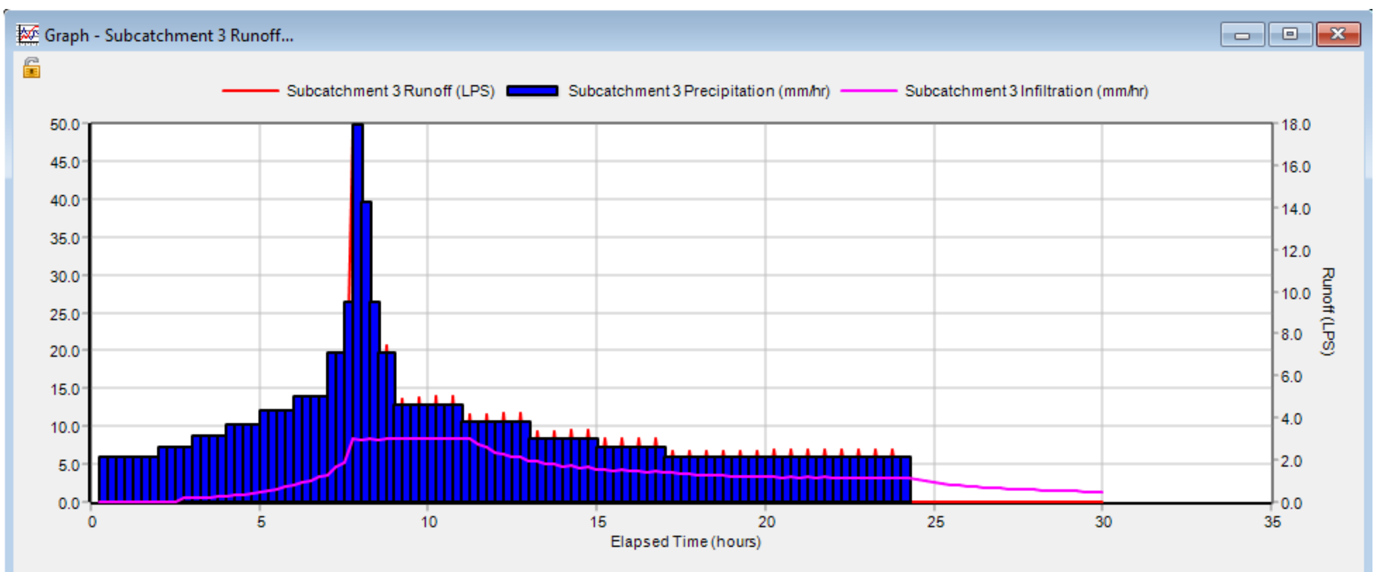


Figure 4-11 Runoff (LPS), precipitation, and infiltration in the current situation in subcatchment 3(fiat testing track)

Designed scenario
Applying LID controls in fiat testing track (second scenario)

Given the substantial presence of impermeable surfaces such as asphalt within this area, coupled with its current state of abandonment, it presents an opportune setting for evaluating the efficacy of permeable pavement. This comparative analysis aims to discern the variation in runoff patterns within this locale. The proposed Low Impact Development (LID) measures tailored to this context primarily encompass the installation of permeable pavement and the integration of bio-retention cells in the asphalt paved spaces adjacent to roadways. In simpler terms, since there's a lot of hard pavements like asphalt here and nobody is using it, we can try putting in some special pavement that lets water soak through. We'll compare how the water flows with this new pavement compared to before.

Within this specific subcatchment, which previously served as the Fiat testing track but is currently abandoned and surrounded by lush greenery, the proposed course of action revolves around the implementation of Low Impact Development (LID) techniques to effectively manage stormwater runoff. This research posits that the substitution of conventional impermeable asphalt road cover with permeable pavement presents a viable solution for enhancing water infiltration and reducing surface runoff. By adopting such an approach, the aim is to transform the existing road infrastructure into a permeable surface, thereby facilitating the percolation of rainwater into the underlying soil layers.

In conjunction with the permeable pavements, the integration of bio-retention cells is recommended to further augment the water management capacities of the subcatchment. These bio-retention cells act as decentralized treatment systems that employ vegetation and engineered soil media to effectively capture, retain, and treat stormwater runoff. By incorporating such elements alongside the permeable pavements, the overall stormwater management potential within the subcatchment can be maximized, leading to improved water quality and reduced peak flow rates.

To ensure optimal sitting of these stormwater management features, a thorough assessment of the site's topography is conducted. Elevation data obtained from reputable sources such as QGIS and Google Earth Pro are utilized to determine the site's slope characteristics. This data-driven analysis aids in establishing a junction where water storage can be effectively accomplished. The primary objective of this junction is to accumulate and retain excess stormwater, effectively mitigating the potential impacts of intense rainfall events. By redirecting the collected rainfall into a designated storage facility on-site, the proposed system not only facilitates sustainable water management but also reduces the burden on existing drainage infrastructure.

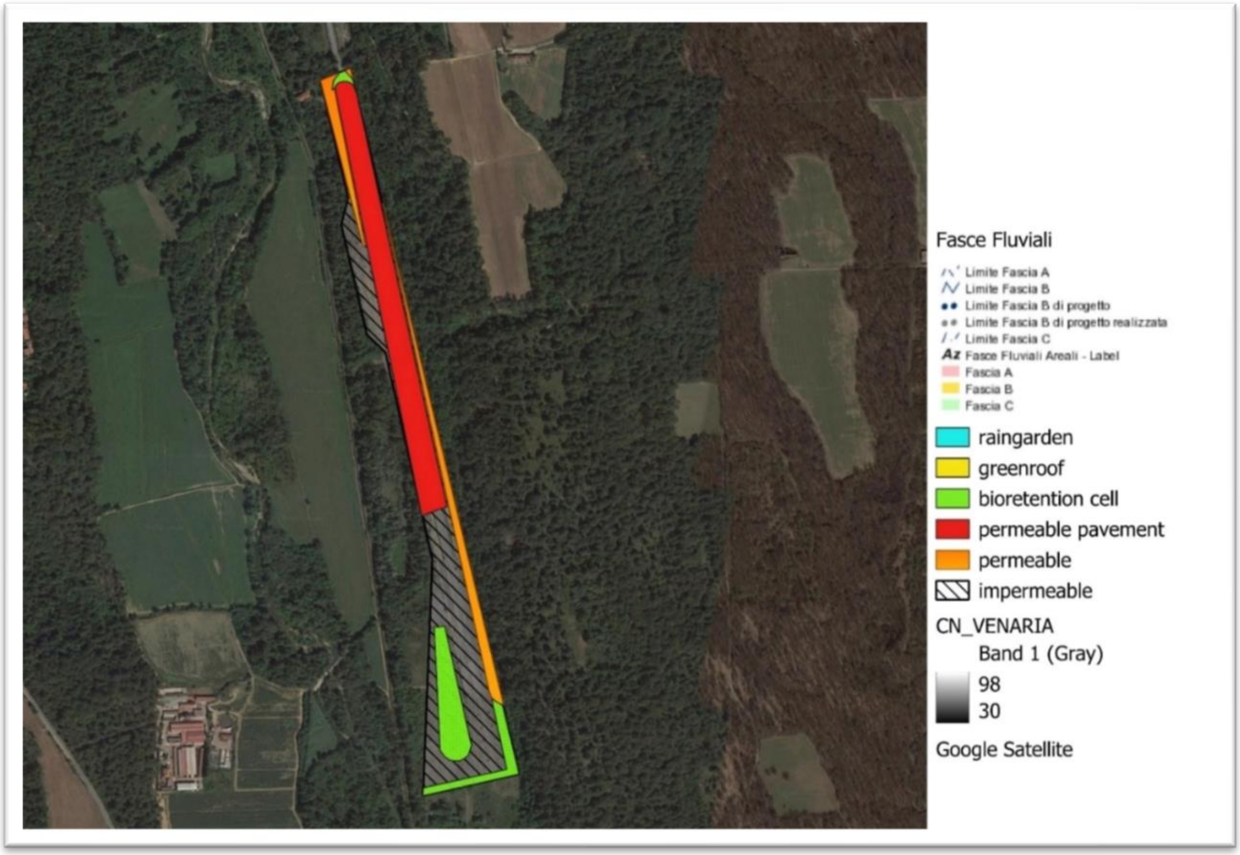


Figure 4-12 designed situation in fiat testing track

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]	LID area[ha]	Bio-Retention cell Area [ha]	Permeable Pavement [ha]
16.13	6.36	1.92	7.85	2.85	5

Table 4-4 Detailed area of each component in subcatchment 3

Additionally, a graphical representation depicts the proportional distribution of permeable surfaces, impermeable surfaces, and Low Impact Development (LID) controls integrated into the area, providing a visual summary of these strategic environmental interventions.

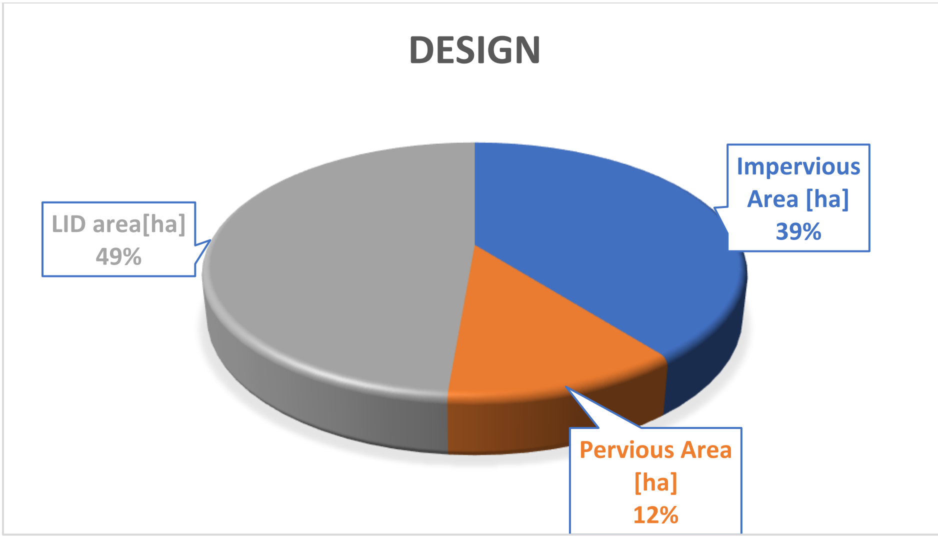


Figure 4-13 Percentage of pervious, impervious and LID area in subcatchment 3

In this graph generated by SWMM, it is demonstrated that the implementation of Low Impact Development (LID) controls results in a notable increase in infiltration within the area, surpassing the runoff generated by precipitation in the subcatchment. This significant finding indicates that the adoption of LID controls effectively mitigates the stormwater management challenges previously faced by the area. By facilitating enhanced infiltration rates, these measures contribute to a more sustainable approach to water management, thereby promoting resilience against urban runoff and improving overall environmental quality.

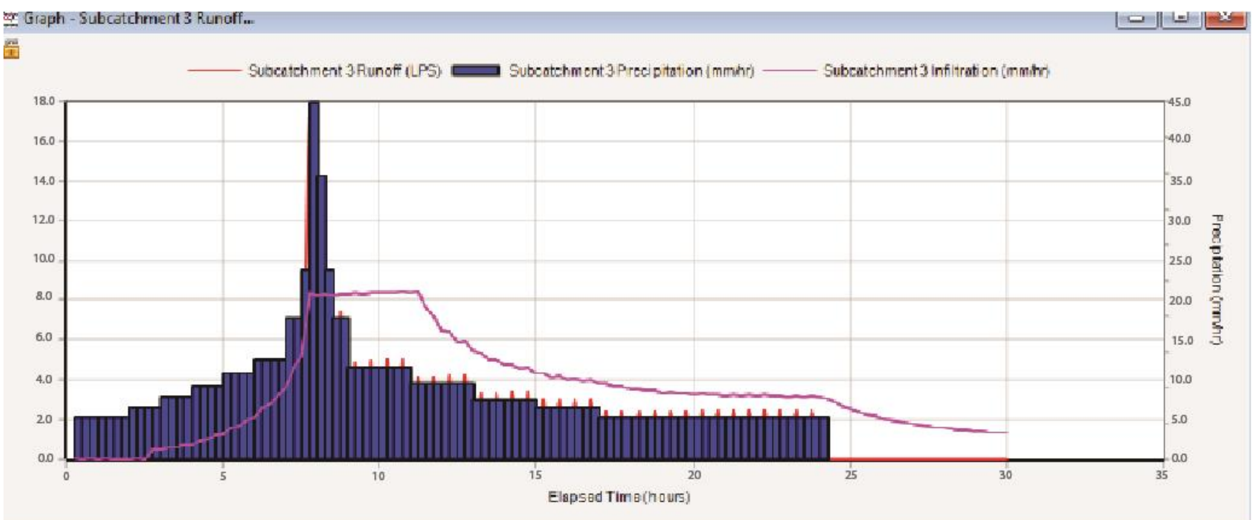


Figure 4-14 Runoff(LPS), infiltration, and precipitation in subcatchment 3

Reduced cost design scenario

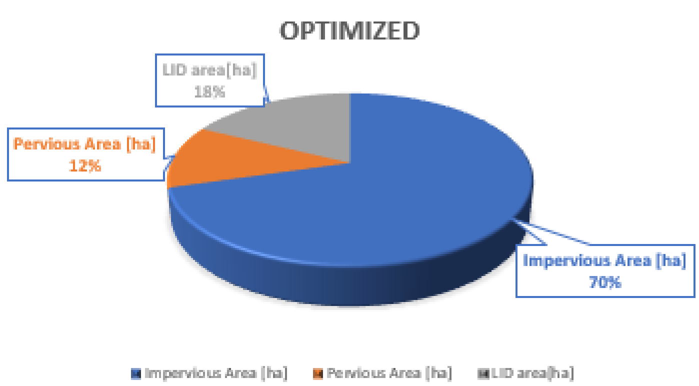
Reduced cost LID controls in the ex-fiat testing track (third scenario)

Building upon the insights gained from the previous scenario, it becomes evident that while Low Impact Development (LID) controls effectively addressed stormwater management challenges in the subcatchment, ongoing maintenance of permeable pavements has emerged as a critical issue over time. The decline in performance of these pavements, coupled with their high maintenance costs, underscores the need for an optimized approach. In response, consideration is given to integrating bio-retention cells, designed to function akin to water-retaining ponds. This strategic shift not only addresses the maintenance concerns associated with permeable pavements but also enhances water storage capabilities, thereby optimizing the sustainable management of urban water resources in the area. the integration of bio-retention cells offers several advantages. These cells not only provide effective stormwater management but also contribute to enhancing the aesthetic and ecological value of the area. By mimicking natural processes of water retention and filtration, bio-retention cells promote biodiversity and improve overall environmental resilience.

Moreover, the decision to transition to bio-retention cells reflects a strategic evolution in urban planning and infrastructure management, driven by lessons learned from the performance of permeable pavements. This adaptive strategy ensures that the subcatchment continues to meet its environmental goals effectively and efficiently, while also fostering community engagement and stewardship in urban water management practices.

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]	LID area[ha]	Bio-Retention cell Area [ha]
16.13	11.36	1.92	2.85	2.85

Areas in optimized design for Fiat testing-track



Percentages of pervious, impervious and optimized LID controls

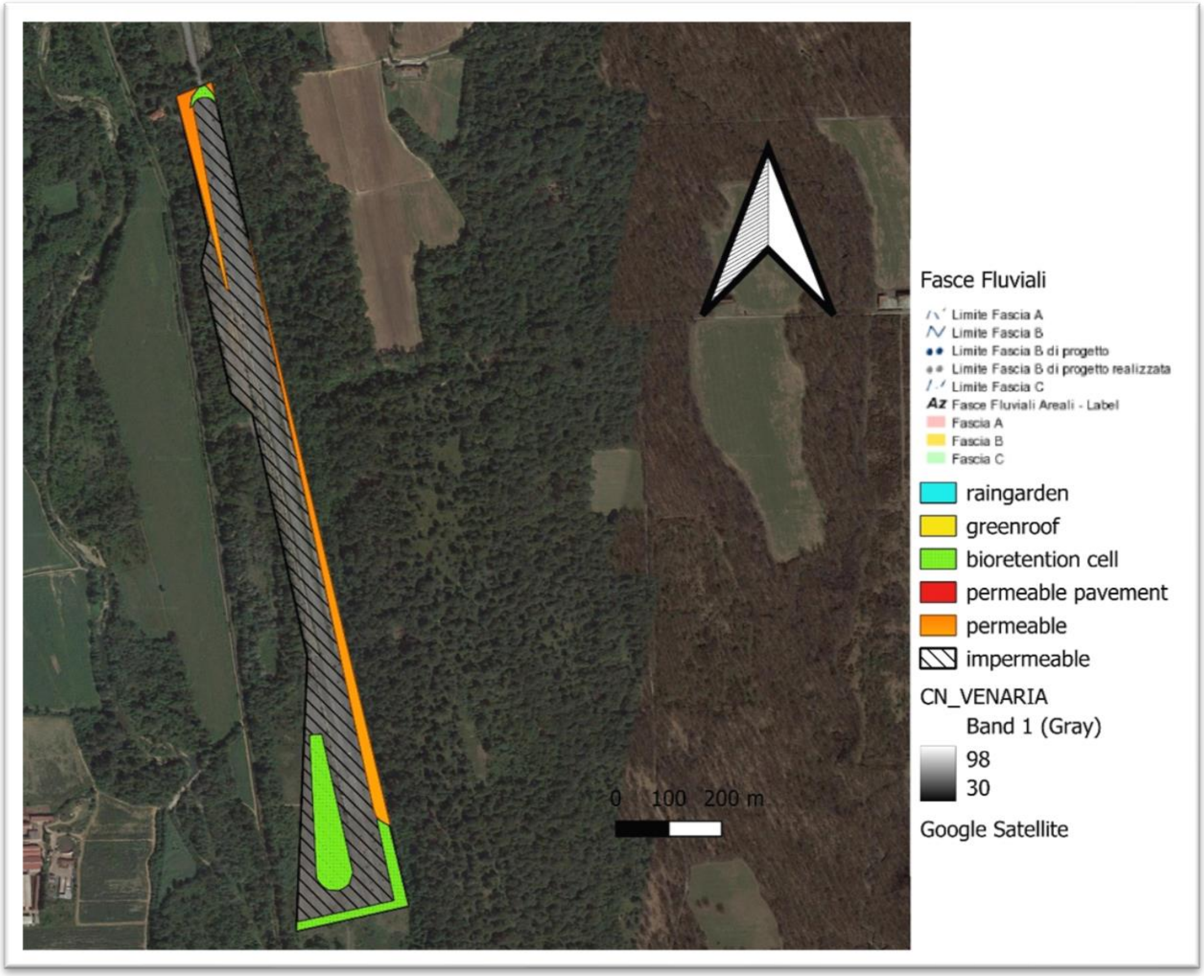


Figure 4-15 Optimized design in Fiat testing-track

As discerned from the SWMM model-generated graph, the removal of permeable pavement in the area resulted in a decrease in infiltration compared to the second scenario. However, it is crucial to note that the surrounding green permeable area facilitates the efficient conveyance of runoff water to aquifers in Parco La Mandria. This strategic utilization of natural permeable surfaces underscores the importance of integrating ecological principles into urban planning, ensuring that runoff management remains environmentally sustainable. By leveraging the inherent permeability of green spaces, this approach not only supports water resource replenishment but also enhances the overall ecological integrity and resilience of the surrounding landscape.

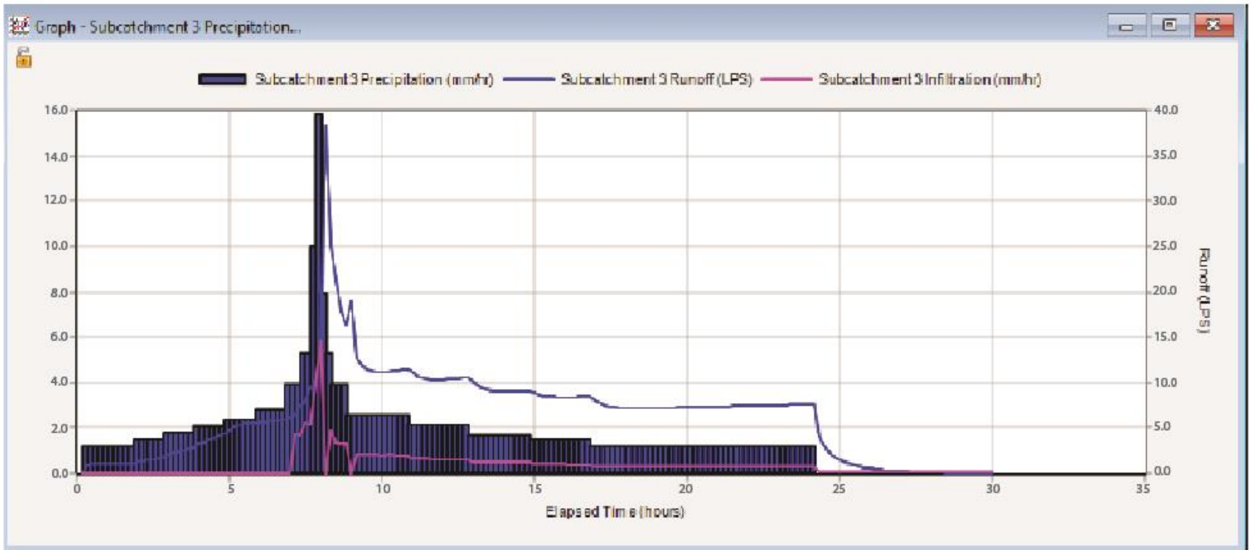


Figure 4-16 Runoff (LPS), precipitation, and infiltration in subcatchment 3 in optimized design

Residential area

Current situation

The area under consideration exhibits a predominantly residential character, complemented by essential amenities such as private residences, educational institutions, medical facilities, and integrated agricultural fields. It is traversed by a network of roads that interconnect different parts of the locality. The intricate interplay of these elements imposes constraints on potential interventions, given the current land use patterns.

Within this urban context, Geographic Information Systems (GIS) data assigns a Curve Number (CN) of 71 to the area, reflecting its hydrological properties. This parameter serves as a crucial indicator in assessing runoff potential and stormwater management strategies. Furthermore, the prevalence of impervious surfaces in the area is substantial, accounting for 84% of its total composition. This high proportion significantly influences the hydrological dynamics, affecting surface runoff rates and water infiltration capacities.

In the modeling framework in SWMM, this specific area is designated as subcatchment number 5, with junction number 6 assigned accordingly. These delineations provide a structured basis for simulating and analyzing hydrological responses within the urban environment, facilitating informed decision-making for sustainable water management practices.

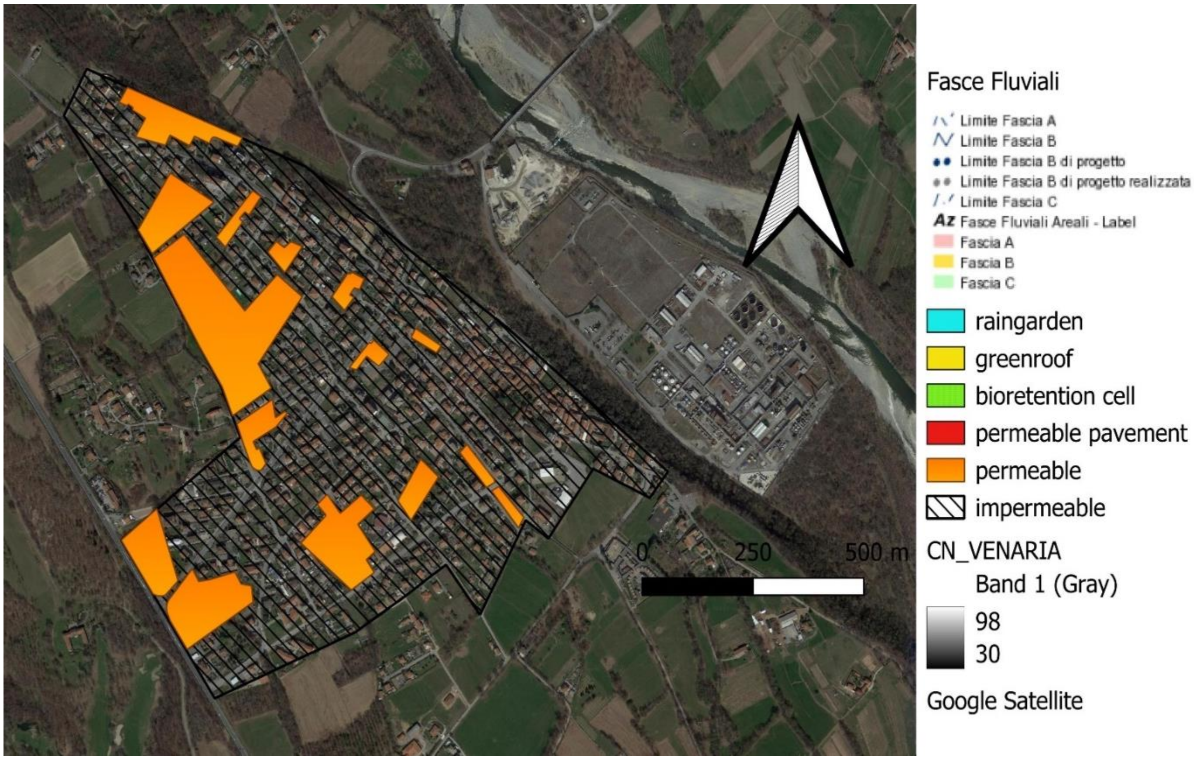


Figure 4-17 Permeable and impermeable surfaces in subcatchment 5

In the presented table and accompanying graph, the distribution percentages of the total area, permeable surfaces, and impermeable surfaces are depicted in the current situation existing now.

Total Area[ha]	Impervious Area[ha	Pervious Area [ha]
79.37	66.99	12.38

Table 4-5 areas in the residential area

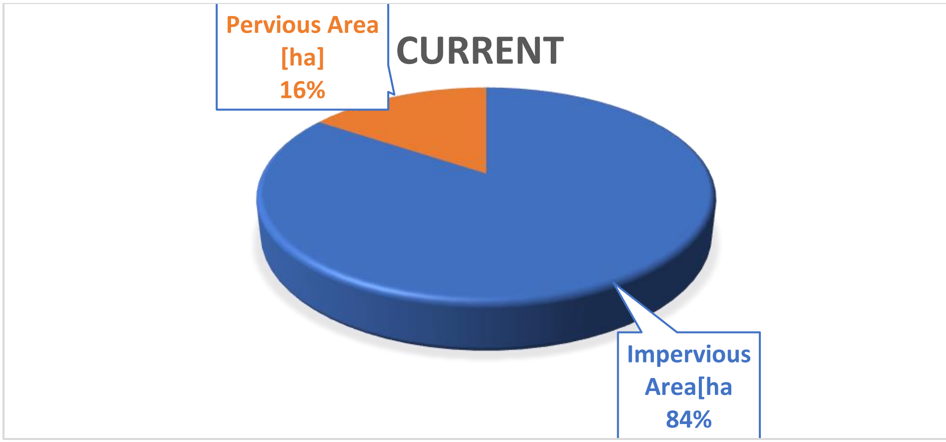


Figure 4-18 Percentage of permeable and impermeable area

The graphical representation of precipitation, runoff, and infiltration in subcatchment 5 indicates a pronounced peak in runoff observed at 8:00, accompanied by minimal infiltration. This hydrological imbalance has the potential to induce runoff and, under certain conditions, lead to localized flooding within the area.

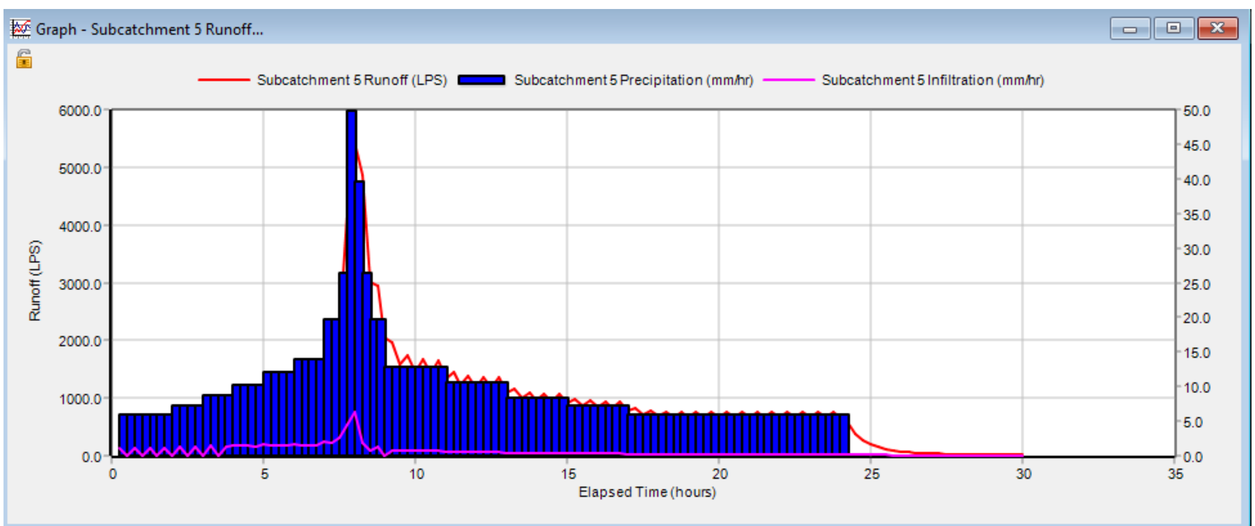


Figure 4-19 Runoff(LPS), precipitation, and infiltration in current situation subcatchment 5

Design scenario

Applying LID controls in residential areas (second scenario)

Fortuitously, the geographical positioning of this area outside flood risk delineations augments the feasibility of stormwater management endeavors, thereby affording a more straightforward implementation of mitigation measures. The absence of flood risk boundaries mitigates the complexities typically associated with water management strategies, facilitating a more streamlined approach to addressing potential runoff and drainage concerns within the locale. This advantageous spatial characteristic not only reduces the inherent challenges in stormwater management but also provides an opportune environment for the deployment of tailored interventions aimed at enhancing overall hydrological resilience and sustainability within the area. but the area under investigation exhibits a higher concentration of impervious surfaces, owing to its predominantly residential character. This is evident through the presence of an extensive road network, impervious roofs atop residential structures, and sizeable vacant plots that currently remain undeveloped, showcasing their natural state. However, a notable challenge arises within this context, stemming from the installation of solar panels on rooftops. Consequently, the implementation of Low Impact Development (LID) controls, particularly in the form of green roofs, may face limitations due to the presence of these facilities.

In certain areas of the park characterized by residential fabric, the feasibility of implementing green roofs as a form of Low Impact Development (LID) control is constrained by considerations such as privacy concerns and property ownership dynamics. Consequently, alternative LID controls, including bioretention cells, rain gardens, and permeable pavement, are prioritized for deployment in these contexts. These alternatives offer effective stormwater management solutions while circumventing the complexities associated with private property rights and individual consent. By establishing specific percentage targets for the coverage of bioretention cells, rain gardens, and permeable pavement within the area, the park management can ensure the systematic integration of LID practices into the built environment, thereby optimizing stormwater retention and infiltration capabilities. This strategic approach acknowledges the unique socio-economic and cultural factors influencing land use decisions in residential settings, while simultaneously promoting sustainable urban water management objectives within the park. The curve number is 71 gained from GIS data and the LID controls that are applied in this scenario are permeable pavements, rain gardens, bio-retention cells, and green roofs.

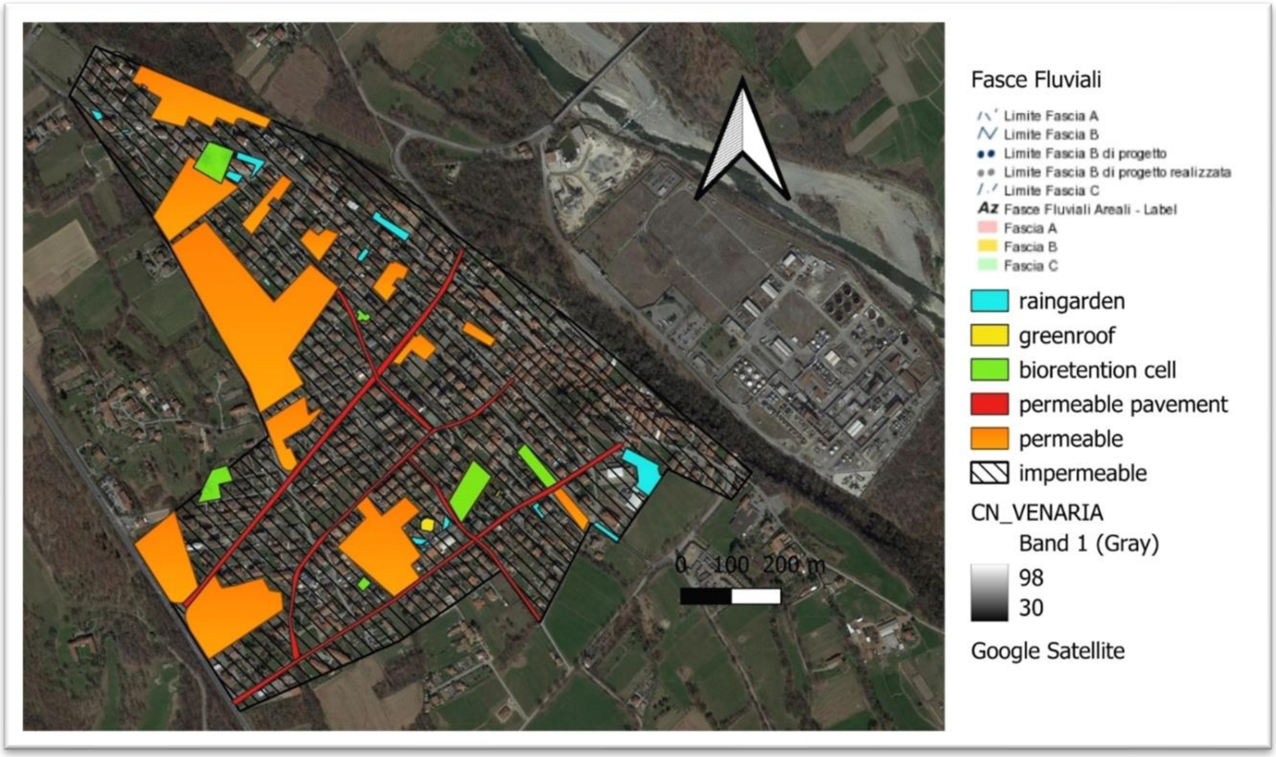


Figure 4-20 LID controls applied in subcatchment 5

The accompanying table and chart provide a detailed illustration of the quantities and percentages of permeable surfaces, impermeable surfaces, and Low Impact Development (LID) control implemented within the area and the amount of permeable area increased. The data clearly delineates the spatial distribution and proportional representation of each surface type, offering valuable insights into the area's land use and hydrological management. By presenting this information in both tabular and graphical formats, a comprehensive understanding of the extent and impact of LID interventions is facilitated, highlighting their role in mitigating runoff, enhancing infiltration, and promoting sustainable urban water management practices. This dual representation underscores the effectiveness of integrating LID controls in achieving a balanced and resilient urban ecosystem.

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]	LID area	Green Roof Area [ha]	Permeable Pavement (ha)	Rain Garden Area [ha]	Bio-Retention cell Area [ha]
79.37	60.3	12.38	6.69	0.07	3.5	1.82	1.3

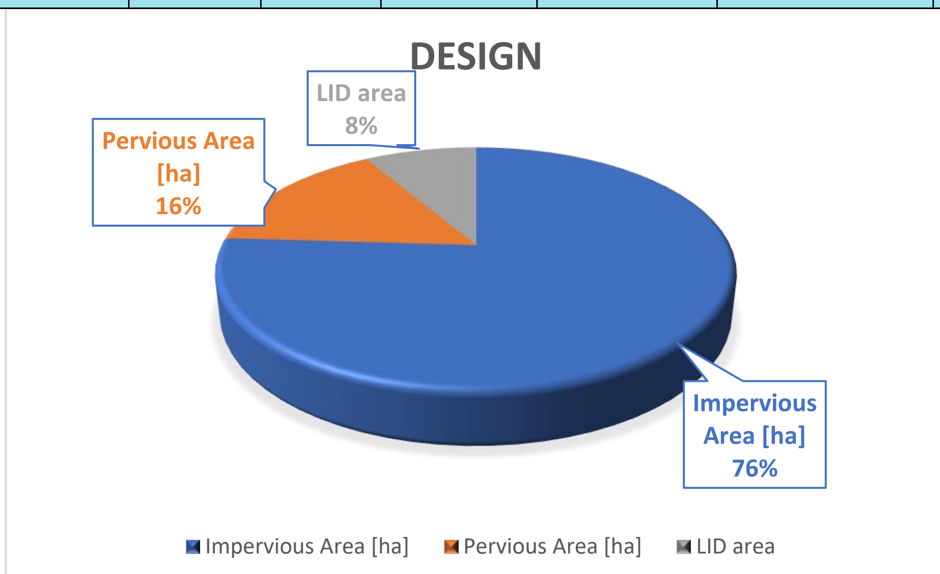


Figure 4-21 percentage of areas in the designed area

In this graph generated by SWMM, it is demonstrated that the implementation of Low Impact Development (LID) controls results in a notable increase in infiltration within the area, surpassing the runoff generated by precipitation in the subcatchment. This significant finding indicates that the adoption of LID controls effectively mitigates the stormwater management challenges previously faced by the area. By facilitating enhanced infiltration rates, these measures contribute to a more sustainable approach to water management, thereby promoting resilience against urban runoff and improving overall environmental quality.

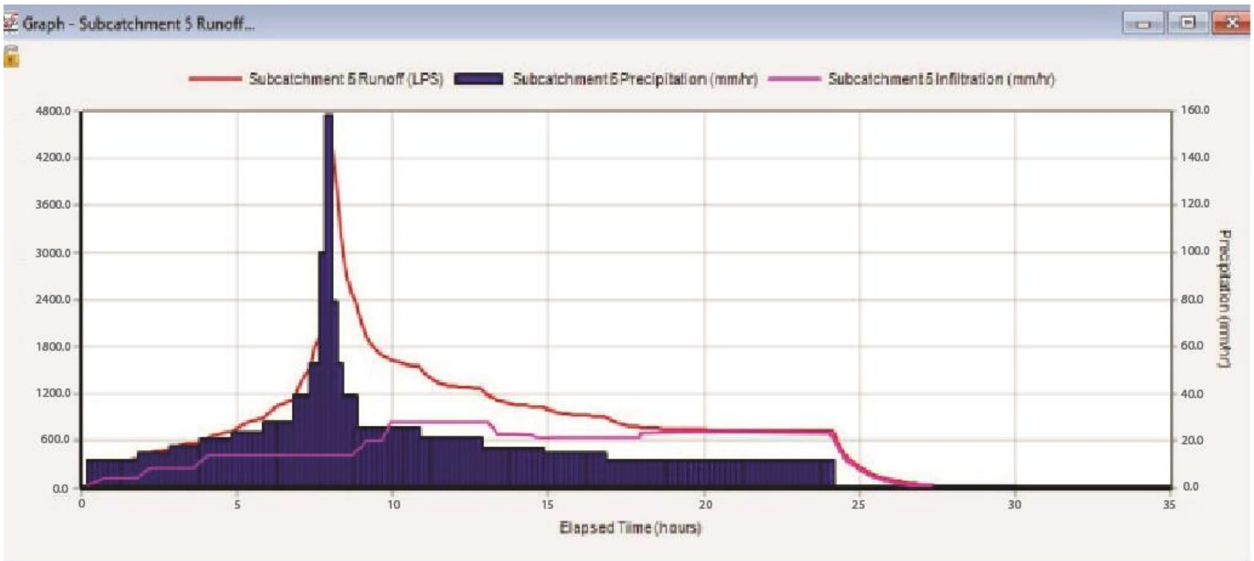


Figure 4-22 Runoff (LPS), infiltration and precipitation in designed area

Reduced cost design scenario

Reduced cost design in the residential area (third scenario)

In this part rain garden is eliminated in order to reduce the cost of applying the LID controls also this area is distinctive due to the combination of various textures and land uses, necessitating a thoughtful and optimized design of stormwater management components. The integration of green roofs, bio-retention cells, and permeable pavements has been strategically applied to address the unique hydrological and environmental challenges presented by this mixed-use landscape. These components work synergistically to enhance infiltration, reduce runoff, and improve the overall sustainability of the area. The accompanying map below illustrates the spatial distribution and implementation of these green, natural-based infrastructure elements, providing a comprehensive overview of their placement and intended impact within the subcatchment.

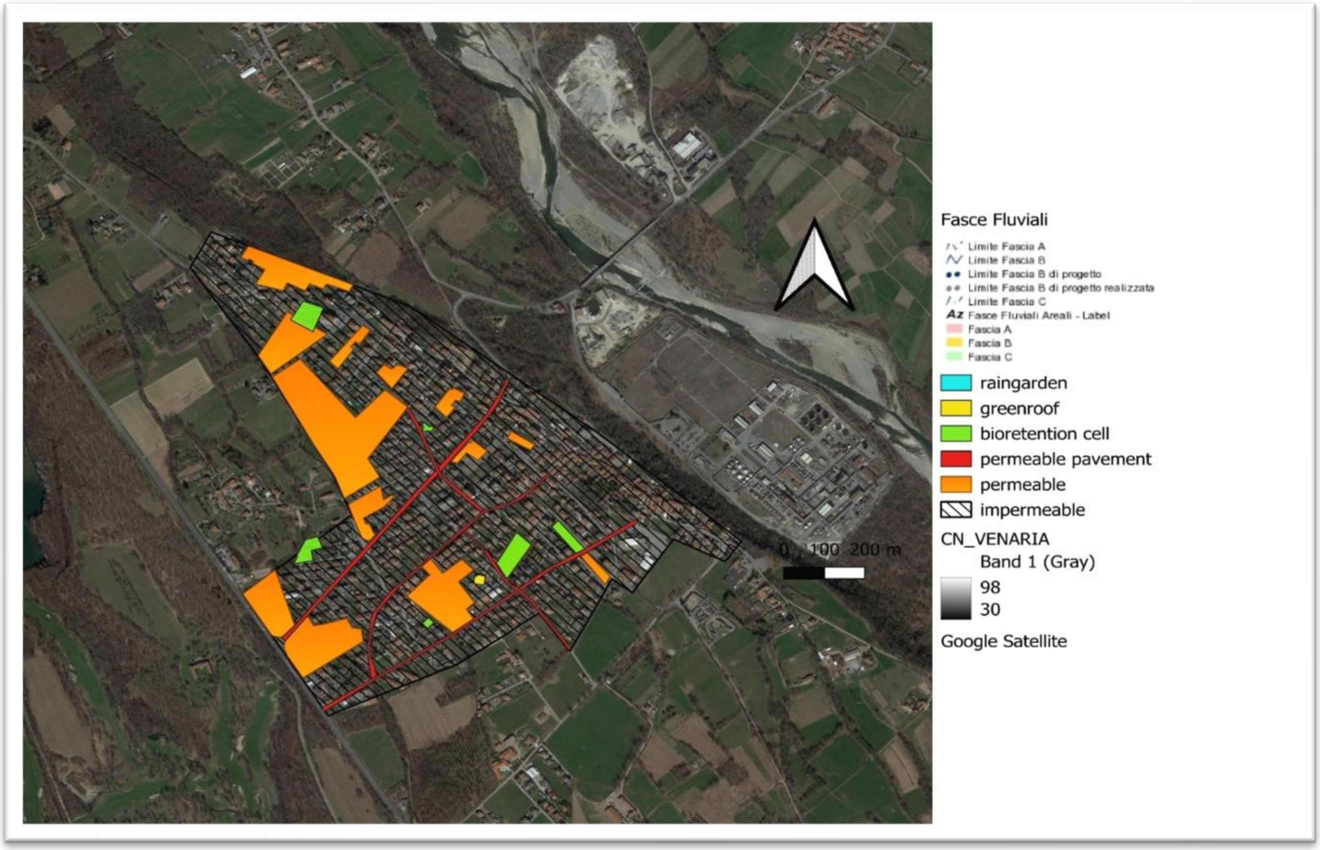


Figure 4-23 Optimized design in subcatchment 5

The following table shows the dispersion of permeable, impermeable, and LID areas in the subcatchment and also the percentages are illustrated in the pie chart. To show the differences in increasing permeable surface compared to the existing situation. As it can be resulted only 2% of LID area is decreased in this design. And the percentage of impermeable are is reduced to 78%

Total Area [ha]	Impervious Area [ha]	Pervious Area [ha]	LID area	Green Roof Area [ha]	Permeable Pavement (ha)	Bio-Retention cell Area [ha]
79.37	62.12	12.38	4.87	0.07	3.5	1.3

Table 4-7 areas in optimized design

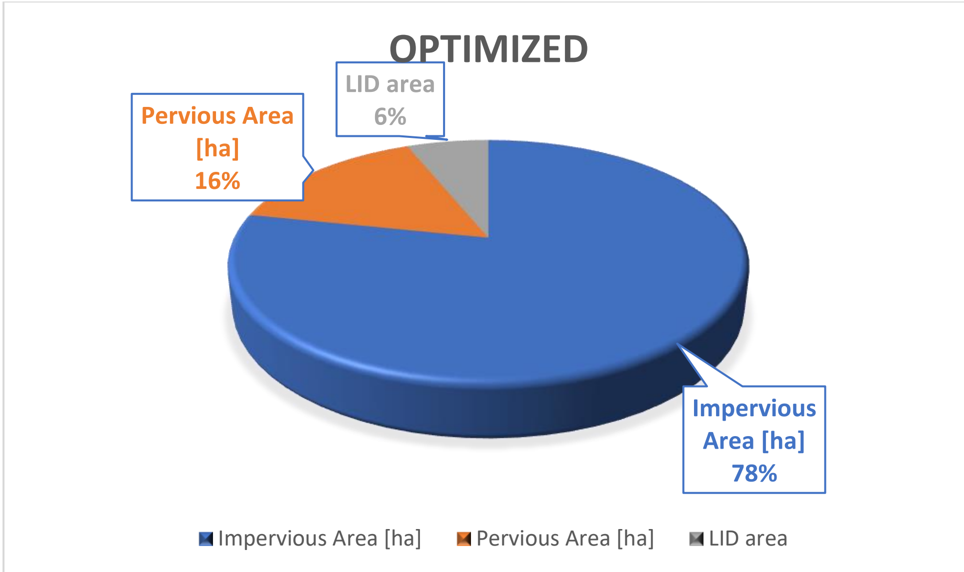


Figure 4-24 percentage of area in optimized design

Here in this table the runoff, precipitation, and infiltration are illustrated gained from the SWMM model in order to compare the performance of applying LID controls. As discerned from the SWMM model-generated graph, the removal of rain gardens in the area resulted in a decrease in infiltration compared to the second scenario whichmeans infiltration is still less than runoff. However, it is crucial to note that the surrounding green permeable area facilitates the efficient conveyance of runoff water to aquifers in Parco La Mandria. This strategic utilization of natural permeable surfaces underscores the importance of integrating ecological principles into urban planning, ensuring that runoff management remains environmentally sustainable. By leveraging the inherent permeability of green spaces, this approach not only supports water resource replenishment but also enhances the overall ecological integrity and resilience of the surrounding landscape.

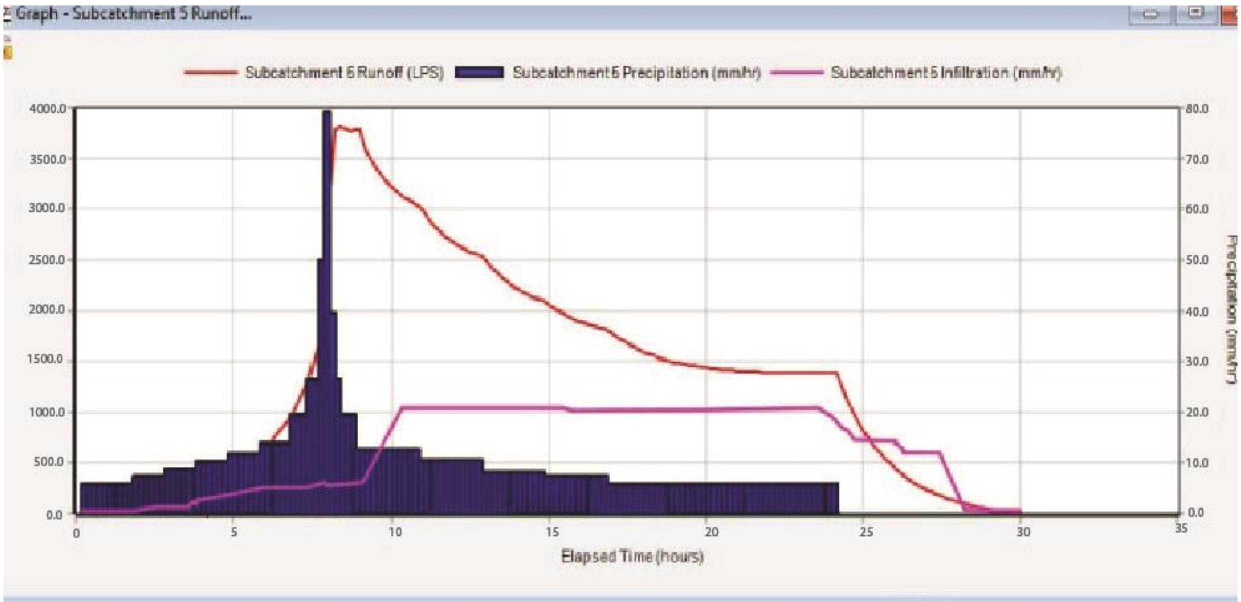
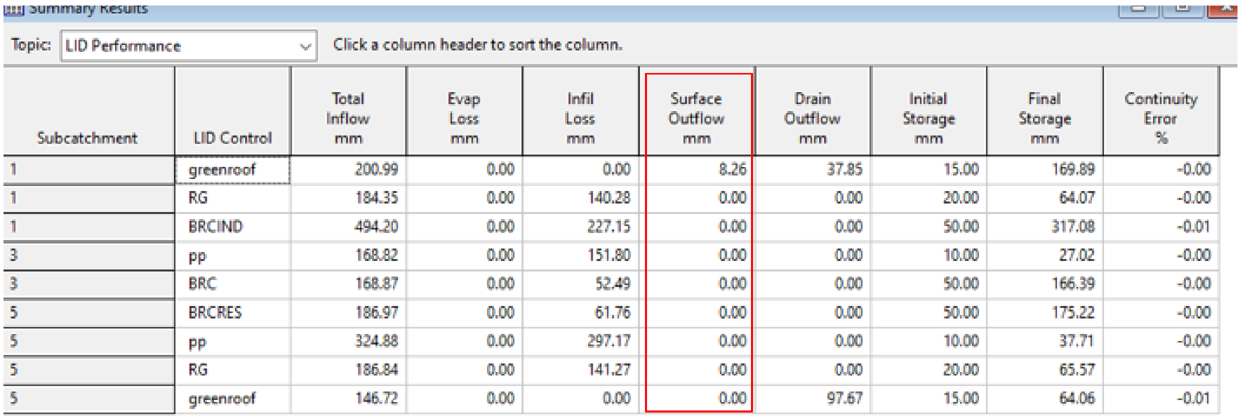


Figure 4-25 runoff-infiltration and precipitation in optimized design

According to the summary results of Low Impact Development (LID) performance in the Storm Water Management Model (SWMM) analysis, the surface outflow in each subcatchment is recorded as zero. This indicates that the LID controls implemented are functioning effectively, successfully mitigating runoff within the analyzed area. This outcome suggests a substantial improvement in managing stormwater, highlighting the efficacy of LID strategies such as permeable pavements, rain gardens, and bioretention cells in reducing surface runoff. However, an exception is noted in the case of green roofs. The surface outflow value for green roofs is not zero. This discrepancy arises because green roofs primarily manage precipitation falling directly on them, rather than enhancing the permeability of the entire area. Unlike other LID measures that contribute to overall watershed permeability, green roofs are designed to capture and utilize rainfall at the source, thereby limiting their influence on the runoff dynamics of the broader area. This distinction underscores the need to consider the specific functions and contributions of different LID practices when evaluating their overall effectiveness in comprehensive stormwater management plans.



Summary Results

Topic: LID Performance   Click a column header to sort the column.

Subcatchment	LID Control	Total Inflow mm	Evap Loss mm	Infil Loss mm	Surface Outflow mm	Drain Outflow mm	Initial Storage mm	Final Storage mm	Continuity Error %
1	greenroof	200.99	0.00	0.00	8.26	37.85	15.00	169.89	-0.00
1	RG	184.35	0.00	140.28	0.00	0.00	20.00	64.07	-0.00
1	BRCIND	494.20	0.00	227.15	0.00	0.00	50.00	317.08	-0.01
3	pp	168.82	0.00	151.80	0.00	0.00	10.00	27.02	-0.00
3	BRC	168.87	0.00	52.49	0.00	0.00	50.00	166.39	-0.00
5	BRCRES	186.97	0.00	61.76	0.00	0.00	50.00	175.22	-0.00
5	pp	324.88	0.00	297.17	0.00	0.00	10.00	37.71	-0.00
5	RG	186.84	0.00	141.27	0.00	0.00	20.00	65.57	-0.00
5	greenroof	146.72	0.00	0.00	0.00	97.67	15.00	64.06	-0.01

Figure 4-26 Summary result for LID performance

The chart below illustrates that there is no flooding within the system, signifying that despite accounting for all precipitation and runoff, the system effectively manages the water flow without exceeding its capacity. This absence of flooding is a crucial indicator of the system's robustness and efficiency in handling stormwater. It demonstrates that the implemented measures and infrastructural designs are sufficient to accommodate the volume of water generated during precipitation events. The successful mitigation of potential flooding highlights the effectiveness of runoff management strategies employed. This outcome provides confidence in its ability to protect the area from flood-related damages, thereby ensuring the safety and stability of the infrastructure and surrounding environment.

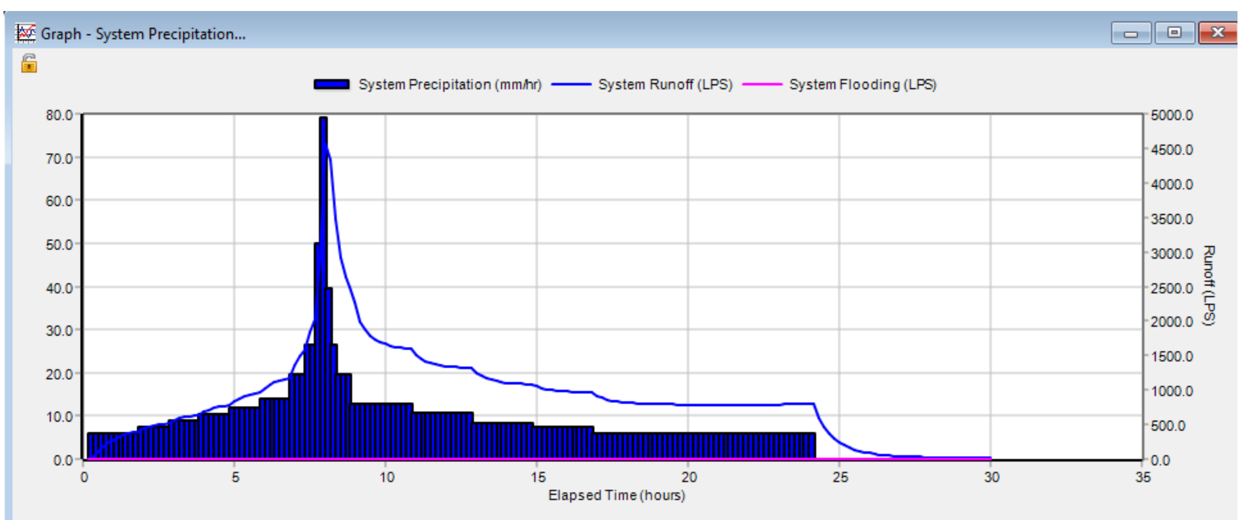


Figure 4-27 System flooding and precipitation

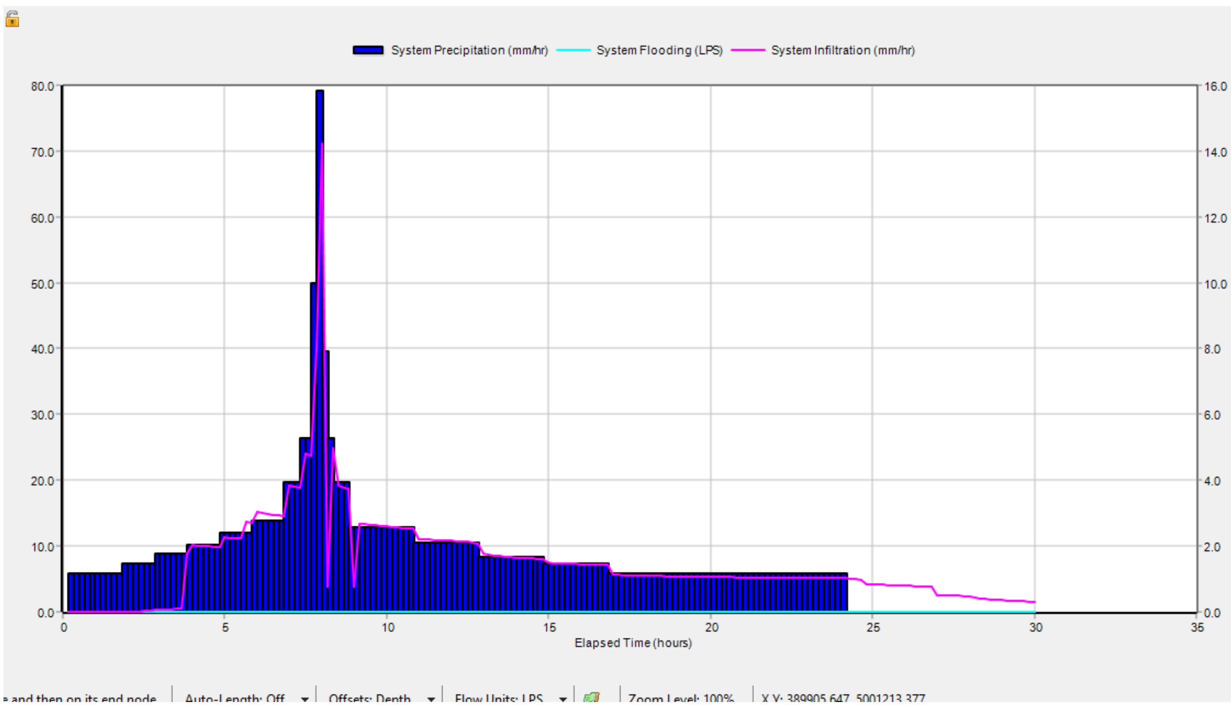


Figure 4-28 Comparing system precipitation, flooding, and infiltration

Chapter five

Costs

Financial and costs

In this chapter, we will undertake a detailed financial analysis of the proposed Low Impact Development (LID) controls for stormwater management in Parco La mandria, Piedmont. Building on the extensive data and findings presented in the preceding chapters, our objective is to meticulously calculate all the associated expenses and costs for the proposed LID measures. By doing so, we aim to establish a clear and comprehensive financial framework that will facilitate the comparison and evaluation of various implementation scenarios.

Our analysis will encompass the total raw costs, which include direct expenditure for materials, equipment essential for the deployment of each LID control. In addition to these direct costs, we will account for general expenses.

Moreover, we will apply the Value-Added Tax (VAT) at the standard rate of 22%, as mandated in Italy, to both the raw costs and the general expenses. This comprehensive approach ensures that our cost calculations reflect the true financial outlay required for the project.

By providing a detailed breakdown of costs for each scenario, our aim is to offer a clear comparison that will aid stakeholders in making informed decisions regarding the performance and feasibility of the proposed LID controls. This chapter will thus serve as a crucial component of our overall feasibility study, integrating economic considerations with the technical and environmental benefits previously discussed.

The price for each facility is described in the table below:

type	price[€/m2]
green roof	53-98
rain garden	100-200
bioretention cell	50-200
permeable pavement	110-112

Table 5-1 prices for utilities (€/m2)

In the industrial section, the estimated costs for the second scenario are presented in the Table:

type	[€] min	[€] max
green roof	2120000	3920000
rain garden	1500000	3000000
bioretention cell	125000	500000
total row cost	3745000	7420000
general expenses	4306750	8533000
VAT 22%	947485	1877260
gross total	5254235	10410260

Table 5-2 Second scenario LID applied in the industrial area

type	[€] min	[€] max
rain garden	1500000	3000000
bioretention cell	125000	500000
total row cost	1625000	3500000
general expenses	1868750	4025000
VAT 22%	411125	885500
gross total	2279875	4910500

Table 5-3 Optimized design (third scenario) in the industrial area

As it can be understood from the tables minimum and maximum costs for the LID area are 5,254,235 Euro and 10,410,260 Euro and for an optimized design, the prices minimum and maximum are 2,279,875 Euro and 4,910,500 Euro respectively which is significantly lower.

In fiat testing company the facilities used are permeable pavements and bio-retention cells the total costs are presented in the table:

type	[€] min	[€] max
permeable pavement	5500000	5600000
bioretention cell	1425000	5700000
total row cost	6925000	11300000
general expenses	7963750	12995000
VAT 22%	1752025	2858900
gross total	9715775	15853900

Table 5-4 Second scenario (LID applied) in fiat testing track

type	[€/m2] min	[€/m2] max
bioretention cell	1425000	5700000
total row cost	1425000	5700000
general expenses	1638750	6555000
VAT 22%	360525	1442100
gross total	1999275	7997100

Table 5-5 Optimized design (third scenario) in fiat testing track

According to these tables, the minimum and maximum costs for the second scenario are 9,715,775 Euro and 15,713,600 Euro. In the third scenario, the minimum and maximum expenses are 1,999,275 and 7,997,100 Euro respectively.

In the residential area as was described, bio-retention cells, permeable pavements, rain gardens and green roofs are applied. According to the data the costs are provided in the table below:

type	[€] min	[€] max
green roof	37100	68600
rain garden	1820000	3640000
bioretetion cell	650000	2600000
permeable pavement	3850000	3920000
total row cost	6357100	10228600
general expenses	7310665	11762890
VAT 22%	1608346.3	2587835.8
gross total	8919011.3	14350725.8

Table 5-6 LID controls applied (second scenario) in the residential area

type	[€] min	[€] max
green roof	37100	68600
bioretention cell	650000	2600000
permeable pavement	3850000	3920000
total row cost	4537100	6588600
general expenses	5217665	7576890
VAT 22%	1147886.3	1666915.8
gross total	6365551.3	9243805.8

Table 5-7 Optimized design (third scenario) in the residential area

According to the tables, the estimated costs for the second scenario range from a minimum of 89,190,113 euros to a maximum of 92,359,658 euros. However, in the optimized design, these costs are significantly reduced, with the minimum and maximum costs dropping to 63,655,513 Euro and 41,290,458 Euro respectively. This substantial reduction demonstrates that by eliminating specific utilities in each subcatchment, a considerable decrease in expenses can be achieved, highlighting the financial benefits of optimization.

Chapter 6

Conclusion

Conclusion

Parco La Mandria, located in the Piedmont region of Italy near the city of Turin, is a significant natural park that faces notable challenges in stormwater management. In this study, three different contexts within the park were selected for cost estimation and analysis. A primary issue identified was the extensive use of impermeable surfaces, such as asphalt and concrete, in urbanized and industrial areas. These surfaces exacerbate flooding during rainfall events due to the lack of permeable surfaces that facilitate water infiltration. Historical records indicate that flooding has occurred in these areas in past years, highlighting the urgency of addressing this issue.

The industrial area within Parco La Mandria is particularly vulnerable, as it is situated within a high flood-risk zone. In contrast, the residential area is located in a relatively safe zone with lower flood risk. Additionally, the Fiat testing road segment is adjacent to a flood-risk area, further complicating stormwater management efforts.

To mitigate these flooding risks and stormwater management, the proposed solution focuses on increasing surface permeability through the implementation of Low Impact Development (LID) controls. These controls are designed to enhance water infiltration and reduce surface runoff in each subcatchment area.

Specifically, in the industrial area, the application of LID controls resulted in a 28% reduction in impermeable surfaces, significantly improving water management and reducing flood risk. In the Fiat Road area, 49% of the impermeable surface was treated, demonstrating substantial progress in enhancing permeability. Meanwhile, in the residential area, where the extent of impermeable surfaces was relatively limited, 8% of the area was treated.

Another approach involved optimizing the design for implementing Low Impact Development (LID) controls in the specified areas to achieve optimal performance at minimal costs. This strategy included selecting natural-based solutions tailored to each zone: treating 8% of impermeable surfaces in industrial zones, 18% of permeable surfaces in field road areas, and addressing 6% of impervious surfaces in industrial sectors. In this mode, the infiltration rate experienced a slight decrease, which was insufficient to completely manage the runoff. However, it remained close to effectively infiltrating the entire amount of runoff water in both the flat and residential areas. By strategically applying these LID controls, the aim was to enhance environmental sustainability and mitigate urban runoff effectively across diverse urban landscapes while ensuring economic feasibility.

These measures are expected to substantially alleviate the flooding problems by promoting better water infiltration and reducing runoff, thereby contributing to the overall resilience of Parco La Mandria against future flood events.

In conclusion, the implementation of Low Impact Development (LID) designs and optimized designs across different areas demonstrated significant improvements in runoff reduction. In the industrial area, the runoff decreased by 66.67% with the LID design and by 33% with the optimized design. On the Fiat testing road, these reductions were 50% and 20%, respectively. Finally, in the residential area, runoff decreased by 20% with the LID design and by 13.33% with the optimized design. These findings underscore the effectiveness of both LID and optimized designs in enhancing stormwater management and reducing environmental impacts across various settings. Furthermore, the economic analysis detailed in the preceding chapter provides valuable insights into the cost implications of implementing Low Impact Development (LID) controls across different urban zones. In the industrial areas, the estimated costs vary significantly, ranging from a minimum of €5,254,235 to a maximum of €10,410,260 for conventional LID applications, with an average expenditure of €7,832,247. In contrast, an optimized design approach reduces costs substantially, with estimates ranging from €2,279,875 to €4,910,500, averaging €2,569,242. For the fiat testing track, implementing LID controls is projected to cost between €9,715,775 and €15,713,600, with an average expenditure of €12,714,687, whereas an optimized strategy suggests costs between €1,999,275 and €7,997,100, averaging €4,998,187. Residential areas exhibit higher costs for LID implementations, ranging from €89,190,113 to €92,359,658, averaging €90,774,885, while optimized designs range from €63,655,513 to €41,290,458, reflecting potential savings through efficient design and planning. These economic estimates underscore the importance of tailored approaches in urban planning to balance environmental benefits with economic feasibility across diverse urban settings.

It is crucial to highlight that this thesis comprehensively addresses all the shared Sustainable Development Goals (SDGs) that align with the objectives of the Life Project. The analysis undertaken herein has effectively resolved the primary cause of runoff and stormwater in the case study area, namely the deficiency of green spaces. Moreover, it is imperative to acknowledge the pivotal roles played by the Municipality and the Metropolitan City of Turin in implementing this project.

This initiative represents a significant stride toward fostering resilient cities and advancing the concept of the implementation of Low Impact Development (LID) techniques. It also addresses the challenges of territorial governance in Piedmont by advocating for adequate budget allocations for such transformative projects. These facilities not only serve to mitigate flood risks but also play a crucial role in recharging underground aquifers and also filtration of stored water from stormwater and runoff. Furthermore, using these techniques will lead to some delay in runoff on impermeable surfaces which will be efficient in reducing flood risks. Moreover, bridging the financial gap for private stakeholders could be achieved through incentives, such as the Super Eco bonus 110 provided by the National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA), aimed at encouraging the adoption of essential LID practices across.

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