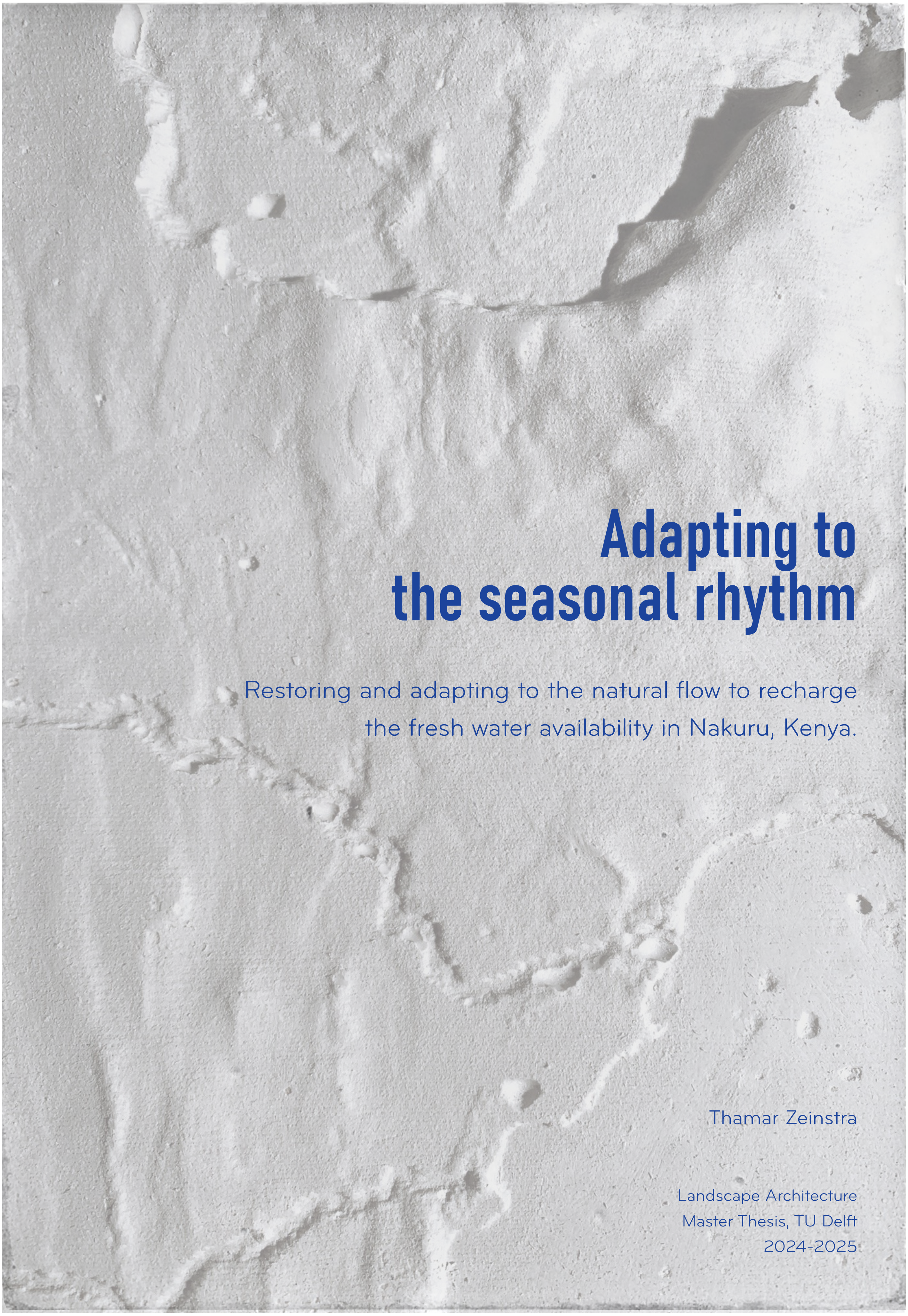

Adapting to the seasonal rhythm

Restoring and adapting to the natural flow to recharge the fresh water availability in Nakuru, Kenya.

Thamar Zeinstra

Landscape Architecture
Master Thesis, TU Delft
2024-2025

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"A source of wealth is the functional ecosystem. The products and services that we derive from those are derivatives. It is impossible for the derivatives to be more valuable than the source.
We need to redefine and revalue our belief systems"

\- *Ecologist John D. Liu (1995)*

Gully formation near the Menengai Caldera, Nakuru (photo by author)

Abstract

Rapid urbanization in Nakuru, Kenya, has intensified the conflict between human development and fragile ecological systems. Land-use changes, deforestation, and inadequate infrastructure have disrupted natural systems over time, leading to excessive surface runoff, erosion, and groundwater depletion. These pressures are further worsened by climate change and the growing demand for basic services in Nakuru City. This research investigates how a landscape-based spatial strategy can strengthen social-ecological resilience by recharging freshwater availability and transforming seasonal runoff from a source of risk into a driver of regeneration.

Using a design-led approach, the study integrates hydrological and socio-spatial analysis with co-design workshops conducted on site to develop a systemic and layered spatial framework for water management across Nakuru's seasonal watershed. Three flow zones were identified within the watershed, guiding the structure of the design strategy: delay and infiltrate in the upstream, transport and purify in the midstream, and collect and reuse downstream. These functions are translated into an interconnected spatial strategy for the western side of Nakuru that manages runoff while restoring ecological and social continuity and improving freshwater recharge.

The research also includes a detailed design study for the upstream zone, testing the applicability of the overall design strategy and its supporting principles on site. This process provided a basis for nature-based and community-led design explorations, showing how hydrological performance can be combined with productive land use, ecological restoration, and local participation. The design outcomes demonstrate that each part of the restoration network generates specific benefits for different stakeholder groups: farmers benefit from improved soil fertility and more diverse yields, institutions gain from increased groundwater recharge and reduced clean-up costs, and local communities experience better living conditions through greener and more accessible environments.

The results highlight the potential of landscape architecture as a practice that links ecological and hydrological processes with socio-cultural dynamics and governance. The proposed framework offers a scalable and transferable approach for restoring water balance and social-ecological resilience in other rapidly urbanizing regions, where environmental degradation and urban growth are closely intertwined.

Keywords

Landscape-based; hydrological restoration; runoff management; urban flooding; urban ecology; Ecopolis Strategy; indigenous knowledge (LO-tek); Nature-Based Solutions; social-ecological resilience; landscape architecture; Nakuru, Kenya.

Njoro river (photo by author)

Acknowledgement

First of all, I would like to thank my supervisors, Nico Tillie and Kristel Aalbers, for their patience, expertise, and open ear throughout this research process. Their guidance and feedback has been invaluable in helping me shape both the direction and depth of this work.

Being the project leader of my own research was both challenging and rewarding. It came with its share of obstacles, but also provided a great deal of freedom to make choices and explore my own path within the design process.

The topic of this research and my visit to Kenya have continuously inspired me during the development of this project. On site, I was able to witness how communities care for one another and live in close relation to the landscape in remarkable and inspiring ways. This experience was made possible by the people I met there, our host Loise, Enoch, Jamal, and Joy, and for whom I am forever grateful. They helped me find direction and inspiration for my research, introduced me to Kenyan culture, and gave me a glimpse into their lives in Nakuru. The warmth, joy, and hospitality I experienced in these places, are what makes Kenya such a special place. I am also grateful to have shared this adventure with my fellow student and friend Bouke.

This research has greatly shaped and broadened my perspective on the field of landscape architecture, deepening my understanding of its role in addressing complex environmental and social challenges. Working in a context so different from my own taught me to approach design with humility and curiosity, to listen before drawing, and to value local knowledge as an essential foundation for meaningful change. It has shown me that landscape architecture is not only about designing spaces but also about connecting people, systems, and stories, creating frameworks that can adapt, grow, and belong to the communities they serve.

Enoch, Bouke, and our host Loise at their home in Nakuru, whose kindness and local knowledge deeply enriched this research experience.

Native Vachellia tortilis, known as Umbrella Thorn (photo by author)

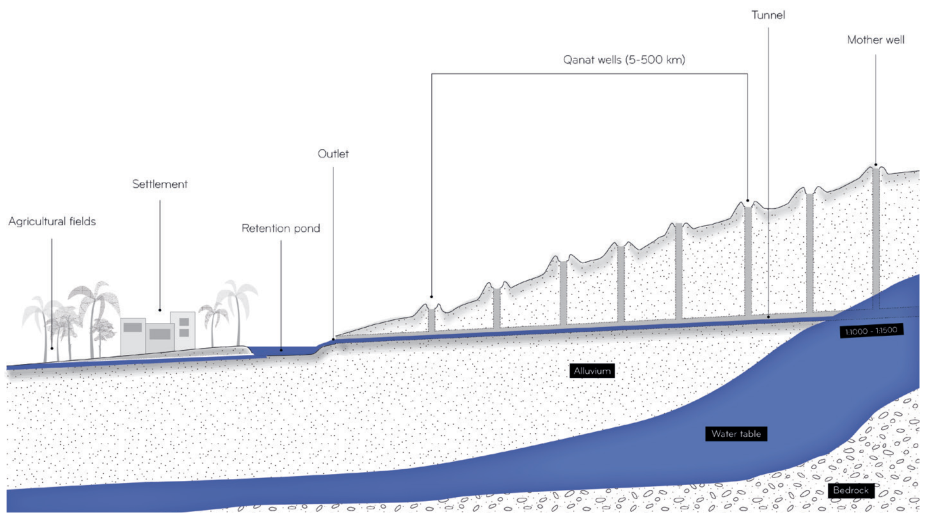
Water as the source of life

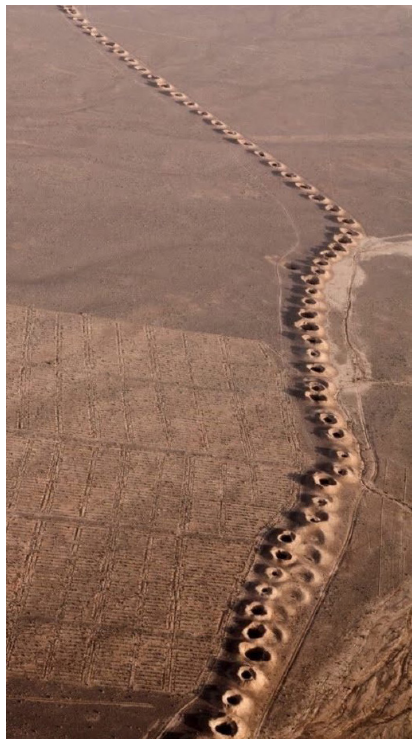
Extreme seasonal variabilities due to climate change call for significant changes and diverse functions in landscapes. What is our relationship with water?

In the Netherlands, we have excelled in using technical innovations to protect ourselves from water-related threats, and historically, we have had abundant water resources. However, regions characterized by scarcity and extreme variability in precipitation patterns require innovative and sustainable strategies to succeed and survive. Such strategies should emphasize sustainable water use and climate adaptation and can provide valuable design principles.

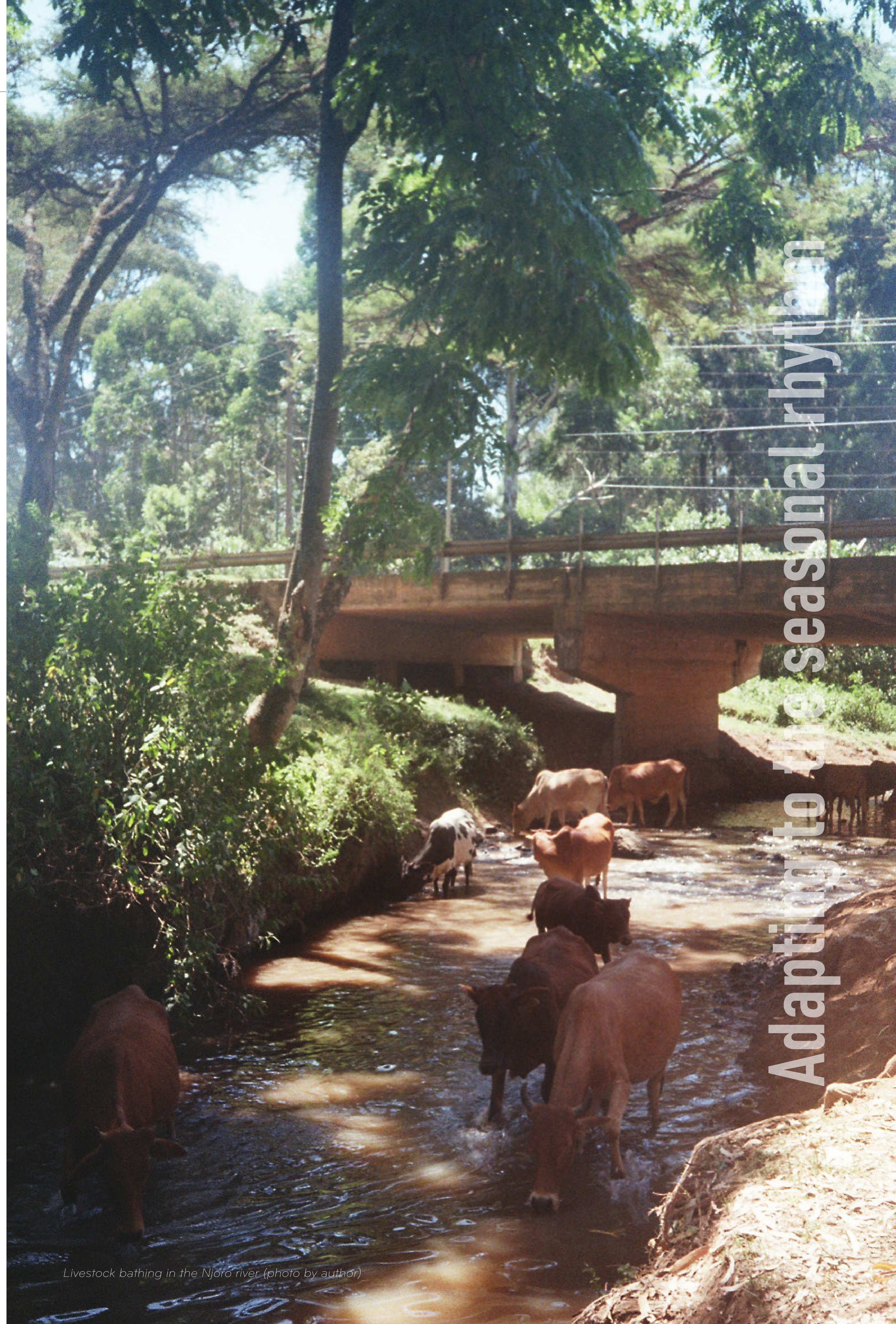
As an example, arid landscapes in the Middle East demand careful water management. Local populations often demonstrate deep knowledge of water sources and effective usage practices. Their proximity to and cultural relationship with water resources provide valuable insights into sustainable and traditional water use in arid climates, such as the ancient irrigation system called Qanat (meaning "to dig") (Watson, 2019).
The system consists of man-made tunnels and channels, first constructed by the Persians around 500 BCE (Watson, 2019). It was introduced to transport underground water from aquifers to lower valleys with human settlements and agricultural patches. The system relies mainly on gravity, without using mechanical power, and has served as a spatial organizer for human settlements over time. Many Qanat systems were built, offering opportunities for the birth and growth of new settlements in arid landscapes. By following and guiding water through a landscape of scarcity, human settlements have been built based on the availability of water. These systems show how the natural availability of water influences the spatial distribution of human settlements in a landscape of scarcity, while using a sustainable water harvesting system that reduces water loss by evaporation and supplies continuous clean water from a renewable resource (Watson, 2019).

As this example illustrates, water is a fundamental pillar of life and movement. It demonstrates that the availability or absence of water influences migration patterns worldwide on various scales. This insight sparked my personal interest and became the starting point of this project.



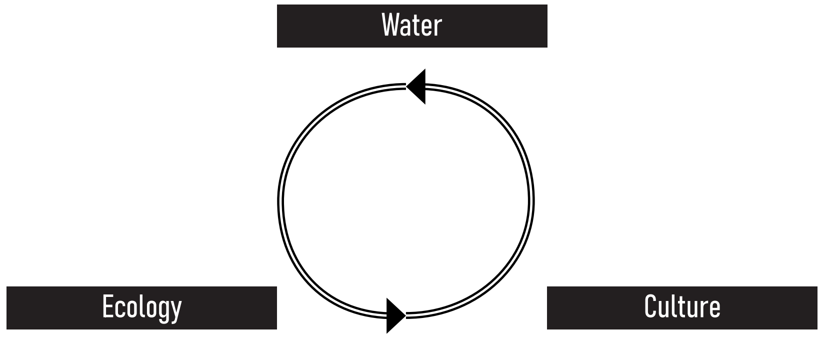


[Figure 1.] Acient irrigation system Qanat in arid landscapes to transport groundwater from underground aquifers to to human settlement at surface-level over long distances (by author);
[Figure 2.] Qanat system visible at the surface; photo by Alireza Teimoury (Watson, 2019).



Livestock bathing in the Njoro river (photo by author)

The ability of water to shape the landscape and the interconnected social-ecological systems.



[Figure 3.] Connectivity between guiding lenses of this research; water, ecology and culture.

In our contemporary landscapes, the availability or absence of clean water is closely linked to human influences on the natural landscape, as shown by Qanat systems and current urbanization conflicts within the natural environment.
Water demonstrates the ability to shape the landscape, and it stands at the foundation of the social-ecological systems within it. Together, they shape the complexity of the landscapes we inhabit.
This cycle forms the starting point of my thesis, in which I propose water, ecology and culture as the guiding lenses for this research.

Adapting to the seasonal rhythm

Road under construction, Kiamunyi area (photo by author)

Reading guide

PART I - Introduction

The first part introduces the reader to the fascination underlying this research and the overall structure of the thesis. It sets the stage by presenting the research context, case study, and objectives, alongside the research questions that guide the process.

PART II - Finding solutions

The second part outlines the search for solutions through a theoretical and analytical lens. Relevant theories are explained and compared, forming the foundation for the research framework. A precedent study is included and critically evaluated within this framework. From this process, design strategies and principles are derived, which serve as guiding tools for the design part later on.

PART III - Designing

The third part focuses on the design phase itself. Here, the developed strategies and principles are applied to the case study through design implementation. The section moves from conceptual design explorations toward detail design, providing insight into how abstract principles are translated into tangible proposals.

PART IV - Lessons taken

The final part contains the reflection, discussion, and conclusion. It synthesizes the findings from both the theoretical and design process, highlighting the lessons learned and their broader implications. This section also critically evaluates the research approach and outcomes, and formulates the concluding remarks of the thesis.

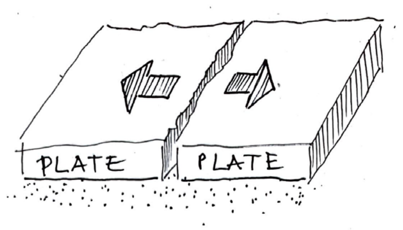
Agroforestry plot near Nakuru city (photo by author)

TABLE OF CONTENT

Divirgent boundary

A natural phenomenon that is part of the Earth's plate tectonics. Plate movement is caused by differences in the thickness and formation of plates, which can lead to plates overlapping (convergent) or sliding past each other (transform). Thirdly, when plates move apart from each other, a divergent boundary is formed.

(Van Andel & Murphy, 2024)

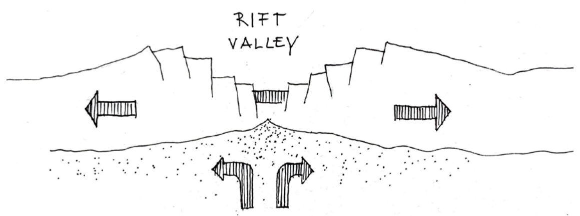


East-African Rift

A rift zone in East Africa that has been created by two tectonic plates moving apart from each other: the Nubian and Somali plates. When diverging plates are covered by continental crust, fractures form, allowing ascending magma to intrude and push the continents even further apart. This process forms a rift valley, such as the East African Rift Valley. As the rift expands, the continental crust gradually thins until the plates fully separate, leading to the creation of a new ocean.

At the early stages of this process, several large lakes have already formed, such as Lake Victoria and Lake Tanganyika. This region is now commonly referred to as the Great Lakes Region.

(Van Andel & Murphy, 2024)

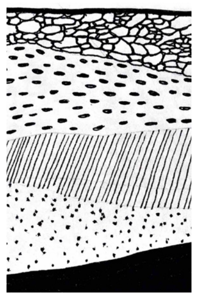


Volcanic Soil

In this graduation project, the volcanic soil created by the divergent boundary of the East African Rift will be frequently discussed.
As a result of this divergent boundary, the Menengai Caldera has formed as the main topographic feature on the northern side of Nakuru City, the study area in this report.

Volcanic soil has many classifications, such as fall deposits or trachytic lava. However, in this report, the overarching term volcanic deposits or volcanic soil will be used.
This soil type is characterized by a loose texture and high nutrient content. Additionally, it has a high infiltration capacity due to these characteristics. Because of these properties and their implications, volcanic soil is widely discussed within this project, as it is the dominant soil type on site.

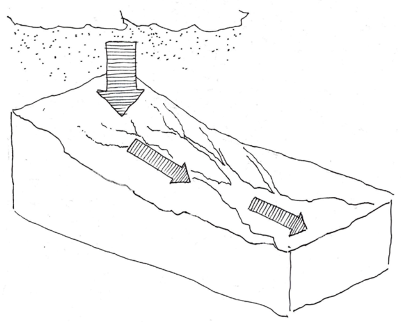
(Conti et al., 2021; Nillesen et al., 2024)



Surface Runoff

As a result of precipitation variability and differences in the permeability of the ground or soil, based on land cover, precipitation can move over land in the form of surface runoff. When the infiltration limit is reached or permeability is reduced, for example due to pavement, water will flow downstream following the elevation gradient.
Rapid urbanization and changes in precipitation patterns caused by climate change will result in growing runoff volumes. Therefore, it "becomes a product of the interaction between climate and changes in land use in a basin."

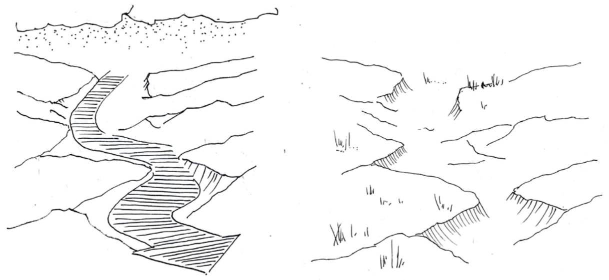
(Nillesen et al., 2024; Kimaru et al., 2019)



Seasonal River

In the context of this research, seasonal rivers are defined as waterways that carry water only during specific times of the year, typically during rainy seasons or periods of abundant precipitation. These rivers form when the volume of precipitation exceeds what can be managed by perennial rivers. Their channels or paths remain visible in the landscape even when no water is present, often in the form of gullies. During their active periods, seasonal rivers create small streams or brooks, playing a temporary but crucial role in draining excess water and transporting sediments. Their flow varies significantly throughout the year.

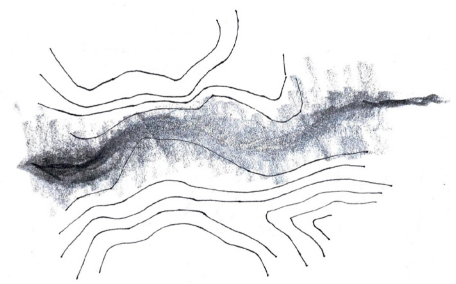
(Dettinger et al., 2000; Kimaru et al., 2019; University of Nairobi & Hongo, 2020)



Perennial River

Perennial rivers are waterways that flow continuously throughout the year and do not dry up, regardless of seasonal variations in precipitation. Although water levels may fluctuate due to differences in rainfall, these rivers are consistently fed by reliable sources such as groundwater or large lakes. Perennial rivers typically serve as the main transport routes for water, sediments and nutrients within a watershed and are vital to ecosystems and human activities.

(Dettinger et al., 2000)



Sustainable Rainwater Management (SRW)

Sustainable rainwater management refers to the strategic planning and implementation of practices that collect, store and utilize rainwater efficiently while minimizing environmental impacts. It is an essential aspect of urban development, particularly in response to increasing urbanization and the proliferation of impermeable surfaces that strain traditional drainage systems.
SRW integrates natural processes, such as infiltration and evaporation, with modern infrastructure to reduce issues like urban flooding, water scarcity and environmental degradation. These solutions help restore natural water cycles, mitigate environmental impacts and promote climate resilience.

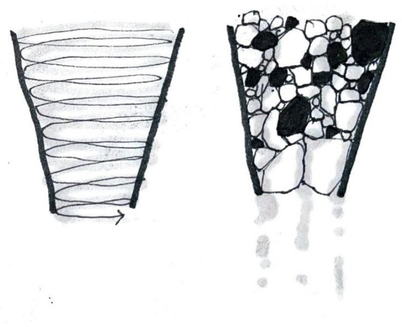
(Dika & Rimac, 2021; Ssekyanzi et al., 2024)

Natural Purification Systems

Natural purification systems, also known as biological rainwater treatment systems, are engineered solutions designed to mimic the processes of natural wetlands using organic materials such as plants, soil and microorganisms. These systems treat various types of water, including stormwater, greywater and industrial wastewater, by using biological and chemical processes to remove pollutants and clean the water.

By replicating natural wetlands, they help restore water cycles, reduce urban pollution and support biodiversity by creating habitats for plants and animals. Additionally, they enhance urban landscapes, offering aesthetic and ecological benefits while providing a more energy-efficient and cost-effective alternative to traditional water treatment methods.

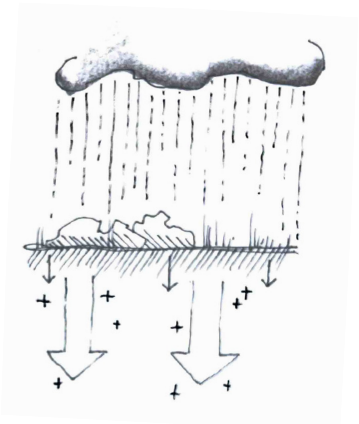
(Dika & Rimac, 2021)



(Active) Groundwater Recharge

A process in which rainwater or surface water is deliberately infiltrated into the ground to replenish groundwater layers, such as aquifers. This is an important strategy for sustainable water management, especially in areas with growing demand for clean water and where climate change affects water availability.

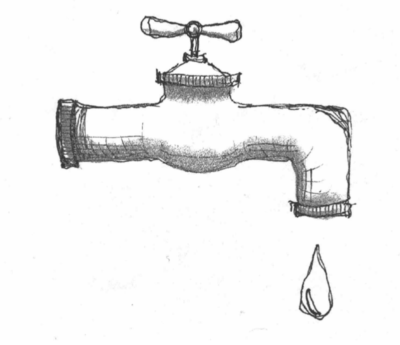
(Nillesen et al., 2024)



Clean Water

Within this project, clean water refers to water of sufficient quality to be safely used for various purposes, including industrial processes, agriculture and domestic uses such as washing and cooking. In the context of this project, clean water is distinguished from drinking water, with a focus on the limitations of natural purification systems. While clean water must be free from harmful levels of contaminants such as chemicals and pathogens, it does not need to meet the stricter standards required for direct human consumption. This distinction highlights the importance of sustainable management of water resources to ensure the availability of clean water for diverse applications.

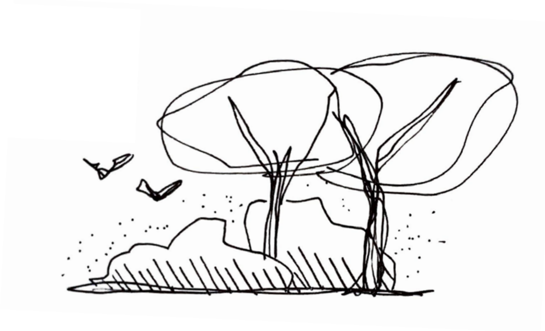
(Ritchie et al., 2024)



Ecosystem Services

An ecosystem is a dynamic and interconnected community of living organisms interacting with each other and with the physical environment that supports them. These interactions form a complex web of relationships, including the flow of energy and the cycling of nutrients. Ecosystems can vary in size and are influenced by both natural processes and human activities.
The balance within an ecosystem helps maintain biodiversity, resilience and functionality, but changes in one component, such as species extinction or climate shifts, can impact the entire system.

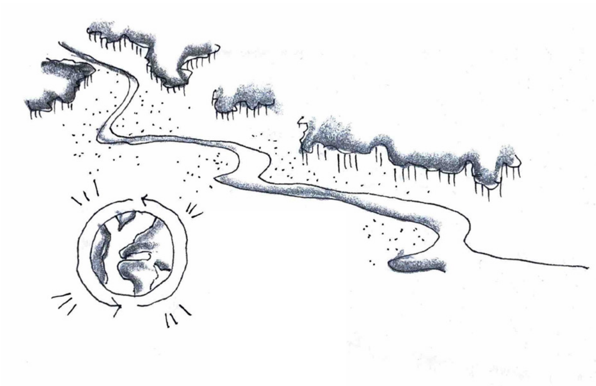
(Berkes et al., 2006; Costanza et al., 1997; Brewer et al., 2024)



Nature-Based Solutions (NBS)

Nature-based solutions (NBS) are inspired by traditional methods and use natural processes to restore the imbalance in our current landscapes. They aim to mitigate and adapt to climate change, preserve biodiversity and enhance human well-being.
NBS contribute to creating sustainable landscapes far more effectively than conventional grey infrastructure and "mean working with rather than against nature." They are not limited to building with green components but focus on finding the most beneficial combination of green and grey elements.
Understanding natural systems is the first and most important step in the Building with Nature process, as it stimulates long-term thinking and ultimately contributes to a sustainable and resilient landscape.

(Seddon et al., 2020; Bouw, 2021)




Inside National park Lake Nakuru (photo by author)

Introduction

PART I

Flooded houses at the edge of Lake Nakuru, due to rising water levels (photo by B. de Jong)

Chapter 1. Introduction


Canadian
Boreal Taiga
Mediterranean
Forests, Woodlands
& Shrubs
Yangtze
Basin
Tibetan
Plateau
Steppe
Amazone rivers
& floodplains
Coral Triangle Marin
African
Great Lakes
Congo
Basin
Atlantic
forests
Urban extent
2000
2030
Rivers
Terrestial eco-regions
Fresh water eco-regions
Floodprone areas
Threatened eco-regions
Urbanization conflict; urban developement puts
pressure on crucial biodiverse eco-regions
Cartographer: Thamar Zeinstra;
Data provided by: Natural Earth, WWF, USGS, HDX and NASA

1.1. Urbanisation conflicts at the expense of vulnerable ecosystems

Ever since the Agricultural Revolution, there has been a significant shift in human social structures. With the development of reliable food resources, humans began building permanent settlements, which led to population growth and the gradual transformation of natural landscapes. Today, more than half of the world's population lives in urban regions, and this figure is expected to rise to 70% globally by 2050 (Brewer et al., 2024; Nijhuis, 2024). The ongoing migration from rural to urban areas, driven by economic opportunities and lifestyle changes, often comes at the expense of fragile natural ecosystems, creating an urgent situation.

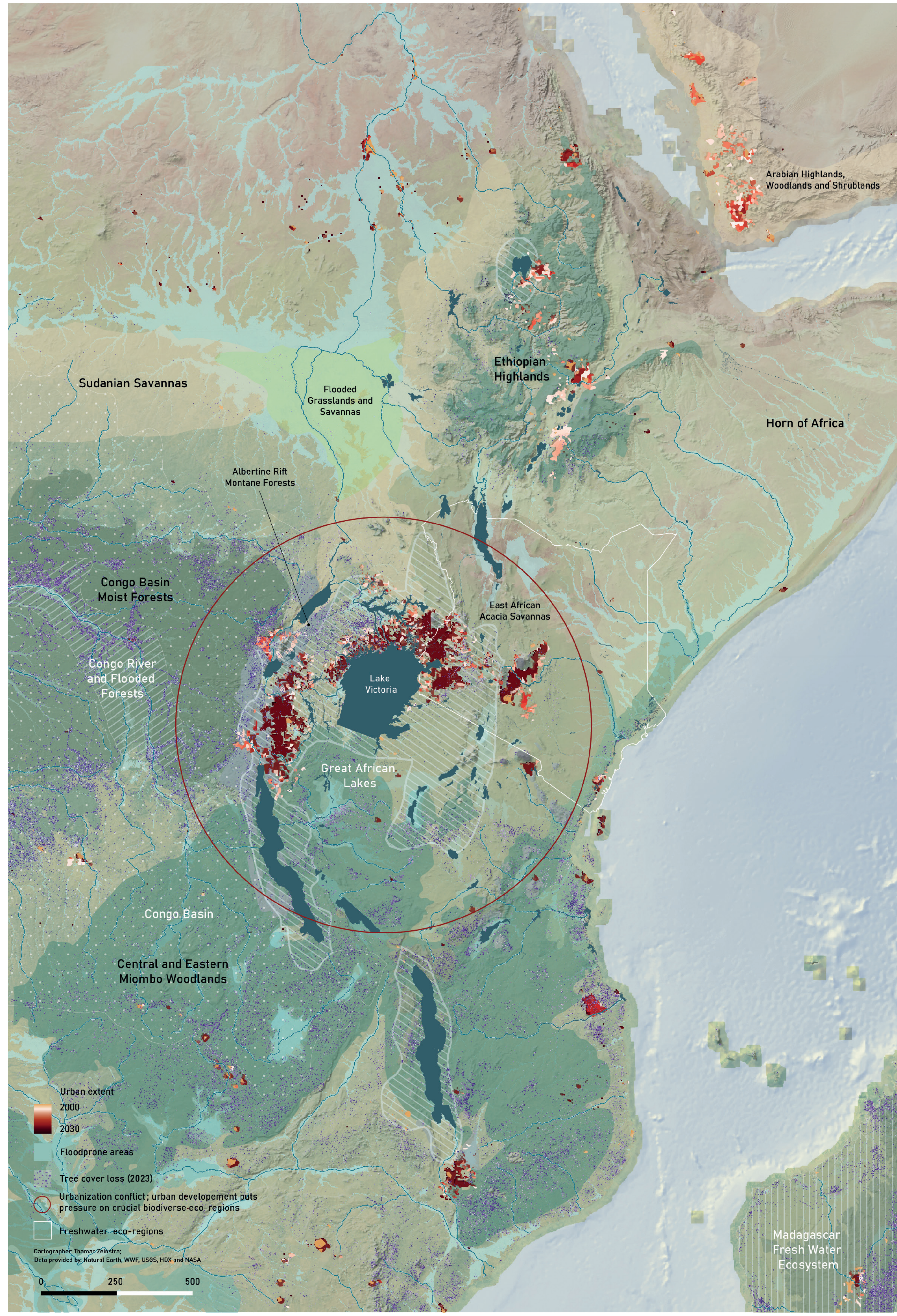
Climate change further worsens the negative impacts of urbanization, increasing environmental and societal challenges, particularly in regions experiencing urbanization conflicts. These conflicts are most visible in valuable terrestrial and freshwater ecoregions around the equator, where urban expansion threatens biodiversity hotspots. In many of these areas, rapid migration to urban centers that lack adequate infrastructure leads to unplanned urban settlements. Such settlements are often situated in environmentally vulnerable regions, prone to flooding, water pollution and scarcity, which heighten social inequalities even further (Kempenaar et al., 2024).

The United Nations Human Settlements Programme (UN-Habitat, 2023) emphasizes that the current urbanization trend places an immense strain on urban infrastructure, including water and waste management systems. Although clean and safe water is recognized as a basic human right, growing global demand for water and unchecked urban expansion have heightened the risk of a global water crisis. This challenge is particularly acute in developing regions where urban growth intersects with fragile ecosystems.

The availability or absence of freshwater is linked to human influences on the natural landscape. Over time, we have been "transforming the natural landscape into urban, logistic, industrial and waste landscapes," unconsciously distancing ourselves from nature and underestimating the consequences of these land-use changes for societal and ecological resilience (Nijhuis & Jauslin, 2015; Corner, 1999). The result is a fragmented water cycle that struggles to sustain itself under the pressures of land-use transformation. This research focuses on the Rift Valley lake system, part of the terrestrial and freshwater ecoregion known as the Great African Lakes, located in Kenya. These lakes and their surrounding forests provide essential resources such as freshwater, food and livelihoods. However, the Great African Lakes region is now designated by the World Wildlife Fund (WWF) as an ecoregion under threat due to deforestation, urban expansion, overfishing, water pollution and the impacts of climate change.

In the coming years, unprecedented urban growth is expected in the Great African Lakes region, further intensifying pressures on this freshwater ecosystem. Deforestation to accommodate expanding urban areas leads to soil erosion and increased sedimentation in the lakes, thereby reducing water quality. Water pollution from untreated sewage, agricultural runoff and industrial waste threatens biodiversity in this region. Moreover, rising populations in informal settlements without adequate water or waste infrastructure increase the vulnerability of these communities to waterborne diseases and water scarcity (UNEP, 2010).

The unsustainable urban development of this area threatens not only the natural landscape but also the people living in it, as the region faces significant societal challenges. Rural-to-urban migration driven by poverty and conflict often results in overcrowded settlements with limited access to basic services (UN-Habitat, 2024). Climate change compounds these issues, with rising temperatures and unpredictable rainfall patterns worsening water scarcity and increasing the frequency of extreme weather events such as floods and droughts.



1.2. Impact of Catchment Degradation in the Rift Valley Basin

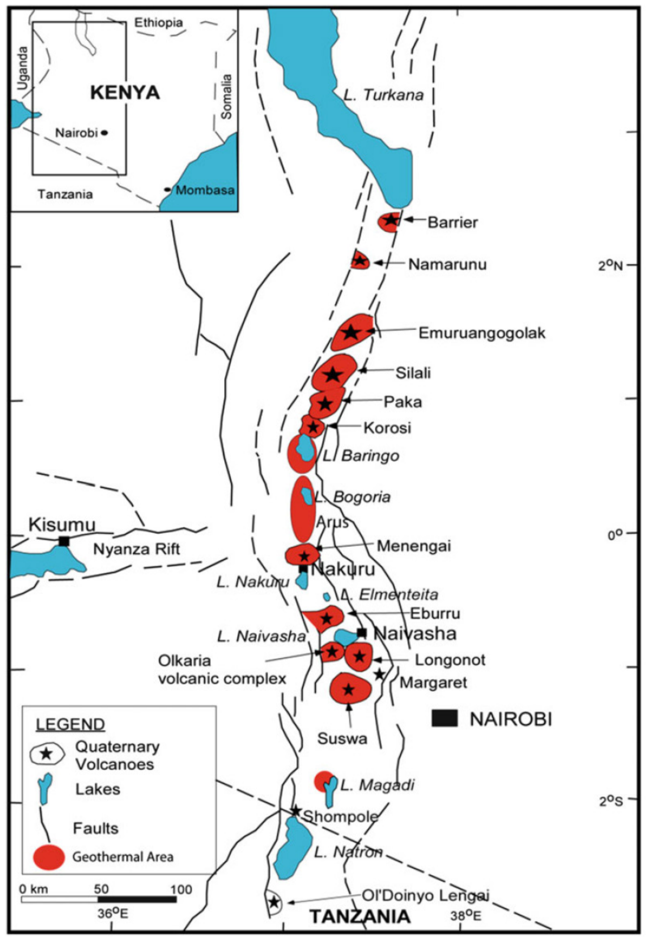
The Rift Valley lake system is linear and endorheic, with no outflow to an ocean, making it vulnerable to changes in the catchment areas. As a result, the water balance is extremely sensitive and quickly becomes unbalanced, particularly due to climate change and human interventions such as urbanization, deforestation and agricultural changes (Obando et al., 2016).

The overall lake system is of great ecological value, and many people depend on the natural resources provided by the landscape, which also brings tourism to the area as one of the main financial drivers. With expected large-scale urbanization in the area, the natural resources and systems are coming under increasing pressure, and the environmental conditions will become more varied and extreme.

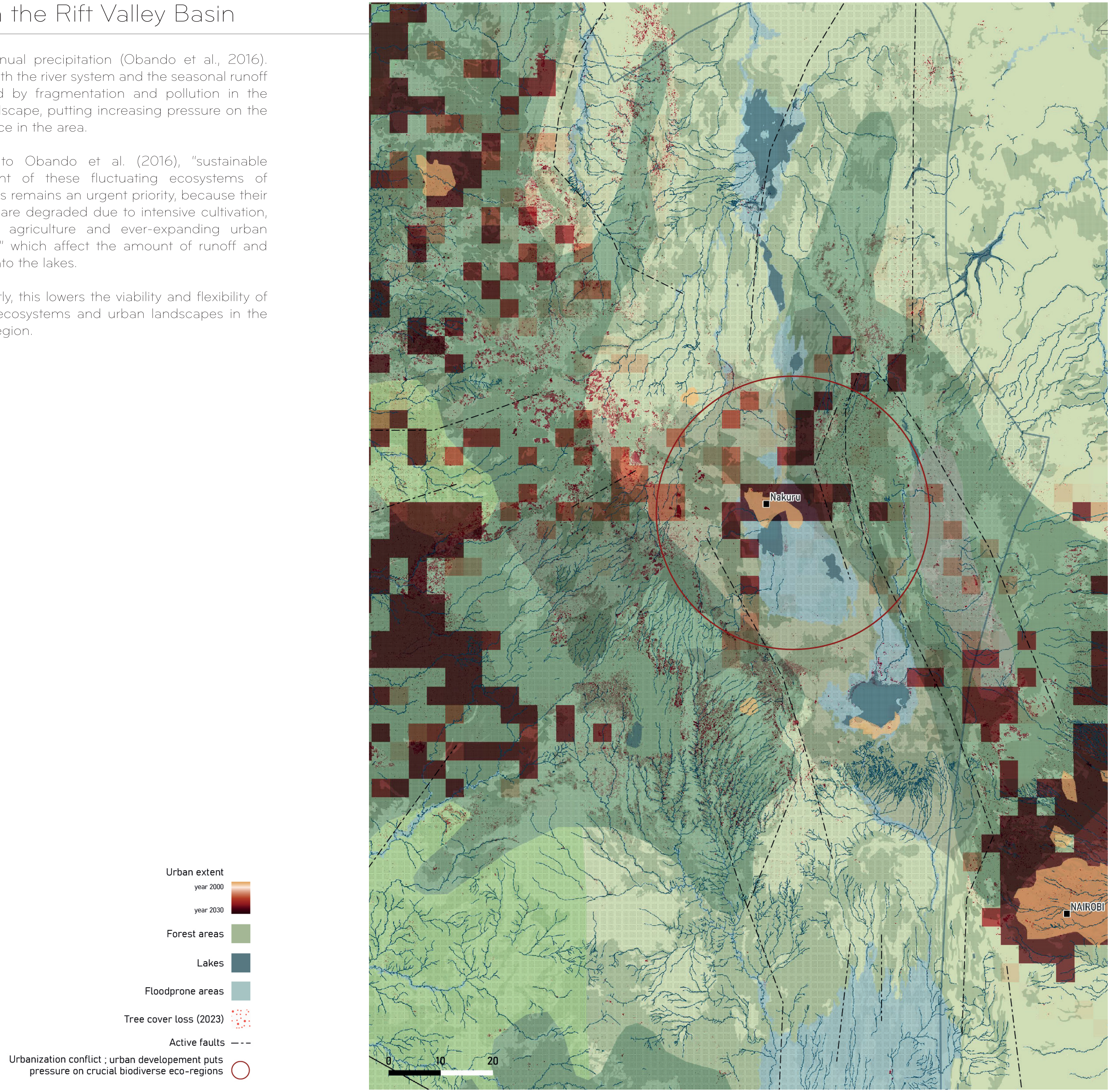
The water system of the Rift Valley lakes depends entirely on inflow from rivers and surface runoff after rainfall, which is generally characterized by highly irregular annual precipitation (Obando et al., 2016). However, both the river system and the seasonal runoff are affected by fragmentation and pollution in the current landscape, putting increasing pressure on the water balance in the area.

According to Obando et al. (2016), "sustainable management of these fluctuating ecosystems of tropical lakes remains an urgent priority, because their watersheds are degraded due to intensive cultivation, subsistence agriculture and ever-expanding urban settlements," which affect the amount of runoff and discharge into the lakes.

Consequently, this lowers the viability and flexibility of the fragile ecosystems and urban landscapes in the Rift Valley region.



[Figure 4.] Rift Valley Lake System, Kenya (Obando et al., 2016).



1.3. Land-use changes in Lake Nakuru catchment

The Rift Valley lake system is linear and endorheic, with no outflow to an ocean, making it vulnerable to changes in the catchment areas. As a result, the water balance is extremely sensitive and quickly becomes unbalanced, particularly due to climate change and human interventions such as urbanization, deforestation and agricultural changes (Obando et al., 2016).
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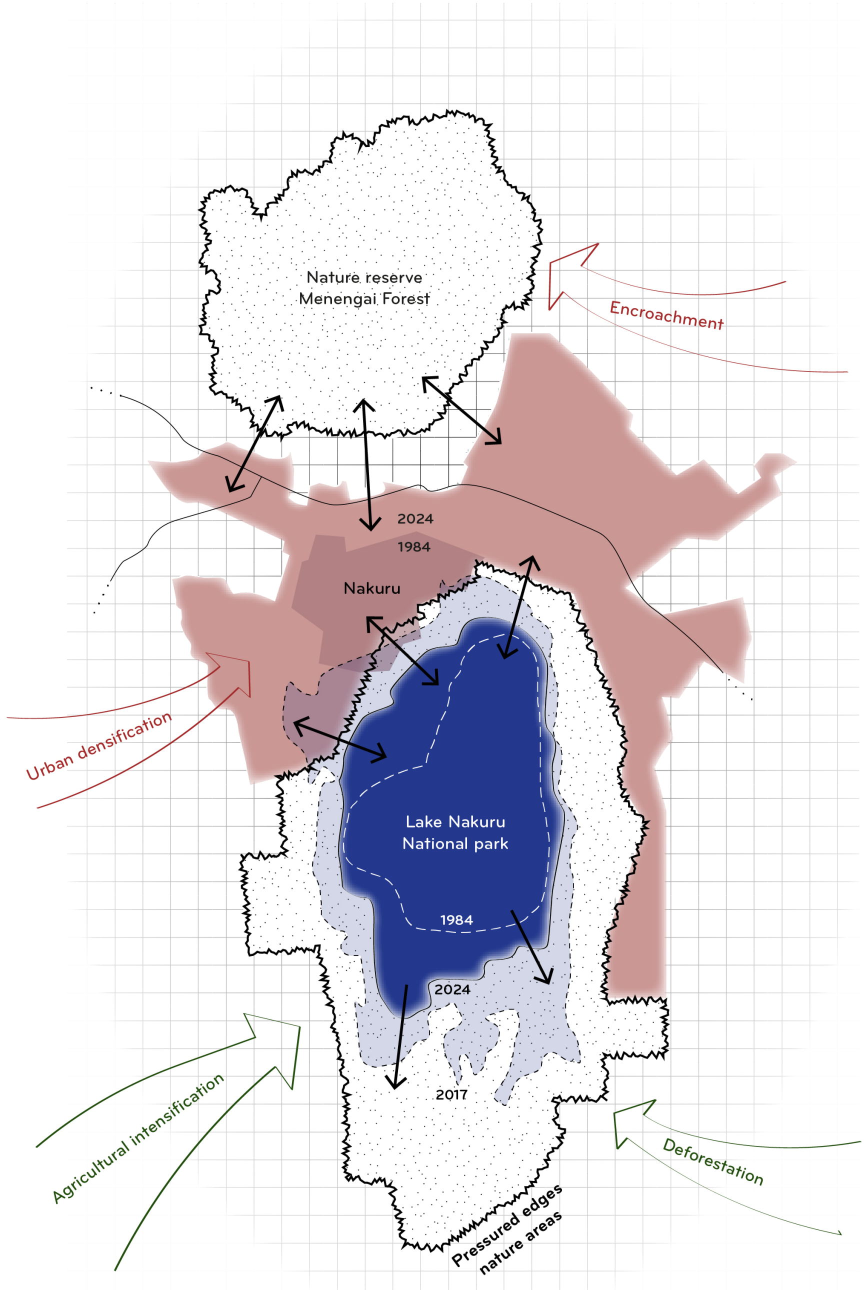
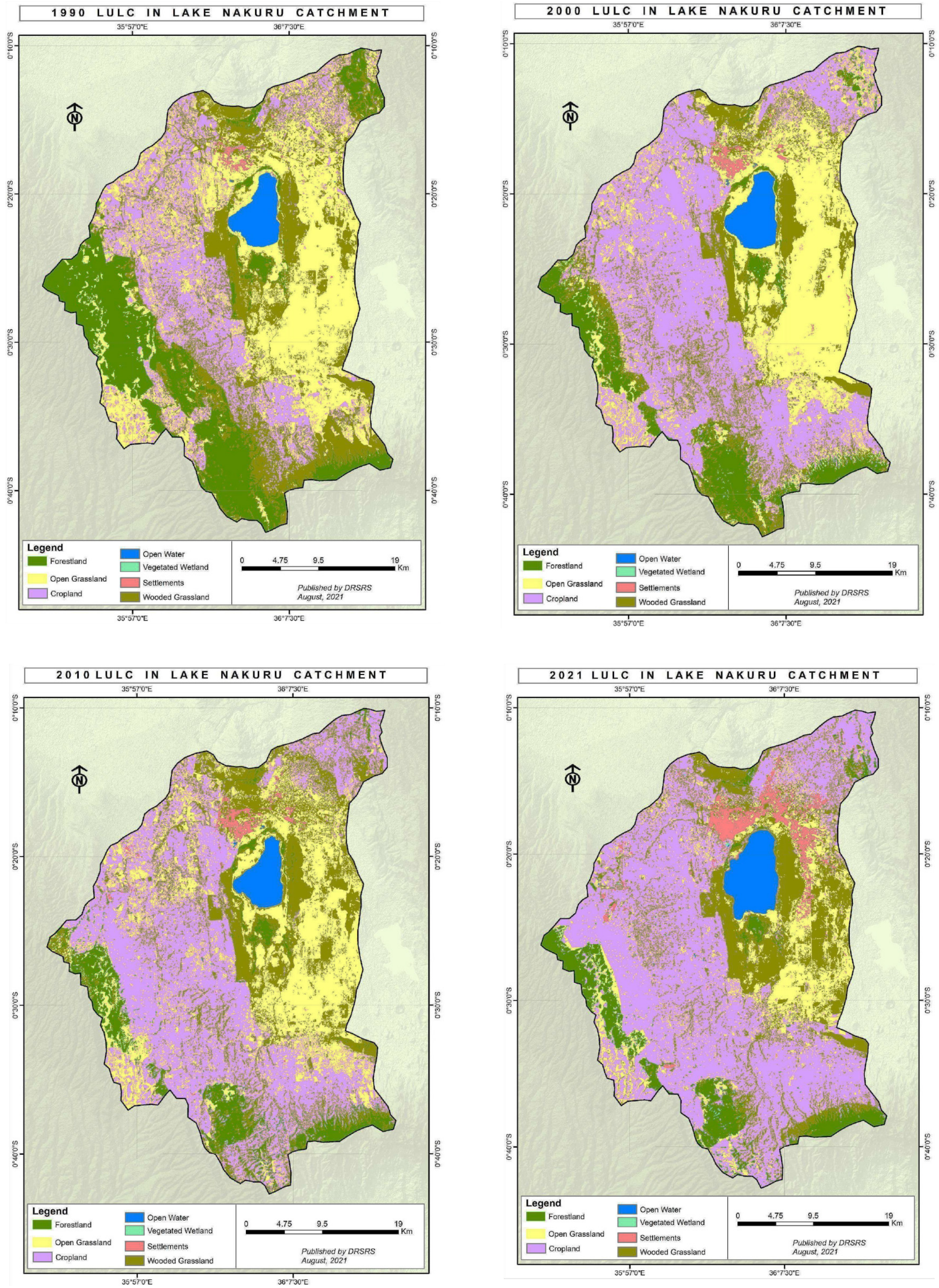


[Figure 5.] Land use changes putting increased pressure on the natural system of the catchment of Lake Nakuru



[Figure 6.] Land use changes over time (Kiogora et al., 2021)

Erosion of conventional drainage pipes in Nakuru city (photo by author)

Chapter 2. Research Structure

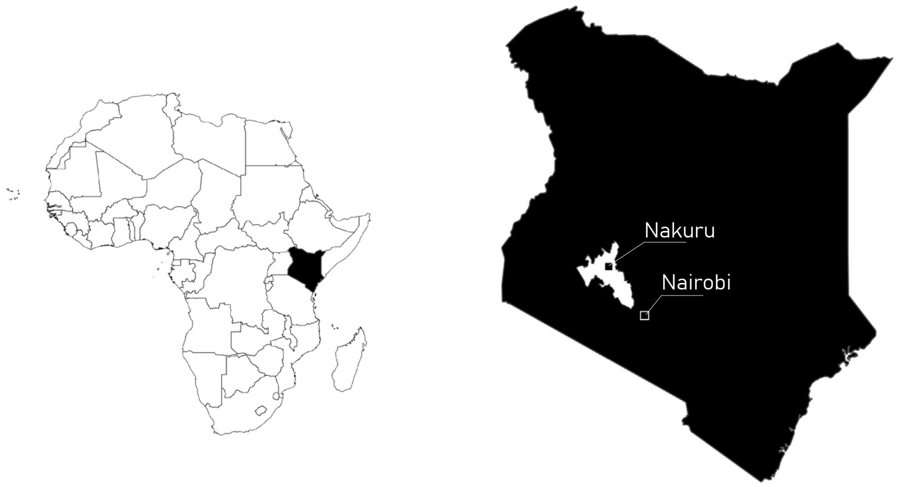
2.1. Nakuru: A case study

Located within the pressured freshwater "Great African Lakes" ecoregion and part of the Rift Valley lake system, the city of Nakuru provides a critical case study for understanding and researching the intersection of rapid urbanization and environmental vulnerability. As one of Kenya's fastest-growing cities, Nakuru faces an escalating water crisis marked by increasing water scarcity and declining quality. As a result, the urban expansion and unsustainable development practices place immense pressure on the fragile natural landscape and its resources (Nillesen et al., 2024; Kanda, 2010). In this case, and in many others, urbanization contributes to the fragmentation and depletion of habitats for humans, plants, and animals (Nijhuis, 2024).

Land use changes in the catchment area of Lake Nakuru, such as intensified agriculture, industrial growth, deforestation, and rapid urbanization, have degraded the water quality. Climate change further reduces the resilience of the natural landscape to extreme weather, including unpredictable rainfall and prolonged droughts. As stated by Nillesen et al (2024), heavier rainfall will intensify with 32%, which will cause overflows and urban floodings with the current drainage system, which is designed to dispose the rainwater as quickly as possible into Lake Nakuru.
With the population projected to grow from 500,000 to 2,000,000 by 2050, Nakuru's rapid urbanization follows the trend across the Great African Lakes region (Nillesen et al., 2024). Combined with a future water demand increase of 500%, the availability of clean water in Nakuru city becomes critically important. Over-abstraction of groundwater and contamination from surface runoff exacerbate this crisis, disproportionately affecting low-income communities, which make up over 50% of Nakuru's population. The low-income communities mainly live in informal settlements, often located in flood-prone zones, are most vulnerable to seasonal flooding and have limited access to basic services (Mokaya et al., 2016).

As Nakuru City is located between two nature reserves and vital ecosystems, Lake Nakuru and the Menengai Caldera, they suffer from severe pollution caused by agricultural runoff, industrial waste, and inefficient waste-management. This contamination endangers biodiversity, reduces clean water availability, and poses health risks to residents. Poor drainage systems amplify these issues, resulting in untreated surface runoff, urban flooding, and waterborne diseases, especially in densely populated informal areas (UNEP, 2010; Kempenaar et al., 2024).

These challenges demand urgent attention and a long term strategy for sustainable urban development. Polluted runoff, ecosystem degradation, and urban flooding highlight the need for sustainable strategies that improve water management, restore natural systems, and address the inequities faced by vulnerable communities. It shows that the existing urban landscape and infrastructure of Nakuru City, is not flexible and resilient enough to deal with the changing weather patterns and rapid urbanization. Therefore, a landscape-based strategy and mainly focuses on the following issues: 1) surface runoff causing floodings and water pollution, 2) the unbalanced and unequal fresh water availability and 3) the unsustainable urban development leading to fragmentation of habitats of humans and animals. Because Nakuru has a favorable climate, is located on a volcanic soil with high infiltration potential and the surrounding natural landscape is still partly intact, there is an opportunity to design space for (seasonal)water, ecology and human connections. There is a potential to develop a landscape-based strategy to collect, delay and purify (seasonal) water, while setting out a spatial structure for sustainable urban development.



[Figure 7.] Location of research site (data from ESRI, mapping by author)

Main issues

[Figure 8.] Main water-related issues in Nakuru that are assessed within this research (photos by author)

2.2. Problem statement

Nakuru City faces worsening freshwater shortages, pollution, and flooding due to rapid urbanization, land-use changes and climate change.

Expanding into flood-prone areas near fragile ecosystems, the city disrupts the natural water balance, worsening environmental degradation.

Over-extraction of groundwater, unsustainable agricultural practices and poor waste management further deplete clean water sources and threaten biodiversity.

In addition, land-use changes in the northern catchment, such as in the Kiamunyi area and on the slopes of the Menengai Caldera, increase surface runoff that flows through Nakuru before reaching the lake, thereby amplifying flood risks in the city and contributing to rising lake levels (Schalkwijk, 2025).

Low-income communities, often in high-risk zones, suffer the most from water insecurity, flooding, and inadequate infrastructure.

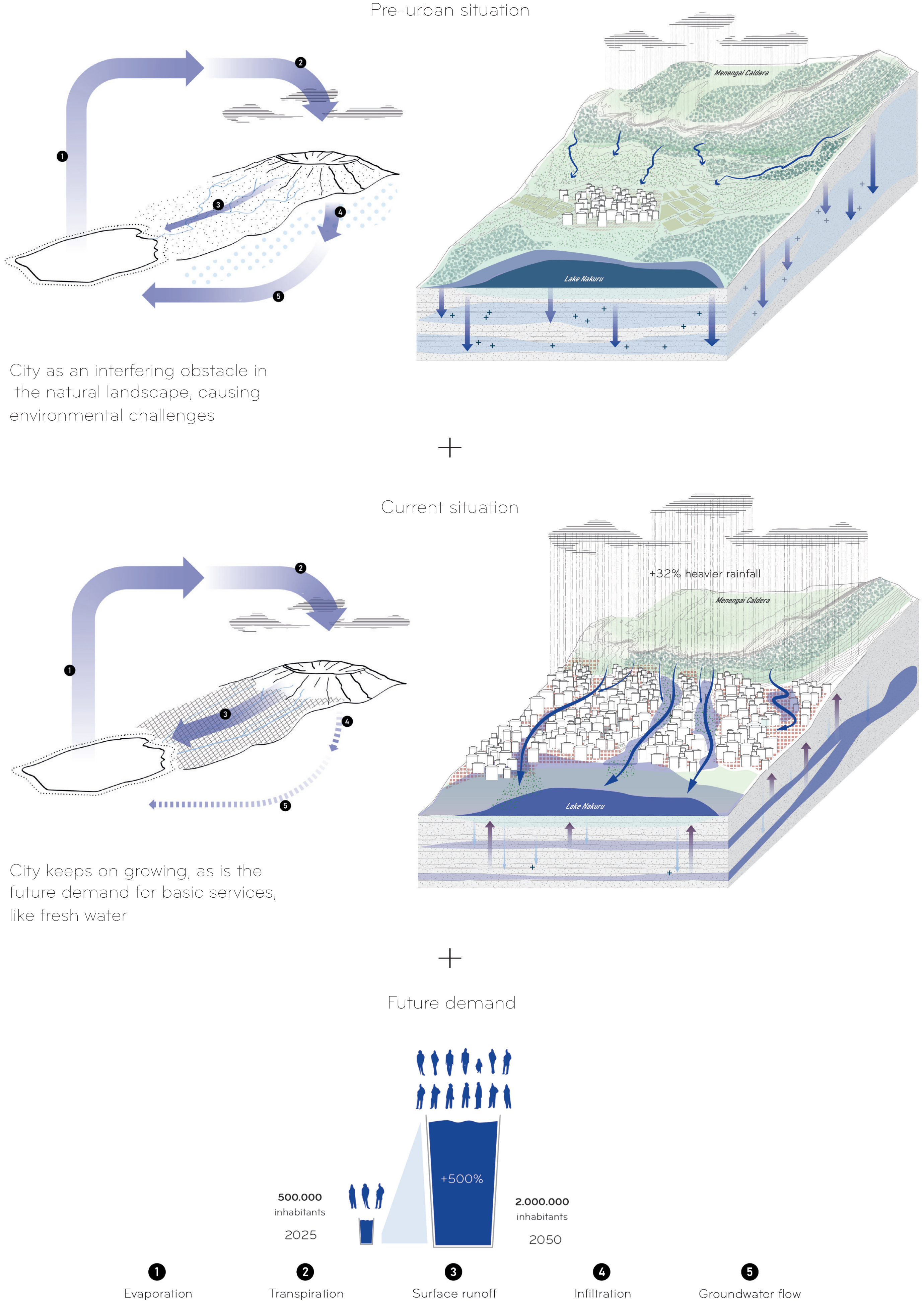
A resilient, landscape-based strategy is urgently needed to restore the water balance, reserve ecosystems, and support resilient urban development in the future.

Water — *Disturbance of the natural water balance by human activities has led to uneven fresh water availability and urban floodings.*

Culture — *The growing disconnection between the urban and natural landscap e is driving rapid, unsustainable land-use changes.*

Ecology — *Fragmentation and deforestation are causing a loss of essential ecosystem services, weakening the natural landscape.*

[Figure 9.] Flooded houses of informal neighborhoods bordering Lake Nakuru, due to the rising water level of the lake. (photo by Cynthia van Elk for Water as Leverage, 2023)



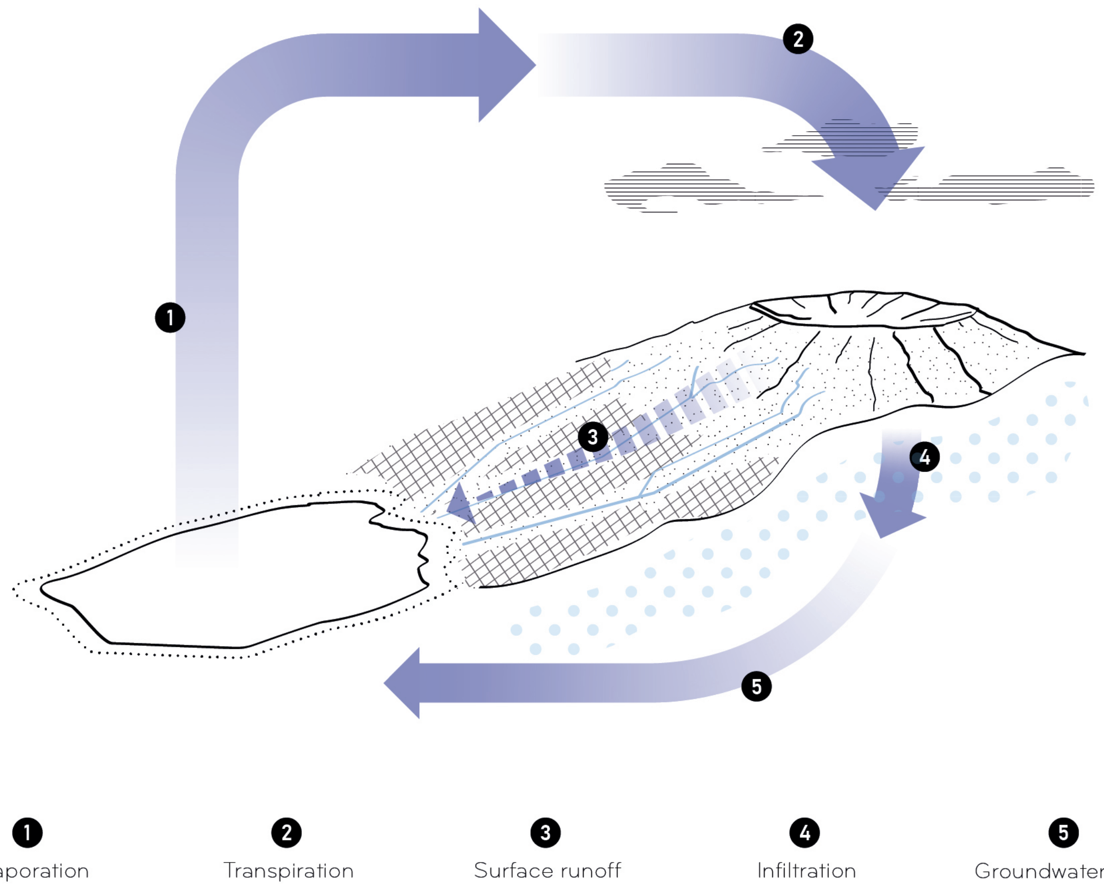
[Figure 10.] Effects of landscape changes over time due to urbanization on the waterbalance and natural landscape. Additionally a diagram how this trend will affect the future fresh water demand.

"A source of wealth is the functional ecosystem. The products and services that we derive from those are derivatives. It is impossible for the derivatives to be more valuable than the source. We need to redefine and revalue our belief systems"

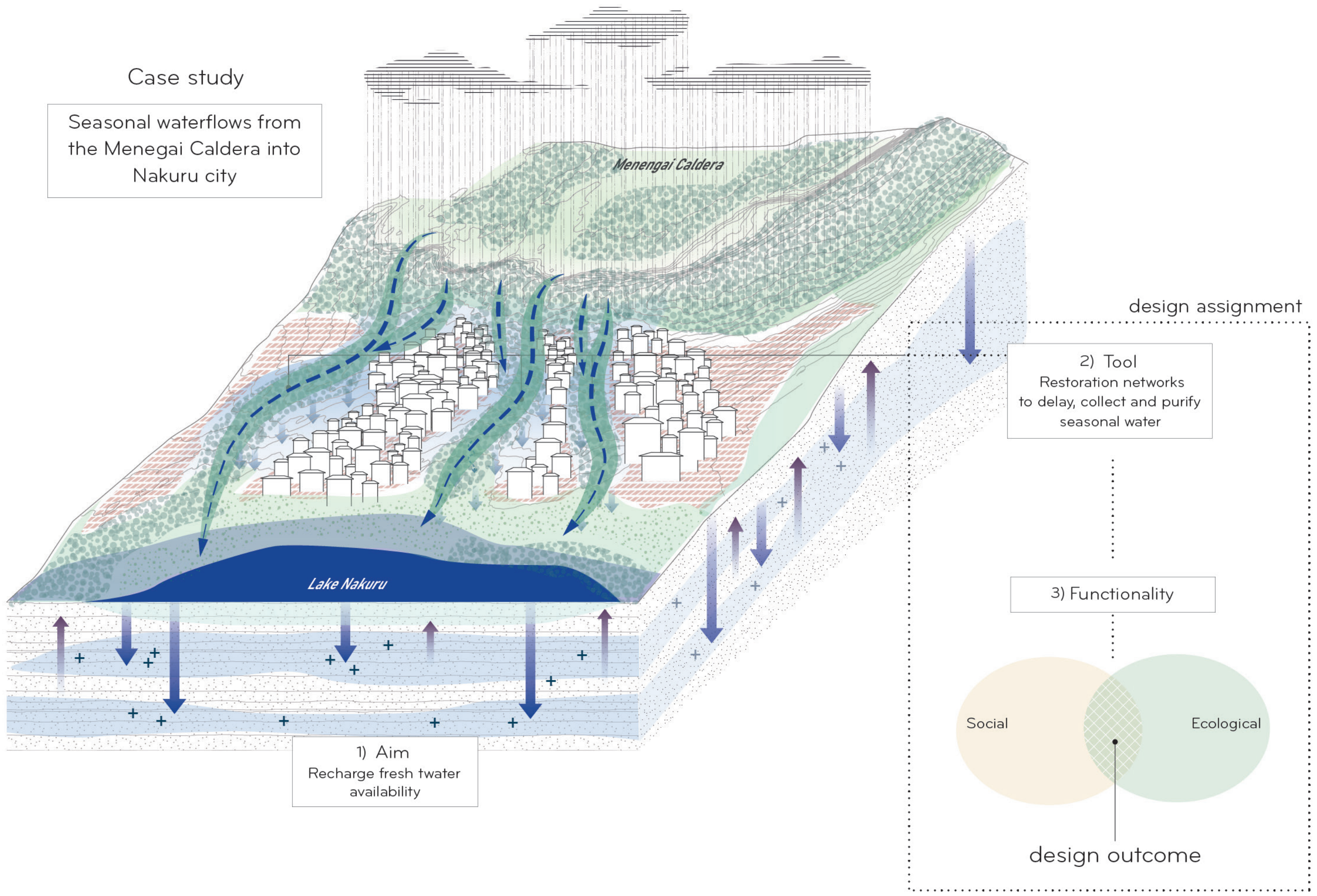
- Ecologist John D. Liu (1995)

This research explores the potential of a landscape-based approach to mitigate issues related to seasonal runoff from the Menengai Caldera into Nakuru City.
In the current landscape, the water balance is disrupted due to reduced infiltration capacity and unsustainable water infrastructure, leading to excessive surface runoff (figure 11). This has resulted in urban flooding, soil erosion, water pollution, over-exploitation of groundwater and an unbalanced freshwater availability. Vulnerable communities are the most affected by these challenges. As the city continues to grow exponentially and the demand for freshwater increases, sustainable and systemic management of surface water is becoming critically important.
Through a spatial strategy that aligns with Nakuru's cultural and ecological context, this research aims to develop a framework that contributes to restoring the natural water balance. By integrating seasonal surface runoff into the system, the strategy seeks to enhance freshwater availability for Nakuru's residents.
The main objective is to restore the natural flow of seasonal water, thereby recharging freshwater resources and integrating them into a sustainable urban development framework with spatial interventions for Nakuru. This strategy and its interventions will build on local cultural structures and knowledge, making it applicable to other case studies with a similar socio-ecological context, such as Nakuru, Kenya.

For water balance and ecosystem restoration

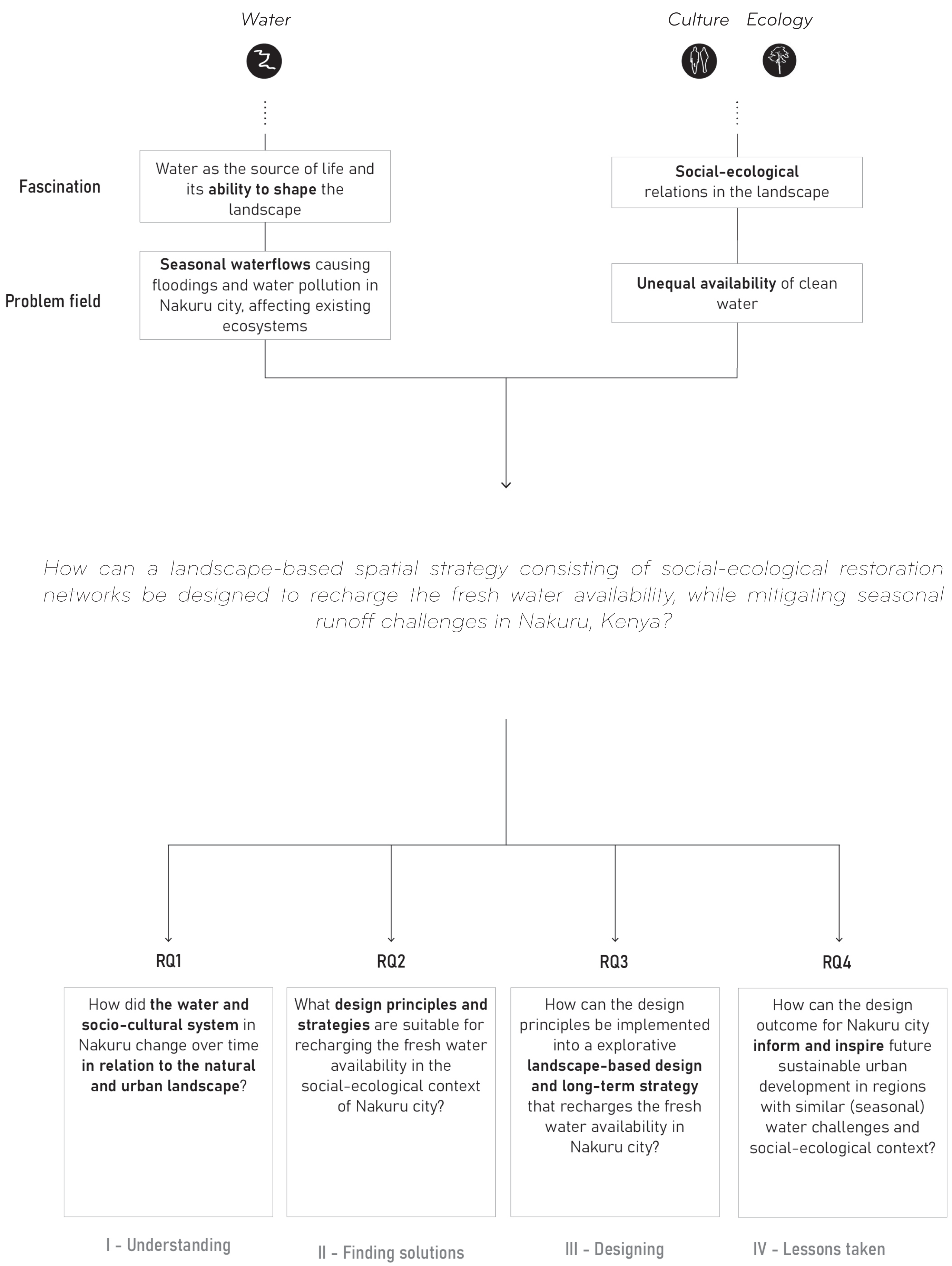


[Figure 11.] Proposed waterbalance by restoring the natural and urban system in the catchment of Lake Nakuru



[Figure 12.] From systemic strategy to local interventions: A landscape-based framework for designing socio-ecological restoration networks to recharge freshwater, while mitigating the effects of seasonal waterflows in Nakuru.

The design assignment will be conducted through a research-through-design approach to generate new, explorative, and applicable knowledge that can be used on the specific sites in this research (see Chapter 2.8). The assignment will consist of a landscape-based spatial strategy for Nakuru City, focused on recharging freshwater availability by setting out social-ecological restoration networks in and along the urban edge, whilst mitigating the water challenges related to seasonal surface runoff.
The main goal of the design is to recharge the freshwater availability in Nakuru. This will be achieved by designing restoration networks that delay, collect, and purify seasonal water flows, ensuring that they function effectively within the social-ecological context of the city, as illustrated in Figure 12.
During this process, it will be examined how seasonal surface runoff can be reframed as a design tool for creating and structuring socio-ecological restoration networks within the (peri-)urban context of Nakuru City. In addition to the overall spatial strategy, a detailed landscape design for a selected site will be presented within this report. This design will consist of socio-ecological networks or structures aimed at collecting, delaying, and purifying seasonal surface runoff to support water balance and ecosystem restoration in Nakuru City.



This scheme shows the structure of the main research question and the four sub-questions. The starting point lies in the three guiding lenses of this thesis, water, ecology and culture, and the problem field of seasonal waterflows, unequal freshwater availability, and their social-ecological impacts in Nakuru. From this foundation, the main research question was formulated, asking how a landscape-based spatial strategy of socio-ecological restoration networks can recharge freshwater availability while mitigating seasonal runoff challenges.

The sub-questions (RQ1–RQ4) break down this overarching question into different phases of the research process. RQ1 focuses on understanding the historical and current dynamics of water and socio-cultural systems in Nakuru. RQ2 develops design principles and strategies that are suitable for the local context. RQ3 explores how these principles can be implemented through an explorative, landscape-based design and long-term strategy. Finally, RQ4 reflects on the design outcome and considers how it can inform and inspire sustainable urban development in regions facing similar challenges.

2.6. Research approach

Exploring the living landscape

"Representation was or is the act that turned the land into landscape" (Corner, 1999, p. 17).

As graduation students, we need to define our position within the dynamic and academic field of landscape architecture, especially for a design project in a foreign country with distinct cultures and ways of living.

The origin of landscape architecture lies in the classical conception of landscape as a representation of scenery, idealizing the landscape and creating space through beauty, composition and experience (Di Palma et al., 2016). However, challenges such as climate change and the increased complexity of urban areas have forced the academic field of landscape architecture to diversify and expand its theoretical base (Klemm et al., 2017).

To acknowledge the complexity of landscape, J. Corner (1999) introduces Landschaft as an additional living layer to landscape, implying an active landscape shaped by its everyday users, which produces more engaging environments. Consequently, the landscape carries not only the natural dimension but also the cultural and social connections embedded within it. In recent decades, landscape architects have sought to balance the design of environments that support healthy natural systems with the demands of urban and social development.

Through cross-disciplinary collaborations with, for example, ecologists, urbanists or civil engineers, general knowledge can be integrated to achieve sustainable landscapes without losing sight of their natural and cultural dimensions (Van den Brink et al., 2022).

However, this still raises questions about our role as landscape designers in achieving such sustainable landscapes. How far does our responsibility extend in sustaining natural systems without neglecting the cultural layer within the same landscape? This question becomes especially relevant in this design project, given my personal lack of familiarity with a foreign country and its cultural landscape.

Therefore, a research-by-design approach is applied in this project to address natural and, in particular, societal challenges and narratives within the design process without generalizing the context. Within research through design, four different strategies are proposed by Cresswell (2009) to identify the knowledge to be generated and the questions to be asked during the process. In this project, a constructivist research-through-design approach will be adopted. This strategy aims to address socio-cultural challenges and is deeply embedded in context. It is based on a position of "exploring and generating the new and unknown" while remaining thoughtful and reflective (Lenzholzer, 2013). Can the design bring a shift in people's sensing, perception or behaviour? The design outcome will therefore be suggestive and contextual, grounded in qualitative research derived from expert groups and local knowledge on site. To overcome the discussed knowledge gap, my position will be to express existing narratives in the cultural landscape and integrate them within a landscape-based design for a complex urban system with a unique natural environment.

2.7. Project relevance

This research shows that the existing urban landscape of Nakuru City is not flexible or resilient enough to deal with changing weather patterns and a growing population, driven by climate change, and rapid urbanization. Therefore, a landscape-based spatial strategy is needed to address the following issues:

1. Surface runoff causing flooding and water pollution in the city and nature reserves.

.2. The unbalanced and unequal availability of fresh water.

3. Unsustainable urban development, leading to habitat fragmentation for both humans and animals.

Social relevance

This research addresses critical water-related issues such as urbanflooding, water scarcity, and pollution, which disproportionately affect vulnerable, low-income communities. By integrating social-ecological restoration networks into Nakuru's urban fabric, the project promotes accesability to fresh water and safer living environments. By researching the (traditional) socio-cultural context of the study area, the outcomes of this graduation project examines the specific needs of Nakuru's residents and integrates it within the design outcome. This approach strengthens community resilience to climate challenges and provides a practical spatial strategy for urban development in regions dealing with similar environmental problems.

Scientific relevance

From a scientific perspective, the project applies and advances design-led research in urban ecology, climate adaptation, and landscape-based water management. It contributes to knowledge on designing resilient urban systems by demonstrating how nature-based solutions can address seasonal water variabilities, habitat fragmentation, and pollution while acknowledging and integrating the socio-cultural context of the research area. By applying research-through-design methodologies, the project offers replicable principles and strategies for sustainable development in rapidly urbanizing regions.

Professional relevance

The project demonstrates how landscape architecture can address complex urban challenges by integrating ecological, landscape-based solutions. It highlights the role of landscape architects in shaping adaptive, multifunctional urban ecosystems that balance ecological and human needs, bridging gaps between disciplines such as urbanism, civil engineering, and environmental planning. The project introduces an alternative way of thinking about landscapes for Nakuru's residents through systemic thinking. By visiting the area, conducting workshops, and engaging with local experts and international institutions, a meaningful connection to the professional field is established.

Worldview

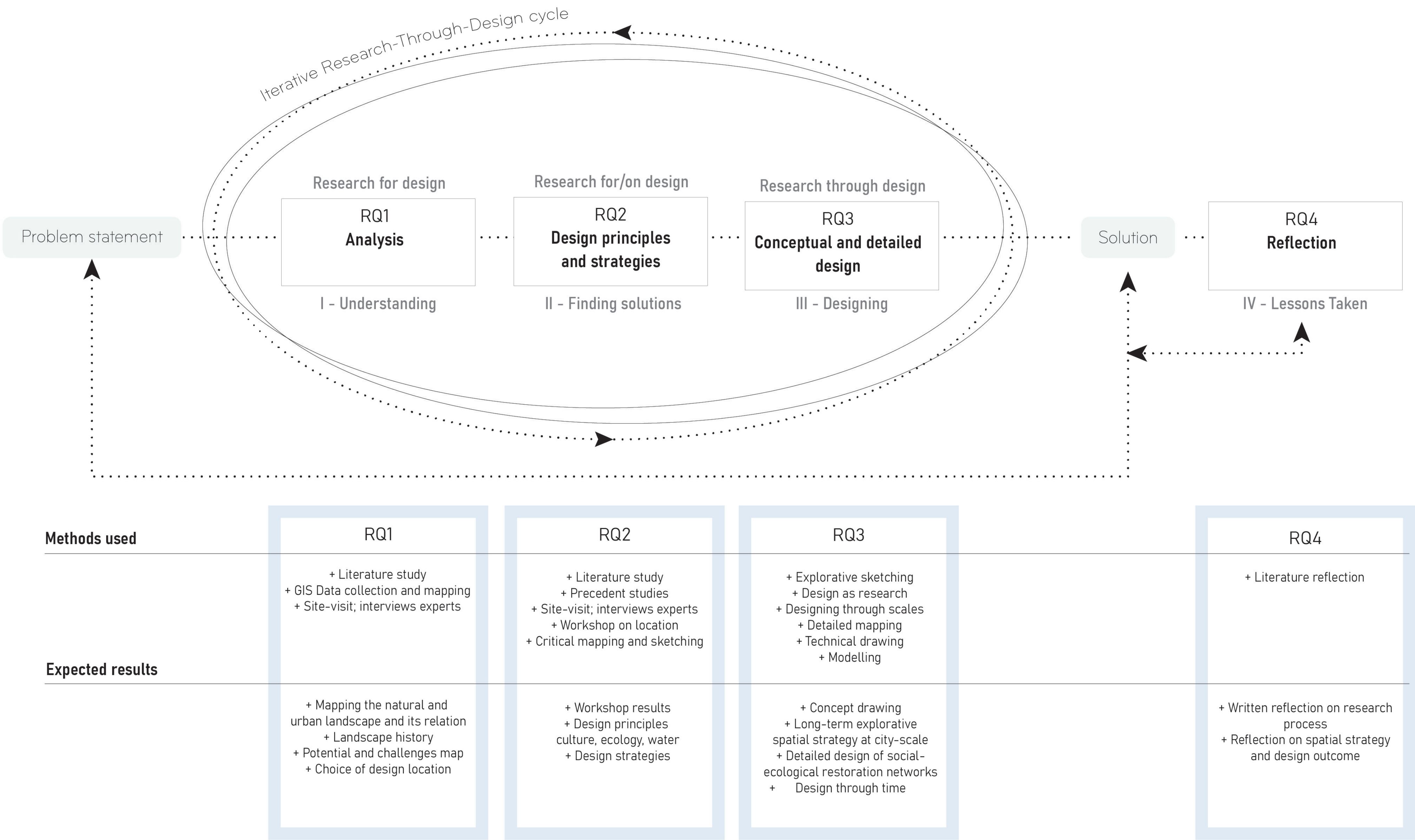
As discussed in the position paper, this research will be conducted through the lens of an constructivist, which means that the generated knowledge is represented and expressed as new knowledge and can be described as suggestive, contextual and interpretative, since the lack of familiarity with the cultural layer of a foreign country. (Creswell, 2014; Lenzholzer et al., 2013)

2.8. Methodological structure

The four research questions are addressed through a sequence of methods that move from analysis, to the formulation of design principles, to the development of a design strategy, -concept, and finally to a detailed design. This process ensures that the outcome responds to the social-ecological context of Nakuru while ultimately answering the main research question and objective of this thesis.

This research follows the Research-Through-Design cycle (Nijhuis et al., 2019), which serves as the overarching methodological framework. Each phase of the cycle delivers a distinct result, ranging from analytical insights to spatial strategies and design outcomes. Importantly, the process is iterative rather than linear: insights from later stages may loop back to inform earlier steps, allowing continuous refinement of both the research and design.

Figure 13 illustrates this methodological structure, presenting the connection between the research questions, the methods applied, and the expected results. The figure highlights how different types of research (for, on, and through design) are integrated to generate knowledge.



[Figure 13.] Explanatory scheme of the methodological structure of this report, including the methods used accompanied with the expected results in terms of (design) products.

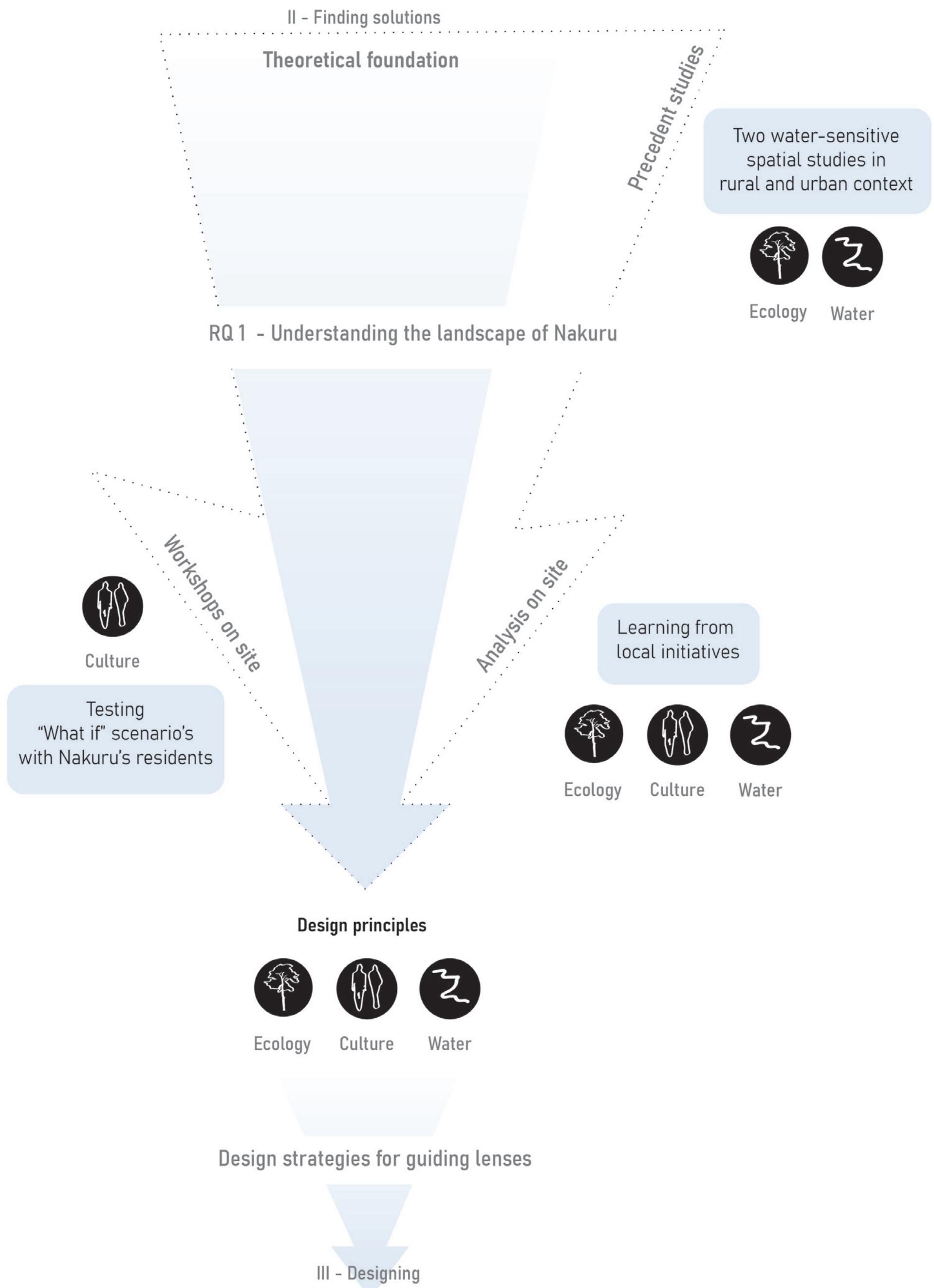
The *Finding Solutions* phase translates theoretical insights and contextual knowledge into concrete design strategies. Due to a lack of familiarity with a foreign cultural and ecological landscape, the research on/for design phase consists of multiple components.

It begins with a theoretical foundation and precedent studies, which provide spatial strategies for water-sensitive design in both rural and urban contexts. These are combined with the findings of RQ1 – *Understanding the landscape of Nakuru*, to establish initial strategies for the guiding lenses of water, ecology, and culture.

To complement this foundation with locally grounded knowledge, fieldwork is essential. On site, three activities are undertaken:

- Workshops with Nakuru residents, where "what if" scenarios are tested to gain socio-cultural perspectives;
- Analysis of local initiatives, which provides insights into existing ecological and cultural practices;
- Interviews with local experts and research institutions

As the process narrows, the combined input from theory, precedent studies, workshops, and local knwoledge is synthesized into design principles for ecology, culture, and water. These principles are then further developed into a design strategy, which bridges research and design part and guides the next phase: *Designing*.



[Figure 14.] Explanatory scheme of how theoretical insights and on-site research are synthesized into design principles and design strategies.

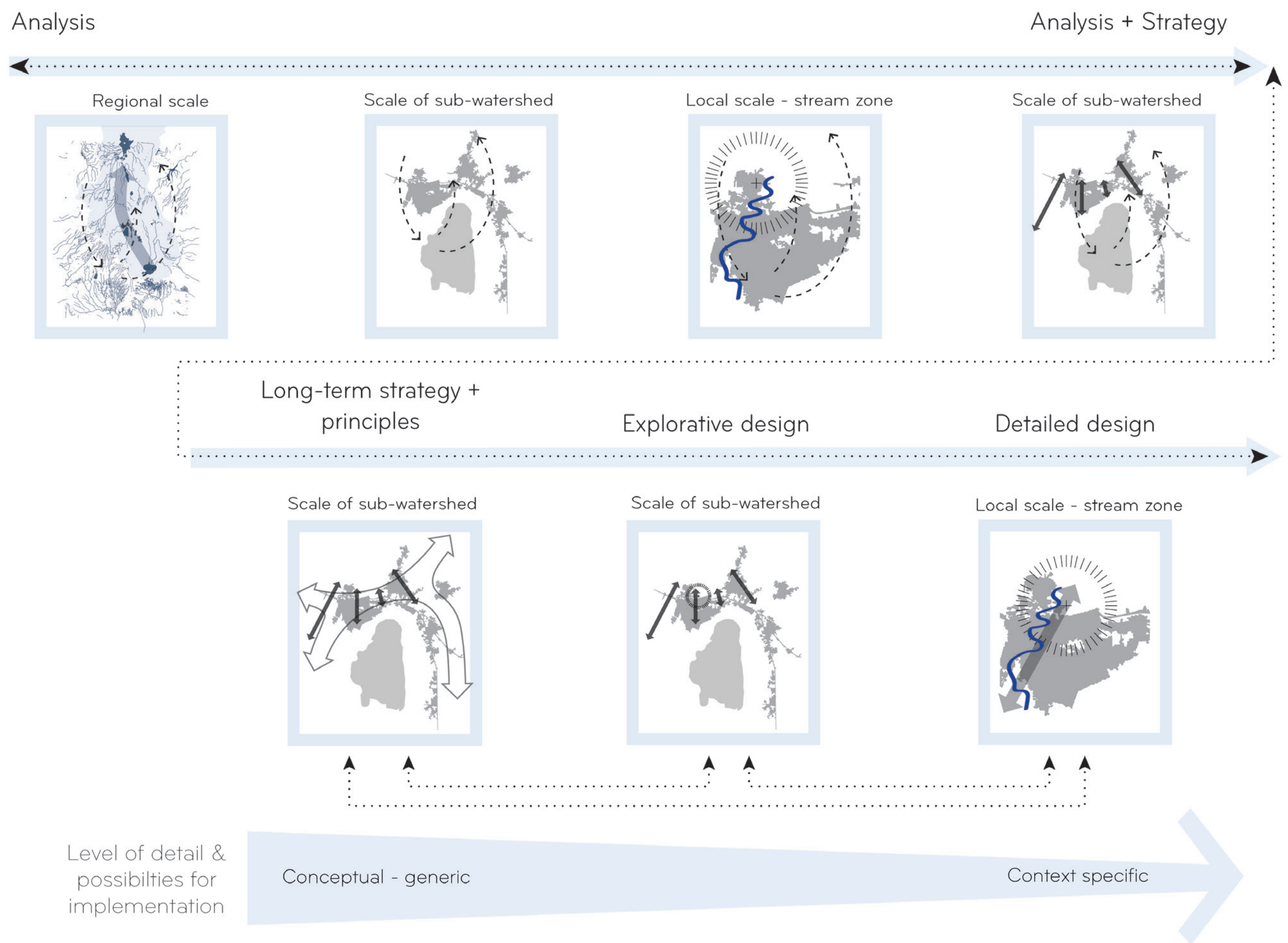
2.9. Expected outcomes

Each stage of the research delivers a specific product at the scale most relevant for answering the research objective. The analysis stage produces maps at the regional scale, showing ecological and urban relations; at the sub-watershed scale, identifying potentials and challenges; and at the local stream-zone scale, detailing conditions along the watercourses.

Based on these insights, long-term strategies and design principles are formulated at the sub-watershed scale, providing a framework for future interventions. These principles are then tested through explorative design, mainly at the sub-watershed scale, to examine spatial possibilities.

Finally, the process results in a detailed design at the local stream-zone scale, where strategies are translated into context-specific and implementable solutions.

Not all products are developed for every scale; instead, outcomes are deliberately assigned to the scale where they are most meaningful for the research aim.



[Figure 15.] Expected outcomes at different scales, from conceptual strategy to context-specific design

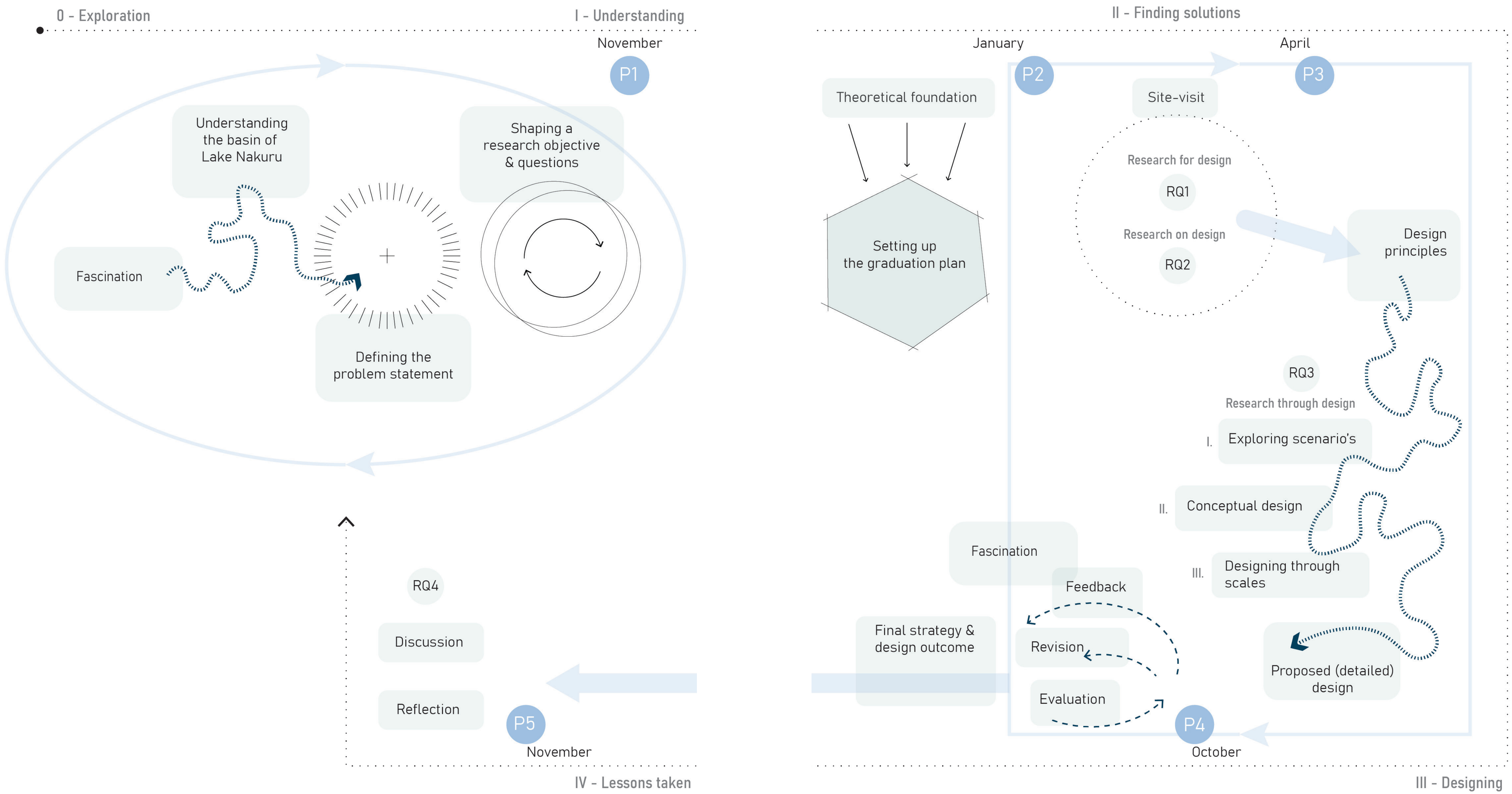
2.10. Research planning

The research is organised in several phases, while remaining iterative rather than strictly linear. It begins with an exploration phase, focusing on the initial fascination, understanding the basin of Lake Nakuru, and defining the problem statement.

The understanding phase includes setting up the graduation plan, building a theoretical foundation, and shaping the research questions.

In the finding solutions phase, theoretical work and precedent studies are combined with a site visit. This phase addresses RQ1 and RQ2 and results in a set of design principles. These principles guide the designing phase, where scenarios are explored, conceptual designs are developed, and strategies are tested across scales, leading to a proposed detailed design.

Finally, the lessons taken phase includes reflection, evaluation, and revision, resulting in the final strategy and design outcome



[Figure 16.] Timeline of the research-through-design process: from fascination to reflection

Finding solutions

PART II


View on Lake Nakuru (photo by author)

Chapter 3. Theoretical framework

3.1. Introduction

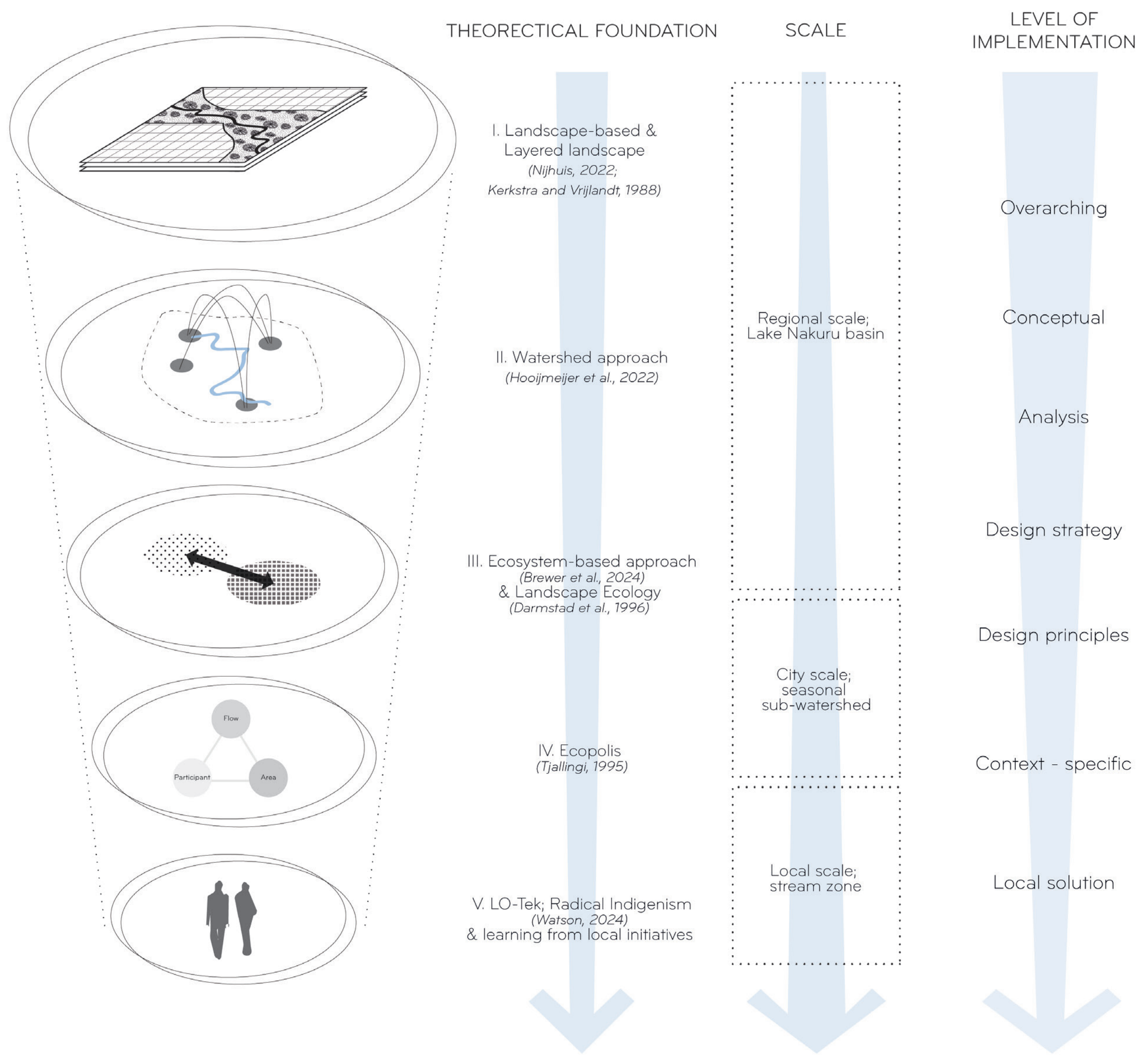
This thesis develops a spatial strategy for water balance and ecosystem restoration to address the interconnected issues of seasonal runoff in Nakuru city. To support this aim, five theoretical approaches are selected that connect to the guiding lenses of this research—water, ecology, and culture. Together, they provide the structure for the research, inform the analysis across scales, and guide the development of design strategies and principles.

The overarching theories that frame the research and guide the site analysis on different scales are the Landscape-based and Layered Landscape approach (Nijhuis, 2022; Kerkstra & Vrijlandt, 1988), the Watershed approach (Hooijmeijer et al., 2022), and the Ecosystem-based approach (Brewer et al., 2024; Forman, 1996). These form the analytical foundation at the regional and city scales.

To connect the analysis to design, two additional approaches are applied: the Ecopolis strategy (Tjallingii, 1995) and the Lo-TEK Radical Indigenism approach (Watson, 2019), complemented by learning from local initiatives. These approaches inform precedent studies and provide methods for developing context-specific design strategies and principles.

At the most local level, insights from local initiatives and interviews with experts became part of both the theoretical and analytical phases. These contributions informed the research on themes such as soil stabilization through vegetation, agroforestry practices, and cultural dynamics in the region, ensuring that the framework is not only grounded in academic theory but also rooted in the lived realities of Nakuru.

Each theoretical approach thus plays a distinct role within the framework, supporting different stages of the research and design process—from overarching analysis to local design solutions.



[Figure 17.] Overview of theoretical approaches and their role in analysis, design and implementation

3.2. A layered landscape

Landscape-based urbanism

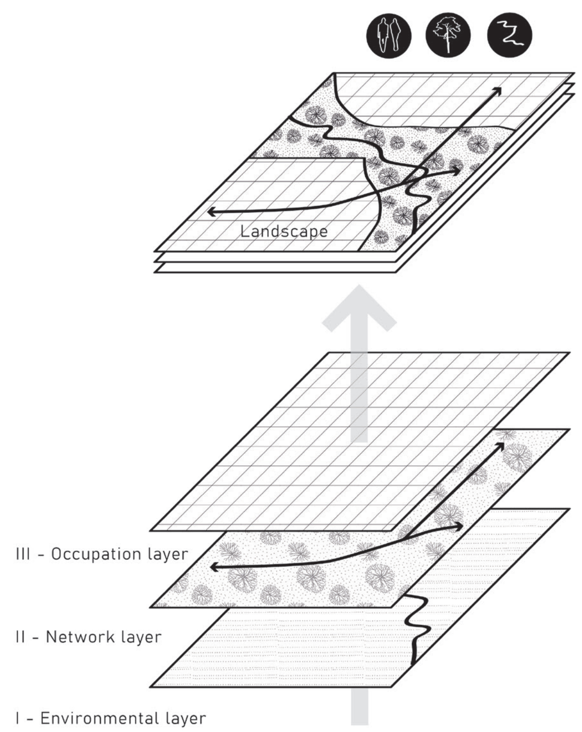
The first, and overarching theoretical layer is the landscape approach called Landscape-based Urbanism, which takes landscape logic as a guiding principle and underlines the need for resilient and flexible landscapes. It takes the landscape processes and structures as a foundation for sustainable urban development and acts as a multi-scaled and area-specific design approach.
Crucial to this theory is that it not only operates by designing with nature, but underlines the importance of social-cultural aspects of the landscape as well. This theory forms the base theory of this thesis, while it identifies water signing with nature, people and history through. It sees the landscape as base for spatial development and requires an understanding of the complexity of the living landscape that has been created by an interaction between the abiotic factors (climate, relief, water and soil) and biotic factors (vegetation, animals and humans).
(Nijhuis, 2024; Nijhuis, 2022).

Casco concept

The consideration of dynamics in the landscape in "Landscape-based Urbanism" corresponds to the Casco concept, a spatial strategy or framework that analyzes the landscape based on differences in dynamics and processes of change. The starting point of this approach is the ecological foundation of landscape architecture and the notion that change is the only constant in the landscape. Kerkstra and Vrijlandt (1988), described the landscape as "the visible result on the surface of the earth of interactions between man and nature" and presented their approach in the "Triplex Landschap" model, which visualizes these interactions (Duchhart & Wageningen University & Research, 2007).
Later, their focus shifted toward land-use dynamics, observing a spatial distinction between high-dynamic functions, mainly based on human activities, and low-dynamic land-use types, such as nature reserves or areas designated for water management. Based on this distinction, they proposed a three-layered model under the name of the Casco concept:

1. The environmental layer, which is slow to change and includes long-term natural cycles, such as geological structures or climate;
2. The network layer, which reflects long-term but high-dynamic land-use types driven by socio-economic and cultural processes, such as transport or water infrastructure;
3. The occupation layer, consisting of short-term developments, such as urbanization or policy-driven changes.

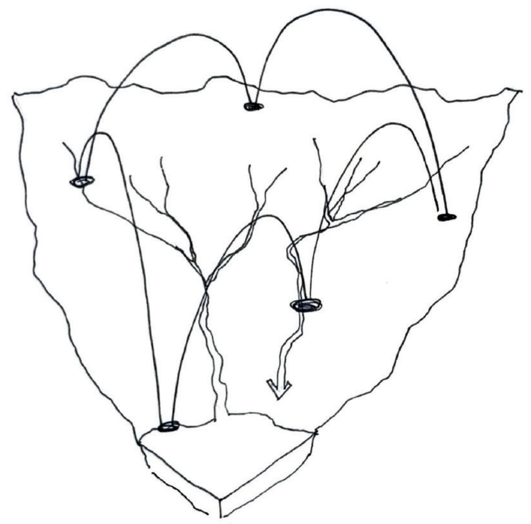
By defining zones of high and low dynamics within the landscape and creating space for each to develop at its own pace, the Casco concept provides a foundation for strategic spatial development, enabling different levels of change to coexist and interact in a more adaptive way (Hoog et al., 1998). Ultimately, this theory thereby helps understand the consequences, connections and possibilities in the urbanization conflict in Nakuru, as discussed in the introduction to this study.



[Figure 18.] The construction layers of a landscape aligned with the present dynamics and processes over time. Redrawn from a representation by Kerkstra and Vrijlandt (Duchhart & Wageningen University & Research, 2007).

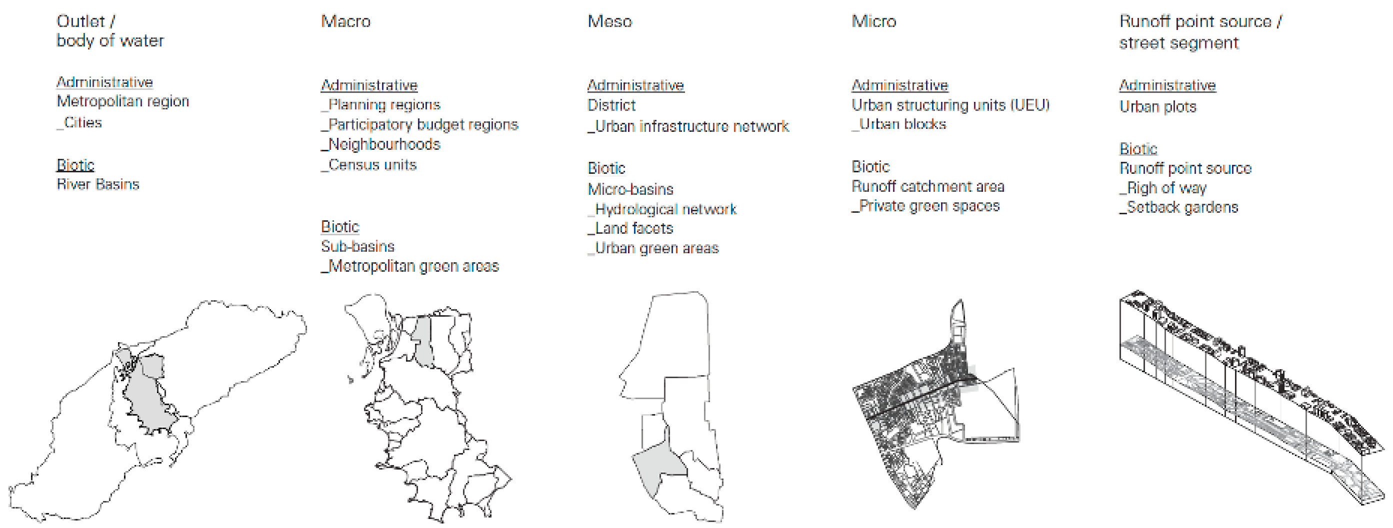
3.3. Watershed approach

This approach involves the understanding of the entire watershed as a living and connected system and how it is interconnected. The system includes interrelationships between rural, peri-urban and urban areas, and their impact on each other (Hooijmeijer et al.,2022). This approach is important because actions taken in one location can have consequences in other parts of the watershed. The city is considered as a part of a larger regional system rather than an isolated island, and is consistent with the guiding lenses in this study. The water system and its waterflows through the landscape sustain the existence of ecology, people and their socio-cultural landscape, which makes multi-scaled watershed approach the second pilar of this research.



[Figure 20.] Visualization of watershed connectivty as explained by Hooijmeijer et al. (2022)

An systematic way of researching the watershed is presented by working through different scales, as presented in the diagram created by Hooijmeijer et al. (2022) and Bacchin (2015). It combines administrative boundaries with hydrological and biotic scales and performs an analysis based on patches and corridors on the higher levels, addresses water cycle restoration potentials on city scale and ends with site-specific interventions that align with the functioning and landscape of this area (Hooijmeijer etal., 2022; Bacchin, 2015)



[Figure 19.] Working through different scales, based on administrative boundaries, hydrological and biotic scales (Hooijmejier et al., 2022; Bacchin, 2015).

3.4. Ecosystem-based approach; "landscapes of hope, instead of regret"

The ecosystem-based approach is based on Nature-Directed Stewardship (NDS) and is about understanding and restoring the natural character of a city, focusing on the ecosystems and water systems that existed before urbanization. It sees cities as living systems with interconnected ecological, social, and physical networks, rather than as artificial environments separate from nature. NDS highlights the human connection to nature and values the inherent worth of ecosystems, not just their usefulness. It encourages seeing cities as living systems with interconnected ecological social and physical elements, while emphasizing on the importance of careful, adaptive restoration connected to social equality and indigenous knowledge. By providing a perspective of ecosystem-thinking by reframing urban areas as ecosystems, rather than an artificial environment separated from nature.
Originally developed for forest ecosystems, NDS principles have been adapted for urban settings to prioritize nature-first urban development. The central idea is to restore the natural ecosystem characteristics of a region, even in densely populated urban areas.

The key principles of Nature-Directed Stewardship:

Watershed indentification:
identify and describe the natural characteristics of the target watershed.

Protection of natural fragements:
preserve remaining fragements of the natural ecosystem

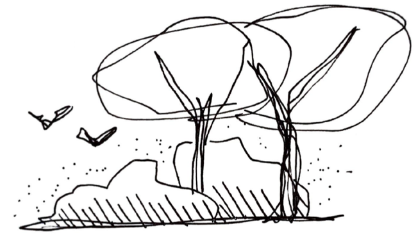
Restoration of Ecosystem fragments:
recreate parts of the natural ecosystem in urban landscapes.

Water flow Network Restoration:
re-establish natural water movement and timing.

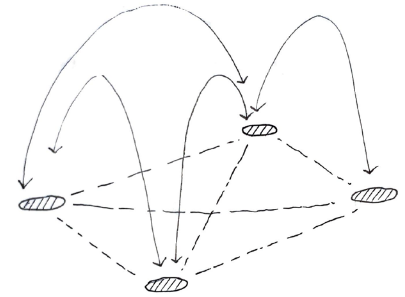
In urban contexts, NDS aims to create "nature-first cities" that prioritize ecological integrity, equity, and urban density. It challenges the traditional Western view of nature as separate from human environments, proposing a new narrative where humans see themselves as integral to nature.
The approach involves collaborative work among governments, scientists, indigenous knowledge holders, and communities to document natural ecosystem characteristics, promote local engagement in restoration, and plan large-scale ecological restoration networks.
To restore the natural character of urban environments and apply the corresponding (design) principles or conditions, a spatial framework is needed. This framework can be derived with design principles from Landscape Ecology, as discussed in the following subchapter.

The core (design) principles are:

Nature
Restoring ecological integrity by reintroducing native ecosystem compositions, structures and functions.



Equity
Ensuring fair acces to and distribution of the benefits of urban green spaces

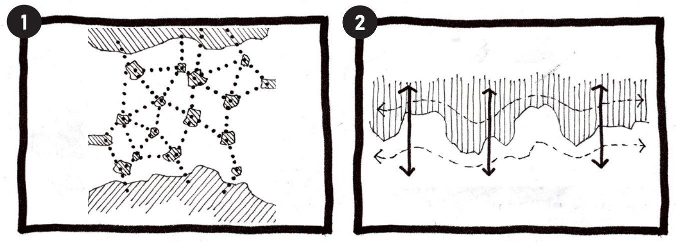


Density
Integrating natural ecosystems seamlessly into dense urban environment.

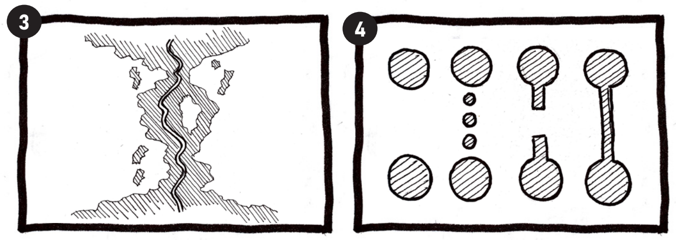
Landscape Ecology *(Darmstad et al., 1996)*

The understanding and implementation of restoration networks or greenways can be strengthened by the field of Landscape Ecology, discussed by Darmstad et al. (1996). The foundations of Landscape Ecology are based on the interaction between ecological processes and 'the spatial pattern of landscape elements" and how these factors interact with each other. The publication by Darmstad et al. (1996) states that Landscape Ecology operates within this interaction, while viewing the landscape as a living system consisting of a landscape structure, a certain functioning or movement by flora and fauna and being subject to change, in which the spatial pattern is continuously altered. In response to the global trend of fragementation and degradation of the environment by human activities, as can be seen in Nakuru as well, this publication introduces key design principles, rather conceptual, to minimize landscape fragmentation, reduce degradation and strengthen the ecological integrity and resiliency by a certain pattern language consisting of universal spatial elements, patches, corridors, and matrix. Within this research, the concepts and design principles of Landscape Ecology are explored, as "spatial pattern strongly controls movements, flows, and changes," and are applied to implement systemic thinking regarding water, ecology, and culture in the development of a landscape-based design strategy.
Darmstad et al., 1996)

Examples of Landscape Ecology design principles (Darmstad et al., 1996):



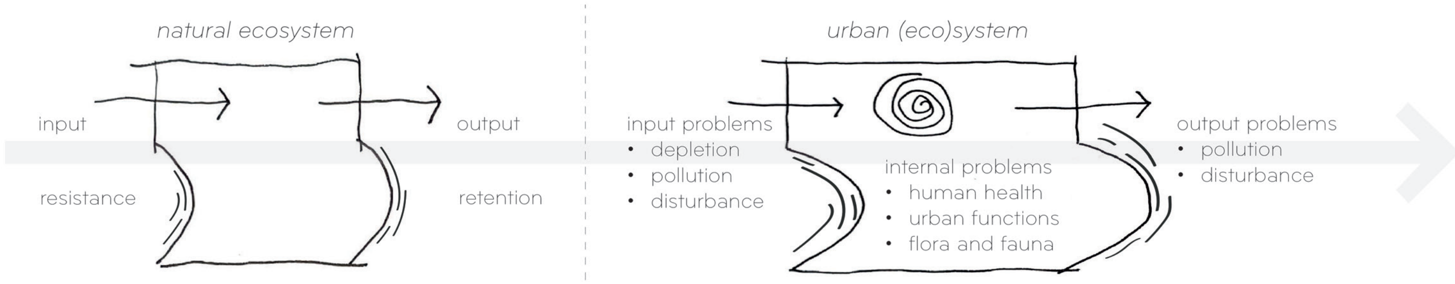
"Patch selection for conservation" *"Edge structural diversity"*



"Connectivity of stream corridor" *"Stepping stone connectivity"*

3.5. Ecopolis

In Ecopolis, developed by Tjallingii (1995), an approach is introduced for ecologically responsible urban development, in which the urban system is understood as an urban ecosystem. The foundation for this perspective lies in the so-called ecodevice model by Van Wirdum and Van Leeuwen, which characterizes natural ecosystems through four fundamental regulatory mechanisms: input, output, the capacity for resistance, and the capacity for retention, such as protection against flooding or the storage of food and water reserves.
Tjallingii applies this model to the urban system and argues that a city can only function by artificially scaling up input and output processes. As a result, the urban (eco)system has, over time, become structurally imbalanced, leading to various environmental problems (figure 21).

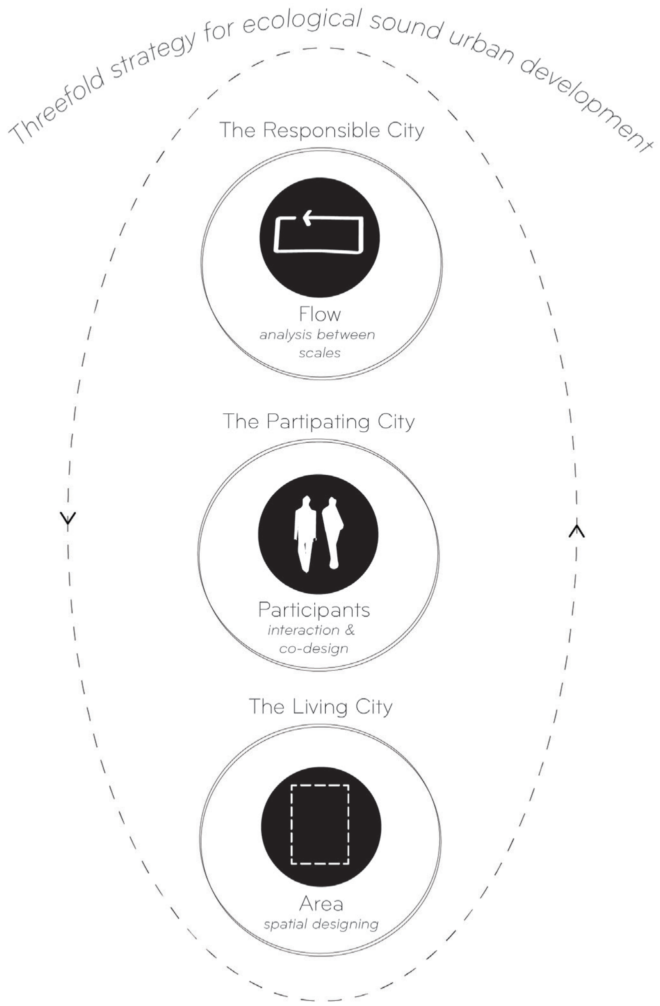


[Figure 21.] Ecodevice model explaining the urban (eco)system (Tjalingii, 1995)

Based on this idea, we can identify three fields that need attention to create an integrated strategy for restoring the urban ecosystem: flows (The Responsible City), areas (The Living City), and participants (The Participating City). Each of these has its own strategy and is considered at different spatial levels, which are used later in this research as tools for a context and site analysis and to guide the design approach.

The strategy for The Responsible City is based on the "ecodevice" model and focuses on the sustainable management of the city's input and output flows. This creates a more solid and sustainable foundation, which is essential for both The Living City, which looks at using the ecological or spatial potential of urban areas, and The Participating City, which depends on the active involvement of all stakeholders to make ecological development work in practice.

Still, it is the management and improvement of flows that forms the base layer, setting the conditions for the other two strategies to succeed over the long term.



[Figure 22.] Threefold strategy as explained in Ecopolis by Tjalingii (1995)

FLOW - The Responsible city

This perspective focuses on the sustainable and long-term chain management of water, energy, waste, and transport, with this research specifically emphasizing the water chain. The most common issue is an overly stable or blocked flow, whose associated environmental problems are often shifted to higher levels or future generations (Kim, 2018). The guiding principles to counter this include efficient use, reuse, the use of renewable resources, and responsibility for the quantity and quality of both incoming and outgoing flows (Tjallingii, 1995).

AREA - The Living City

This perspective regards an area or site not merely as a location within an urban system, but as a node within a larger ecological network and a unit of ecological potential. Each area has context-specific characteristics, such as soil types, vegetation, groundwater levels, and topography, which influence its role in ecological flows as well as its capacity for resistance and retention, in line with the ecodevice model.

Within Ecopolis, guiding models are proposed to implement the Living City perspective. Two models are particularly relevant to this research: the guiding model for the city and the guiding model for the urban fringe, both of which integrate chain guiding principles.

The guiding model for the city focuses on incorporating spaces for seasonal water storage within the built environment and on embedding so-called green wedges, which ensure both the distribution and accessibility of green areas in the urban context (Tjallingii, 1995). In contrast, the guiding model for the urban fringe emphasizes the connection between the city's edge and the surrounding rural areas. Here, the water flow serves as the backbone for less dynamic functions and provides a spatial framework for them. A key principle of this model is that water must flow from clean to polluted areas (Tjallingii, 1995). This model is supported by the Two-Network Strategy, a design-based approach in which the grey network carries high-dynamic functions such as traffic roads, public transport, and intensive agriculture, while the blue (water) network supports low-dynamic functions such as water collection, infiltration, recreation, and ecological services. This strategy translates into a set of spatial principles, where ecological infrastructure guides urban development rather than following it. It is connected to the Casco-concept discussed earlier, wherein a landscape can be designated based on the level of dynamic of functions. The Two-network Strategy can be applied through design interventions such as:

- directing urban expansion along natural gradients (for instance, higher ground for building, lower ground for water retention),
- developing flood zones as green corridors that support water management and biodiversity, and food production;
- aligning roads, railways, and buildings with water flow patterns to enhance infiltration, buffering, and retention.

PARTICIPANTS - The Participating City

In the last perspective, the social dimension of the urban ecosystem is explored, with a focus on participation and interaction. The design and maintenance of an urban ecosystem require the active involvement of stakeholders and local communities, as values, practices, and knowledge must be integrated into the design process. In this context, local communities can contribute by defining the role of green-blue structures within their areas and by informing design through both site-specific knowledge and experiential as well as ecological insights. This approach offers a valuable understanding of social structures, observed patterns (such as locations where water accumulates after rainfall), and the ways in which spaces are used and experienced by residents.

As Tjallingii notes, there is a certain level of self-organization in developing countries that is important to consider in this research, referred to as the "strategy of the commons." This is based on an unspoken agreement in which communal use of space is largely permitted and accepted. Even the poorest residents participate in the informal economy, for example by growing crops or keeping livestock, and in many cases, local markets rely heavily on this group (Tjallingii, 1995). A policy aimed at stimulation and creating conditions can enhance the involvement of the commons, for instance, by encouraging implementation through residents themselves and thereby fostering shared responsibility. An important co-benefit of this approach is the creation of employment opportunities and increased awareness among local inhabitants.

Spatial scales for guiding models

Tjallingii organizes his guiding models (for chains, areas, and participants) around four spatial scales: building, neighbourhood, city, and region. These scales serve different purposes: chain guiding models are elaborated at each scale, while area-based guiding models are applied mainly at the neighbourhood, city, and regional levels.

Rather than defining fixed sizes, Tjallingii treats these scales conceptually, showing how interventions at one level should support and align with those at others. Actions and designs at the building scale should align with and support those at the neighbourhood level, which in turn should integrate into patterns at the city and regional scales. However, some interventions are more effective at particular scales, such as water retention and green corridors at the neighbourhood level, or ecological and transport structures at the city scale.

In Ecopolis, spatial scale is not only an ecological or technical dimension but also a participatory one. Each scale involves a different set of stakeholders whose engagement is essential for the success and legitimacy ovf interventions. In this way, bottom-up knowledge and practices, inform and enrich top-down frameworks and investments (see figure 23).

Sandwich-strategy

Building on the Ecopolis framework, the Sandwich Strategy by Tjallingii (1995) provides a practical model for linking development and implementation. While the Ecopolis framework outlines the conceptual structure of flows, areas, and participants, the Sandwich Strategy translates these ideas into an operational approach. It thereby connects three interdependent layers of action across scales to overcome the ongoing challenge between (too) centralized and decentralized planning.

The top layer represents governments and higher authorities that shape conditions through policy, regulation, and investment. The basic layer consists of citizens and local communities who respond to these conditions through everyday practices and local initiatives. Between them, the intermediate layer forms the space where collaboration occurs and collective projects take shape, making ecological and social improvements visible on the ground.

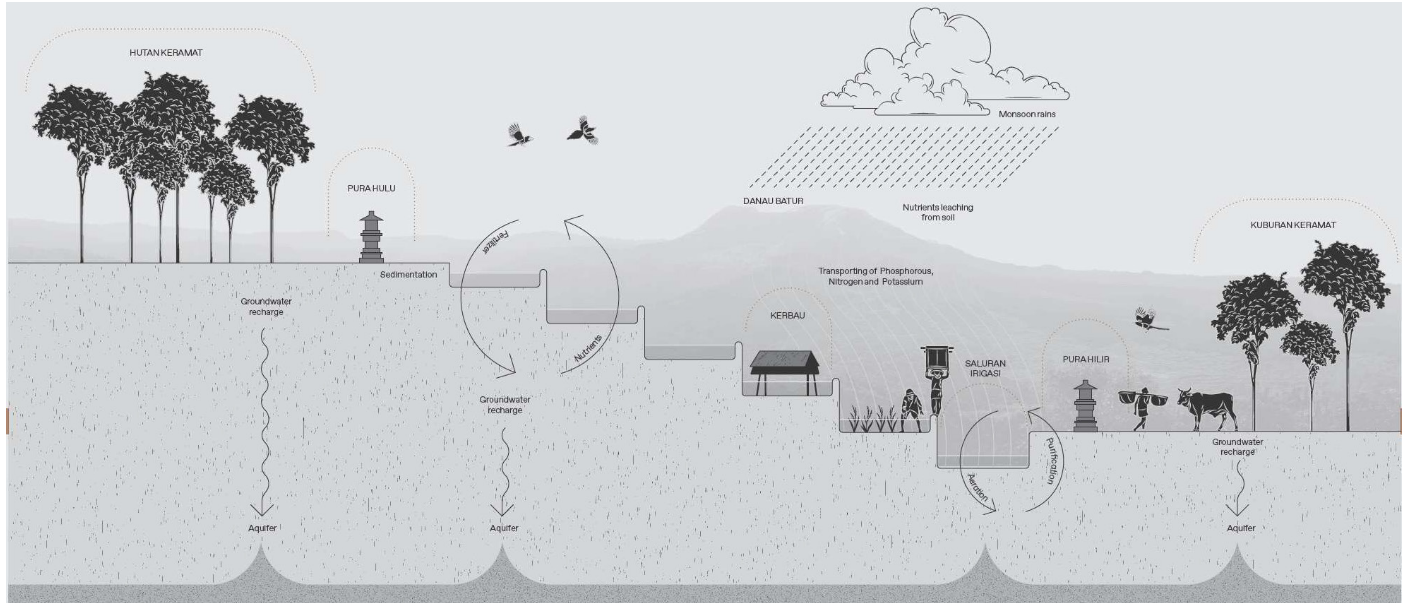
For this research, the Sandwich Strategy offers a governance framework for implementing the proposed landscape-based spatial strategy for Nakuru. It ensures that interventions are neither driven only by top-down planning nor left entirely to self-organization, but co-produced through cooperation between institutions, designers, and local stakeholders. This helps integrating the spatial strategies within existing structures while maintaining space for local initiatives and shared responsibility, and thereby bridges theory, design and practice.

motto	**The Living City**		**The Participating City**
Scale	*What it stands for*	*Estimated size*	*Key stakeholders*
Building/plot	An individual house, including its direct surroundings such as garden or yard.	Very local; measures and interventions at building scale	Households, tenants and property owners
Neighborhood	A coherent cluster of buildings with local streets, public space and shared infrastructure	Mid-scale; interventions could include a layout of streets or a green corridor	Residents' associations, local businesses, schools, community groups, religious institutions
City	The urban system as a whole, with its districts, transport system and main green/blue structures	Large scale; several tens square kilometers, depends on city size	Municipal planning departments, developers, NGO's
Region	The city in its wider ecological and hydrological landscape, including the fringe, agricultural hinterland and natural areas.	Very large; includes an area for ecological infrastructure and is important for structuring the "two network strategy" that goes beyond the built city	Regional governments, agricultural organizations, conservation institutions, intermunicipal alliances

[Figure 23.] Different scales in developing a design strategy, as explained in Ecopolis by Tjalingii (1995)

The last theoretical layer is mainly linked to the guiding lens culture within this research and oversees the socio-cultural layer of landscape and its interaction with water and ecology over time. The Lo-TEK movement, based on Traditional Ecological Knowledge (TEK), aims to understand the traditional interaction between nature and people and how this created certain philosophies, beliefs and practices through time. This movement consists of multigenerational knowledge and connects with the existing, living ecosystems, while adapting to environmental challenges. It prioritizes biodiversity and stands for sustaining natural resources rather than exploit them by promoting regenerative design and community-driven solutions. Within this research the Lo-TEK ideology is providing knowledge on how traditional knowledge and cultures can be used to promote sustainable urban development while respecting natural processes and existing cultural ecosystems in the landscape. By applying the ideology and principles of TEK, urban development can prioritize biodiversity, adapt to environmental challenges, respect local socio-cultural structures and sustain a regenerative relationship with nature.

In Watson's (2019) publication, various examples worldwide are extensively analyzed based on their implementation, cultural value, and the contribution of each intervention to maintaining the landscape. These cases offer inspiration on how to engage with indigenous ecosystems in an ecologically responsible way, while also considering the social and cultural context of the area. Through Watson's in-depth analyses, a clear step is made from theory to implementation, using the Lo-TEK ideology within this theoretical framework as a tool to move towards a design strategy and principles.



[Figure 24.] Section visualizes the adaption of the agricultural system to the natural watercycle instead of depleting it, by constructing terraces in the landscape - location South-East Asia - drawing by Watson (2019)

Terrace system - South-East Asia

An example from South-East Asia, focusing on a terraced agricultural system, is particularly relevant to this research due to its similar ecological and hydrological context. This system is community-led and bottom-up, shaped by local knowledge and practices passed down over generations. It serves multiple functions, not only for food production, but also for water management, soil conservation, and ecological resilience.

The system is closely aligned with the natural water cycle, avoiding resource depletion while recharging groundwater reservoirs, adapting to seasonal variations, and reducing the risk of erosion. Its long-term functionality shows how traditional, place-based systems can offer valuable insights for designing resilient and regenerative, but productive landscapes, particularly in areas facing similar environmental conditions.

Kihamba Forest Gardens - Mount Kilimanjaro Tanzania

Kihamba Forest Gardens – Mount Kilimanjaro, Tanzania
The Kihamba forest gardens at the foothills of Mount Kilimanjaro represent a traditional agroforestry system that integrates agriculture, forestry, and settlement within a single managed landscape. These gardens are organized in vertical layers, with tall shade trees, fruit trees, and crops combined with small livestock, creating a multifunctional, layered, and highly resilient system. Over generations, this structure has maintained soil fertility, conserved water, and supported biodiversity while sustaining local livelihoods. For this research, the Kihamba system is relevant because it demonstrates how traditional, community-based land management can balance ecological health with human needs. Its layered design reflects a close integration of cultural practices with ecological processes, offering lessons for Nakuru on how to create social-ecological restoration networks that respect both natural dynamics and cultural traditions. In particular, Nakuru could benefit from agroforestry and intercropping on steep slopes instead of monoculture farming, by integrating multipurpose trees and shrubs in symbiosis with annual and perennial crops (Watson, 2019).

[Figure 25.] (Left) Settlements surrounded by forest plantations with banana trees integrated; (right) The Kihamba agroforestry system imitates a mountane forest on the slopes of the Kilimanjaro, Tanazania - photos by Watson (2019)

Nature-Based Solutions (NBS)

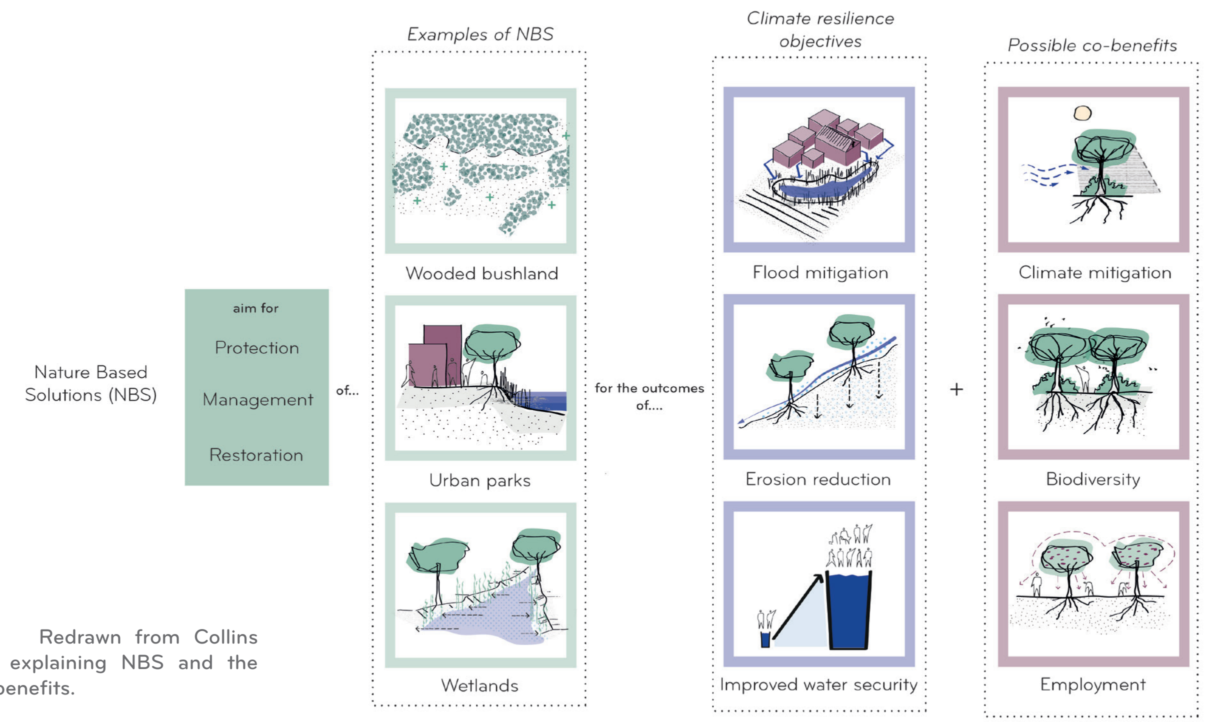
Besides the Lo-TEK ideology, there is a growing interest in Nature-based Solutions (NBS) as natural solutions for protecting against and mitigating the impacts of climate change. To understand the connection between Lo-TEK and NBS, it is essential to first define NBS and outline their key characteristics. In some aspects, NBS are closely linked to traditional methods grounded in ecological knowledge, as seen in the Lo-TEK approach, but differs in the level of working with cultivated land. NBS focus more explicitly on working with natural processes and landscape dynamics, translating these into contemporary interventions aimed at restoring the imbalance in current landscapes.

These solutions require an deep understanding of local environmental conditions and dynamics—such as soil, climate, ecology, and socio-cultural structures—and are closely tied to the layered landscape approach discussed earlier. By engaging with dynamic natural cycles, such as plant succession and seasonal variation, NBS can adapt more easily to changing conditions than static, engineered solutions (Bouw, 2021). Their aim is to mitigate and adapt to climate change, preserve biodiversity, support human wellbeing, and foster more sustainable landscapes—far beyond what current gray infrastructure can offer. As Seddon et al. (2020) describe, this approach means "working with rather than against nature."

In addition to their ecological focus, NBS address broader societal challenges through a wide range of applications by creating innovative "grey-green" approaches. Their main function is to increase climate resilience, for instance, by restoring wooded bushlands to mitigate floods and reduce erosion risk. At the same time, once implemented, NBS generate a range of co-benefits that extend beyond their primary ecological function. These may include supporting biodiversity, enhancing human well-being, creating new employment opportunities, and other locally specific benefits that emerge from the interaction between people and their environment (Figure 28; Collins et a;., 2025). The extent and balance of these benefits may vary across different types of interventions. NBS can be understood along three dimensions: the spectrum of interventions they encompass, the degree to which they enhance biodiversity, and the level of involvement of local communities in their design and implementation. In other words, not every Nature-based Solution provides the same level of ecological or social benefit, but all operate with the shared intention of contributing to both. The ability of NBS to respond to both environmental and social needs closely aligns with the theoretical approaches discussed earlier in this research—the multi-layered landscape, the interconnected watershed, and the ecosystem-based approach.

Overall, NBS are not merely about adding green elements to the built environment, they involve finding the most beneficial interaction between green and gray systems (Bouw, 2021). Their value in this research lies in their multifunctionality and their potential to create space for the dynamic interactions of water, ecology, and culture—the three guiding lenses of this study.

Relevant examples include constructed wetlands that support both flood protection and food or water security, as well as the integration of natural dynamics into urban environments through buffer zones or floodplains that respond to seasonal variability.



[Figure 28.] Redrawn from Collins et al. (2025) explaining NBS and the generated co-benefits.

Field reflections - Local initiatives as LO-tek and NBS

During the site visit to the Nakuru region, several local initiatives were identified that align with a responsible way of engaging with the landscape, similar to the principles of Nature-Based Solutions (NBS). These initiatives, closely connected to the Lo-TEK ideology, demonstrate how communities already interact with their environment in adaptive and sustainable ways. They will be further discussed and analyzed in Chapter 4.6, as they provide valuable insights for developing context-specific design strategies. However, they are currently implemented only on a small, local scale. While this reflects the socio-cultural structure of Nakuru, there are precedent studies (chapter 3.7) from other regions where traditional ecological knowledge, combined with newly developed NBS, have been applied more widely to restore ecological functions and strengthen resilience and flexibility of the landscape.

As Duchhart (2007) highlights, such local initiatives are essential for shifting planning processes from externally defined plans toward community-owned practices. They demonstrate that landscape design can play an integrative role in addressing environmental degradation and social concerns, particularly in the Kenyan context as discussed by Duchart (2007). Three lessons from her work are especially relevant to this research.

1. People-centered approach: sustainable interventions require direct engagement with local needs and priorities rather than externally defined goals.
2. Integration of knowledge systems: combining scientific analysis with indigenous knowledge ensures that interventions are both technically effective and culturally embedded.
3. Ownership through participation: involving communities in both planning and implementation fosters long-term responsibility and resilience.

In this sense, local initiatives in Nakuru are not only case-specific practices but also stepping stones toward a broader design strategy. They can show how small-scale, community-driven actions can inform and legitimize larger-scale interventions when embedded within the social-ecological fabric of the region. At the same time, they provide insights into context-specific practices that directly inform this research, which began with limited knowledge and a lack of familiarity with the socio-cultural dimension of the study area.
By analyzing these initiatives on site through fieldwork, workshops, and interviews with local stakeholders, this challenge can be partly overcome, ensuring that the research is not only theoretically grounded but also informed by lived realities. In doing so, local initiatives support the development of a context-sensitive design outcome that integrates social, ecological, and cultural perspectives.

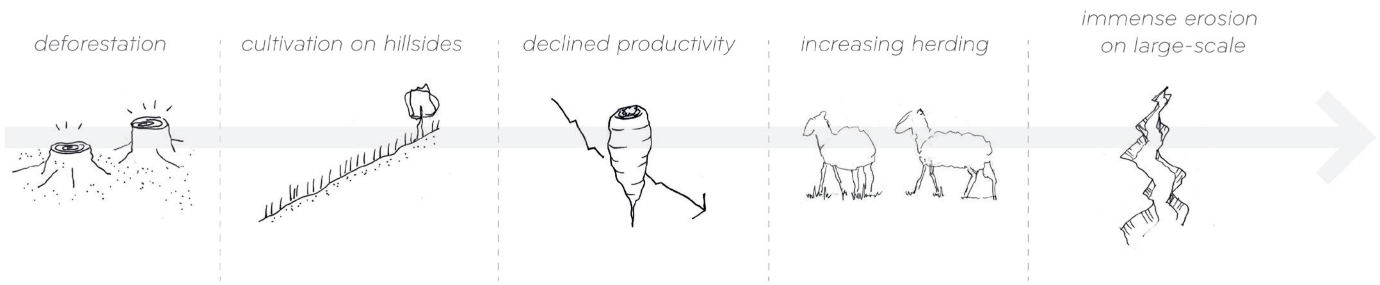
The precedent studies in this research are analyzed through the lens of the three Ecopolis layers—flows (The Responsible City), space (The Living City), and participation (The Participating City), to assess the value of the design, following the method of Tjallingi as applied by Kim (2018).

The first case study focuses on a large-scale rural landscape that was severely degraded by erosion and later restored at the ecosystem level by working with the natural systems and mechanisms present in the landscape. In contrast, the second case study is situated in an urban context and explores how traditional water systems can be revitalized to improve storage and reuse, reduce flooding, and involve local communities in managing the water cycle.

By addressing both a rural and an urban example, the studies highlight how regenerative practices can operate across scales and contexts. Together, they provide inspiration for the development of the design strategy and principles, demonstrating how community-led approaches can contribute to restoring the water balance and native ecosystems while remaining context-sensitive.

(1) Ecosystem restoration on the Loess Plateau, Gansu, China *(John D. Liu, 1995)*

The Loess Plateau, located in northwest China, covers approximately 640,000 km² and has been inhabited and cultivated for thousands of years (Liu & Hiller, 2016). The loess soil was originally formed by glacial activity in the Himalaya region, after which wind carried the material to the plateau. In some places, these loess deposits are more than 100 meters thick, making them highly fertile but also extremely vulnerable to erosion once vegetation is removed.
What was once a thriving landscape became severely depleted and eroded. When ecologist John D. Liu first documented the region in 1995, he described a landscape that had lost most of its ecological functions (Liu & Hiller, 2016). Forest cover had fallen from an estimated 50% to only 7–10% due to unsustainable practices such as deforestation, overgrazing, and inappropriate agriculture. This led to massive runoff and evaporation, with approximately 95% of precipitation lost, topsoil erosion, and the formation of deep gullies (Liu & Hiller, 2016).



[Figure 29.] Actions that increased the environmental degradtion of the Loess Plateau.

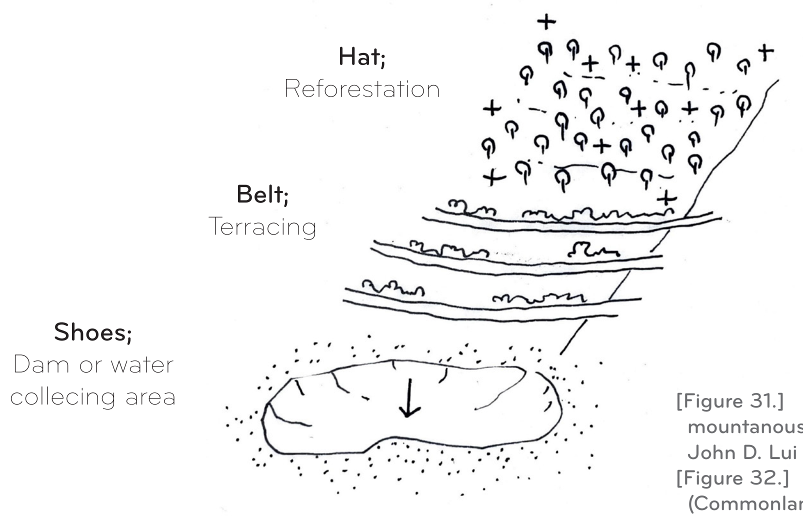
After establishing the value of a functioning ecosystem compared to the services and "short -term derivatives" from the landscape, led to an investment of the World Bank and collaboration on national, provincial and local level to develop a strategy for the region (Liu & Hiller, 2016). After extensively researching the natural and social processes and dynamics in the region, a package of interventions was created including, reforestation, gully rehabilitation, trapping sediment, soil stabilization, terracing of slope-areas and introducing perennial crops that are suitable for the landscape.
The first step in restoration was banning free grazing and designating areas with slopes above 25% as unsuitable for agriculture, creating space for natural vegetation to regenerate. This initiated a "domino effect": vegetation recovery improved infiltration and soil moisture, which in turn benefited surrounding agricultural plots. An important lesson from this project is that even "extensive agriculture can eliminate natural vegetation" and degrade ecosystems (Liu & Hiller, 2016). Conserving and integrating natural vegetation is therefore essential, while simultaneously designating productive land where appropriate within the system.

FLOW -
The project restored the natural water and sediment flows in the plateau. By introducing terracing, re-vegetation, and water-harvesting techniques, it reduced runoff and erosion, improved infiltration, and rebuilt soil fertility. This rebalanced hydrological and ecological processes at a large scale.

PARTICIPANTS - The Participating City
The project strongly involved local communities and farmers in planning and implementation. Training and incentives encouraged residents to adopt sustainable practices, such as agroforestry and controlled grazing. This participation ensured long-term stewardship and linked ecological recovery with improved livelihoods.

AREA - The Living City
The degraded plateau was reorganized into a functional mosaic of ecological zones and productive land. Large parts were reforested and protected for ecosystem services, while designated areas remained available for agriculture and grazing under sustainable management. This spatial restructuring created a balance between ecological restoration and human use.

[Figure 30.] (Left) Degraded and eroded landscape of Loess Plateau before restoration activities, early September 1995; (right) Loess Plateau after ecological rehabilitation, early September 2009, Boyd-Moss (2022).



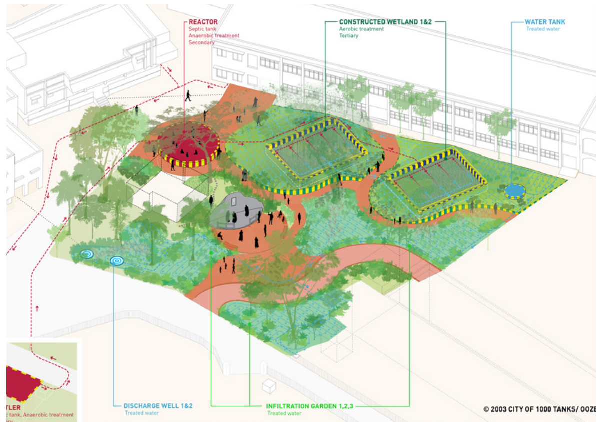
[Figure 31.] Restoration strategy of an degraded mountanous area, drawing based on documentary of ecologist John D. Lui in 1995;
[Figure 32.] Green Gold: Regreening the Desert (Commonland, 2024).

(2) City of 1,000 tanks, Chennai *(Ooze Architects, 2021 - now)*

The City of 1,000 Tanks Water Balance Pilot by Ooze Architects is a water management initiative grounded in landscape architecture, located in Chennai, India. It addresses both water scarcity and flooding by creating a system of so-called "zuiveringstuinen" (purification gardens) throughout the city. Currently, Chennai misses major opportunities to capture, purify, and recharge groundwater (Van den Ende, 2024). Inspired by traditional temple tanks that used to collect rainwater, the project developed a spatial strategy consisting of a decentralized network of water bodies that collect, store, and treat runoff at the local scale. Wastewater and polluted runoff are also managed through decentralized Nature-Based Solutions (NBS) on different scales. The initiative aims to reduce flood risks in the urban context while improving water availability (City of 1000 tanks, n.d.).

A demonstration project has been implemented in the courtyard of a school to illustrate the potential of this system. By repairing infrastructure, harvesting rainwater, and treating wastewater at the local scale with low-cost interventions, the project demonstrates how the urban water balance can be restored and strengthened against changing weather patterns (Van den Ende, 2024). By integrating communal spaces into the system, the project also promotes long-term community involvement, as residents engage with public spaces such as schools.

[Figure 33.] The so-called purification garden pilot in the schools courtyard to collect and purify rain- and waste water, Chennai (City of 1000 tanks, n.d.)



[Figure 34.] System of water collection and purification at the schools courtyard (City of 1000 tanks, n.d.)

FLOW -
Restoring water balance across the urban landscape by collecting rainwater, treating runoff and wastewater locally, and recharging groundwater. The project reduces flood risk and water scarcity by making more effective use of existing hydrological flows inside the city.

AREA - The Living City
A decentralized network of water bodies is integrated into the urban fabric at multiple scales, from school courtyards to neighborhood systems. These spaces serve both ecological and social functions, combining water storage, purification, and public use..

PARTICIPANTS - The Participating City
Local communities are directly involved through interventions in communal spaces such as schools. By embedding water management into shared environments, the project encourages long-term stewardship and collective responsibility across generations.

Landscape-based urbanism (Nijhuis, 2022)	Multi-scaled and context-specific layer approach	1. Analyzing through scales and landscape layers 2. Understanding of natural dynamics in the landscape
Watershed approach (Hooijmeijer et al, 2022)	Interconnected watersystem	1. Systemic thinking of (seasonal) water flows 2. Up-, mid- and downstream are interconnected
Nature-directed Stewardship Brewer et al. (2024)	Restoration networks to create an urban ecosystem	1. (Seasonal) water flows or movement as a carrrier for ecological restoration networks in urban context 2. Understanding the urban context as an urban ecosystem
Ecopolis (Tjalingii, 1995)	Threefold strategy for ecological sound urban development	1. Used for detailed analysis and as a design tool for three fields: flow (chain management), area (specific site), and participants (relevant stakeholders). 2. Analysis of these three aspects provides an integrated spatial strategy for restoring the urban ecosystem in Nakuru. 3. Two-network strategy; linking infrastructure (red) to water (blue)
Lo-tek; Local Traditional Ecological Knowledge Watson (2019)	Use of local knowledge of natural systems; management principles	1. Analyzing and designing tool 2. Linkage between research on site; learning from local initiatives and workshops on-site

Theoretical strategy;

A **multi-scaled** approach linking water, ecology, culture, and local knowledge, using **systemic thinking** of seasonal water flows to design spatial networks that strengthen both freshwater availability and socio-ecological resilience.

Looking over the Rift Valley (photo by author)

Chapter 4. A landscape in motion

This chapter addresses the first analytical research question 1: How did the water and socio-cultural system in Nakuru change over time in relation to the natural and urban landscape? To answer this question, a multi-scalar and layered analysis is conducted, moving from the regional and conceptual scale toward a local and context-specific focus (figure 36).

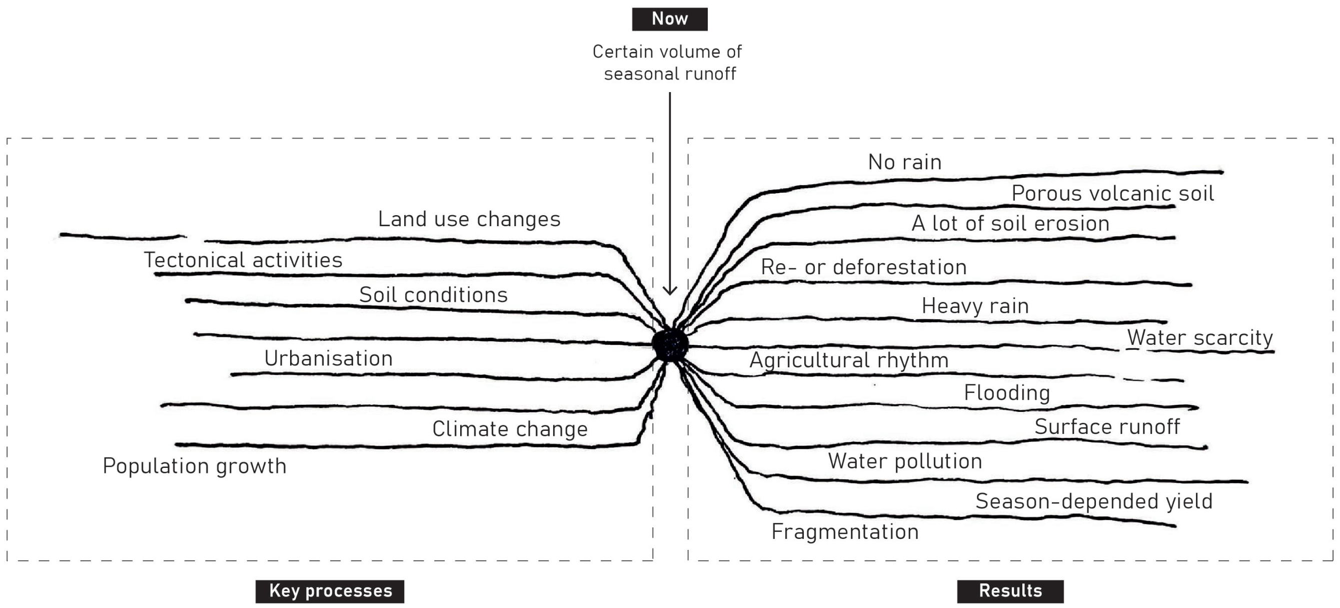
At the regional level, the analysis is structured through the landscape layered model (see Chapter 3.2), which provides insight into the natural and urban systems surrounding Nakuru and their interrelations. This step identifies the broader ecological and hydrological dynamics shaping the Lake Nakuru basin and its connection to the city.

At the city and sub-watershed scale, the Ecopolis framework by Tjallingii (1995) is applied to generate more detailed and context-sensitive insights. This model highlights three critical dimensions: flows (water and resource chains), area (spatial and ecological characteristics of specific sites), and participants (stakeholders and actors involved). By examining these dimensions, the analysis reveals the pressures, potentials, and relevant actors that shape the socio-ecological system of Nakuru.

In addition, fieldwork forms an essential component of this research phase. On-site investigations, supported by interviews, workshops, and direct observations, provided new information on the natural system, local practices, social dynamics, and stakeholder interests. These findings are crucial for connecting theoretical insights with lived realities.

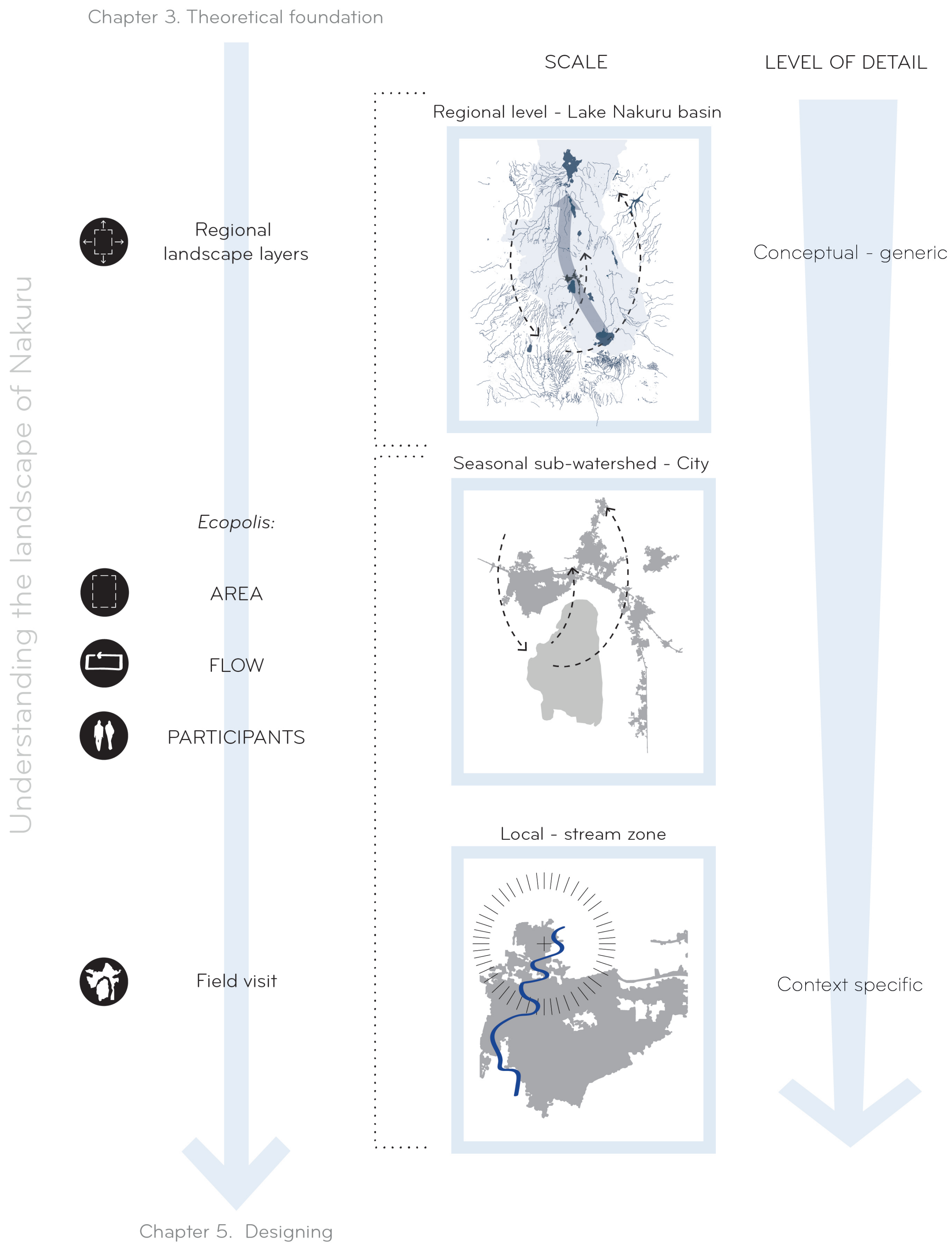
Finally, the analysis zooms in on critical seasonal water flows along the city's edge. These flows, identified during fieldwork as a major source of disturbance in several neighborhoods, form the focus for the subsequent design phase. By tracing their spatial dynamics and social impacts, the analysis establishes a direct link between systemic challenges and local design opportunities.

Together, these steps create a comprehensive understanding of the landscape of Nakuru, bridging scales and perspectives, and laying the groundwork for developing design principles and strategies in the next of the research.



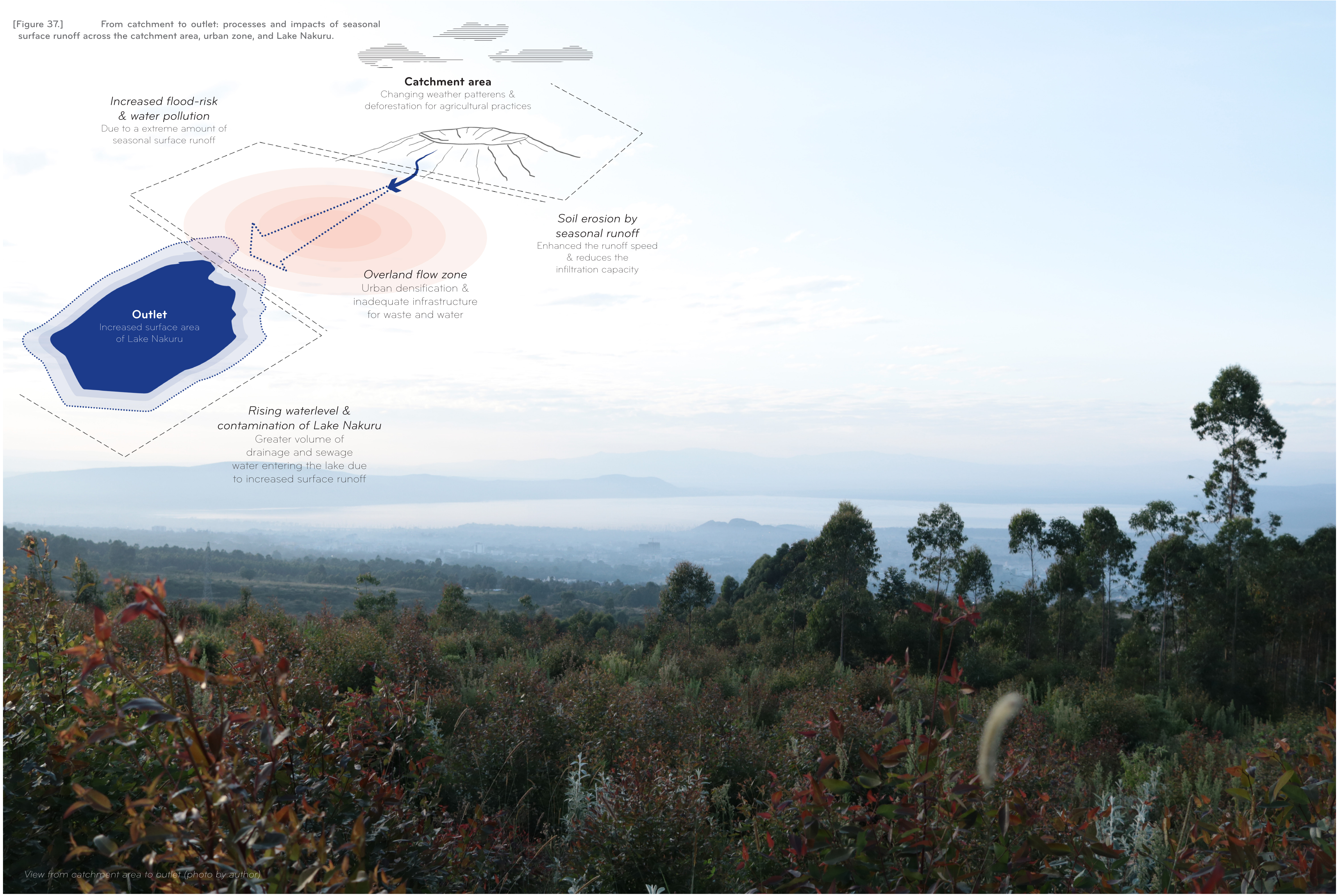
[Figure 35.] Processes and consequences of seasonal surface runoff in Nakuru's landscape.

Figure 35 illustrates the systemic dynamics of seasonal surface runoff in Nakuru. On the left, key processes such as land-use change, population growth, urbanization, and climate change alter the natural and social landscape. These processes interact with local conditions, such as porous volcanic soils and steep slopes, and together they influence how much rainwater becomes runoff. As researched by Schalkwijk (2025), approximately 70% of the urban flooding volume originates from surface runoff, which highlights the critical nature of the issue being studied. On the right, the resulting impacts become visible: soil erosion, flooding, water scarcity, and water pollution, alongside agricultural and ecological disruption. The diagram shows that runoff is not a single cause-and-effect process but the outcome of intertwined natural and human dynamics. Understanding these interconnections is essential for analyzing Nakuru's landscape across scales and for identifying where design interventions can contribute to restoring the water balance.



[Figure 36.] Multi-scalar analysis structure for understanding Nakuru's landscape

[Figure 37.] From catchment to outlet: processes and impacts of seasonal surface runoff across the catchment area, urban zone, and Lake Nakuru.



Topography

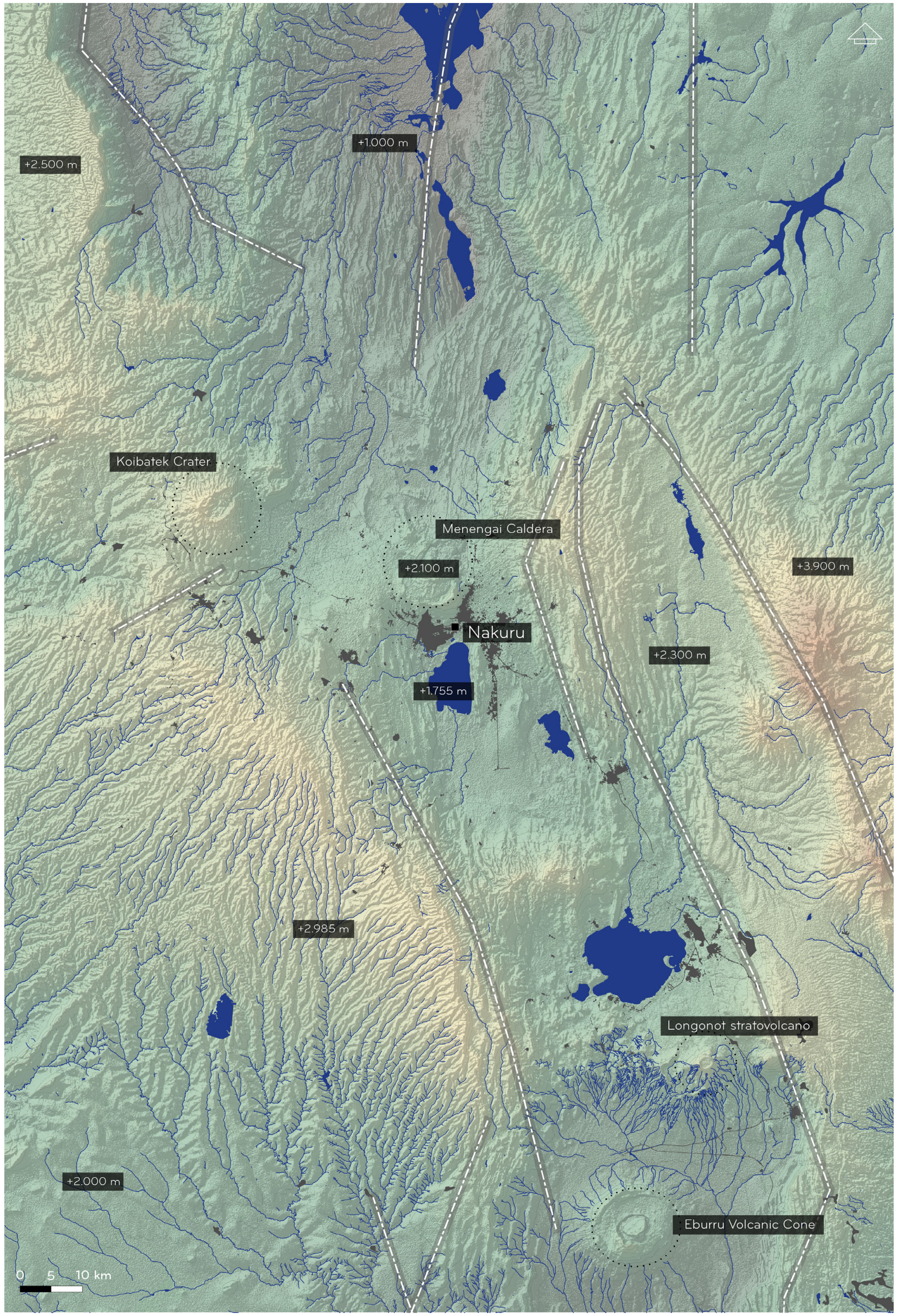
Nakuru is positioned in the Eastern part of the African Rift region and surrounded by several (in)active volcanoes and active fault lines in different sizes. Even though, most of the active fault lines are north-south orientated, the main divergent movement in the rift is NW - SE. The borders of the Rift valley in the region of Nakuru exists of high mountain belts (Mount Kipipiri as part of the Aberdare Rage (west)) and plateaus (Mau plateau (east) and the Bahati plateau (west)), as visualized in the map.
The rifting process is in this part of the Rift Valley already in a quite advanced stage. The tectonic activities left are therefore only located in the "inner trough of the rift" (Conti et al., 2021). The ongoing process led to more volcanism in the Rift during the age of Quaternary and created the "younger" volcanism in the area, like the Longonot, Eburru volcano at the south and the Menengai in the northern part of the area.
Especially the Menengai Caldera is of great importance for the natural system of Nakuru city, as it is positioned on the hillside of the Menengai.

Box 1

The Menengai volcano evolved as a shield volcano with low-angle slopes, that are still visible in its current state. Between 29.000 and 8.500 B.C. the Menengai volcano erupted, collapsed and evolved into a caldera. Volcanic sediments were widely spread into the area after the eruption and can be found up to 30 km from the caldera. This interconnection between topography and soil-characteristics can be seen found in the soil map.

Nowadays, the Menengai Caldera is well-visited by tourists and one of the main resources of geothermal energy on national scale. The grounds on the hillside of the caldera have been transformed over the last decades due to land-use changes, like urbanization, deforestation and the upscaling of agricultural plots.

[Figure 38.] Inside of the Menengai Caldera (photo by author)



[Figure 39.] Topography of Nakuru on regional scale

Soil

As discussed earlier, the rifting process had started a chain process of volcanism in the Rift Valley region. When visiting the Rift Valley visitors can find the volcanic remains peeking out of the quite flat bottom of the Rift Valley, like the Longonot volcano crater. On the soil map, the tectonic activities of the Rift Valley correlate with the position of soil types with volcanic compositions around Nakuru.

The volcanic soil has enormous consequences for the region due to its fertility, porosity, and high infiltration rate (Nillesen et al., 2024), and it has influenced the landscape of the Rift Valley in several ways. Consequently, the volcanic composition of the soil makes the region suitable for agricultural activities. For decades, the Rift Valley has been an attractive area for large-scale agriculture, and the fertility of the soil has been one of the main pull factors for population growth in the Nakuru region (Nillesen et al., 2024).

However, the thin, porous volcanic layer makes the soil prone to erosion as well and heightens the risk of landslides and lose of yield. As a result, the land depletes quickly, raising doubts about the suitability of intensive farming year-round on such fragile soils.

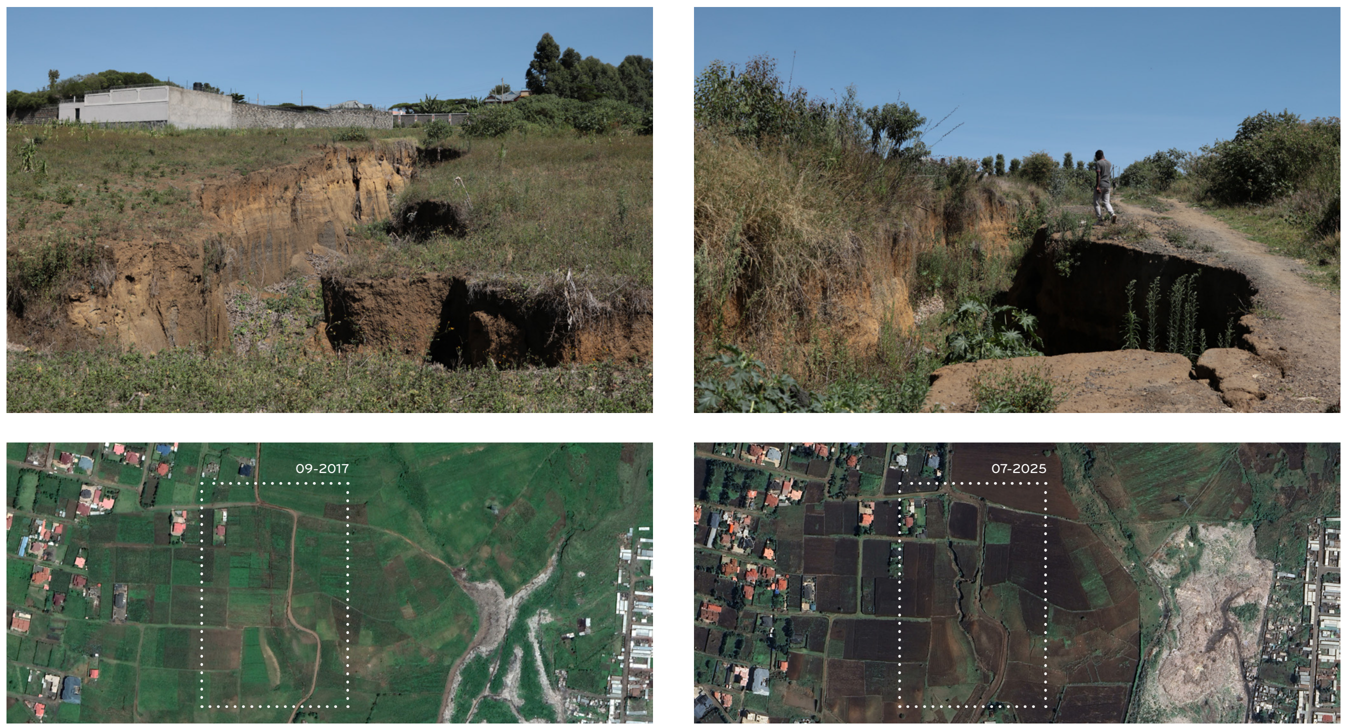
Additionally, studies have found that various zones along the N-S fault lines are subject to subsidence, especially during the rainy season, which poses a significant risk to further development in the area. As part of this research, several photographic records and analysis sketches were made of these fissures and their consequences during field visits (Box 2). During the rainy season, the volcanic soil becomes saturated and eventually collapses into underground (water) channels that follow the orientation of the fault lines (Kanda, 2010).

As a consequence, several cracks and sinkholes have recently been reported in and around Nakuru during or after the rainy season. The formation of these fissures not only have socio-economic consequences but also create a new environmental problem. Since water collects in these depths during the rainy season, it carries a significant amount of waste and pollution along the way and excallerates the speed of surface runoff downhill. Eventually, this leads to groundwater contamination and also causes polluted water to spread downstream, as many fissures develop along the slopes of the Menengai Caldera into the urbanized context of Nakuru city (Kanda 2010, Nillesen et al., 2024).

Box 2

On-site, the consequences, unpredictability and scale of the fissures are clearly visible. By comparing satellite images from recent years, it has been found that the photographed fissure has only existed in this size for a few years. During the rainy season of 2018, a enormous crack was formed in a short period, with an estimated width of 8 meters. In the following years, the fissure continued to erode due to the seasonal water that drains into this area annually.

Although the recent photos were taken during an excursion in the dry season, the extent of the phenomenon is clearly visible in the landscape. The large amount of rain that flows off the surface during the rainy season and enters these fissures, causes widespread erosion and transports a lot of waste and water downhill, into the city.



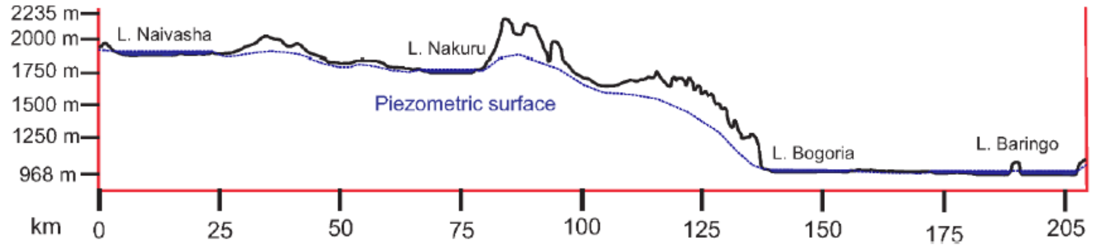
[Figure 40.] Creation of fissures over a period of approximately 5 years in the Kiamunyi area, causing damage to infrastructure and agricultural fields (photos by author, aerial views from Google Earth)

[Figure 41.] Soil types on regional scale, in relation to height differences of the Rift Valley.

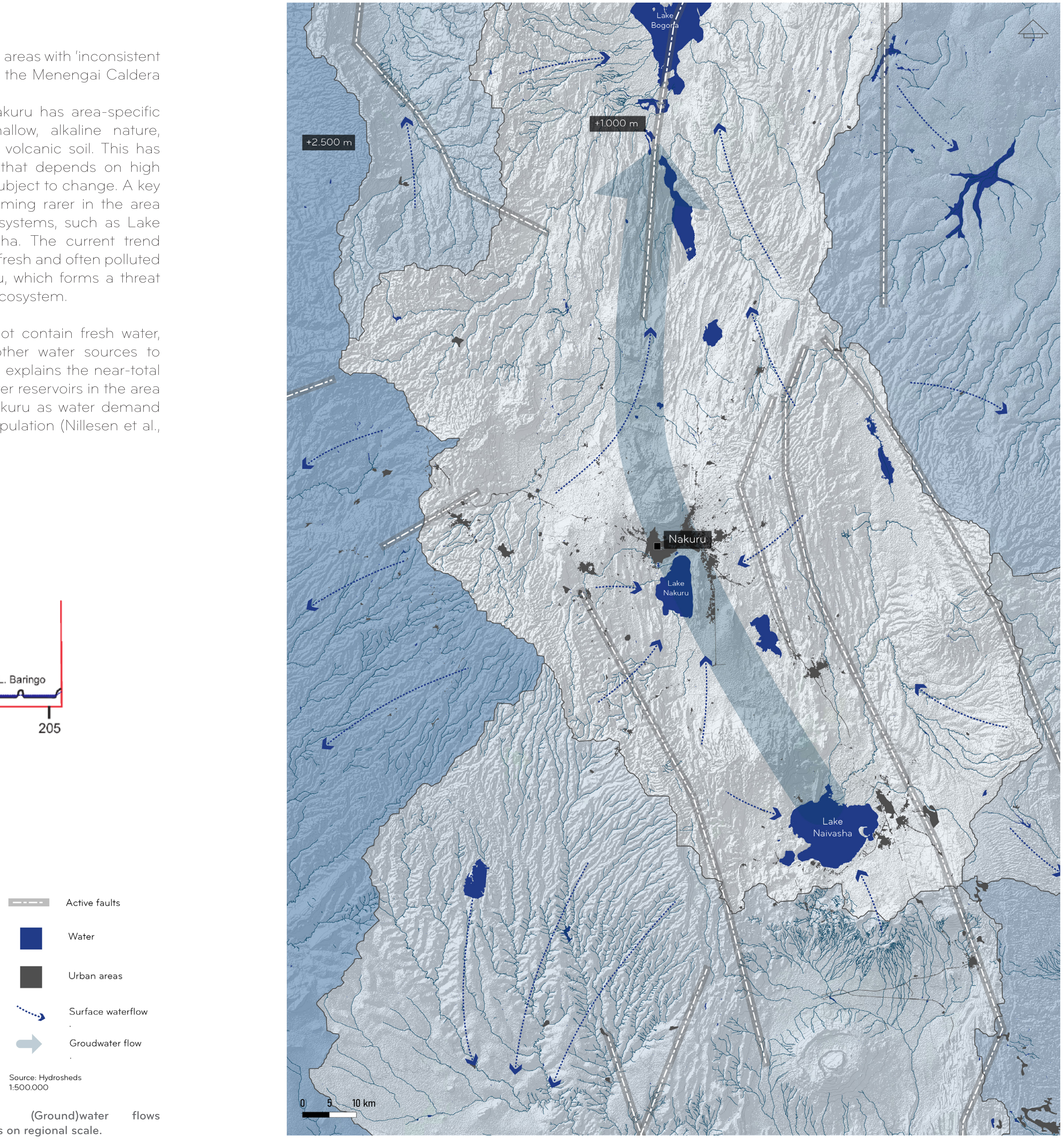
Water resources

Due to the divergent movement of the Rift Valley, numerous shallow lakes have formed in the valley floor over the years. According to the report of County Government of Nakuru, Department of Water, Environment, Energy and Natural Resources, the groundwater system on larger scale can be seen as an interconnected system, in which the groundwater flows to the northern direction of Lake Nakuru, to Lake Bogoria and later Lake Baringo (figure 42 and 43).
In this report several studies are mentioned, that have found this linkage between the lake systems and that the lakes are mainly 'recharged by rainwater on the western and eastern flanks' (Kiogora et al., 2021). Since the amount of precipitation strongly correlates with the topography, the high rainfall values can be found in these upland areas of the Mau and Bahati escarpments and are the main resources of the downstream groundwater reserves and the main rivers, like the Njoro, Makalia and Ngosur (Kanda, 2010).
The aquifers in the area are the primary sources of water production for Nakuru County and are mainly located in the porous volcanic soils. However, the active fault lines in the region can disrupt the logic and position of the aquifers, making the groundwater system complex and variable in areas with 'inconsistent geological formations', such as the Menengai Caldera region (Kiogora et al., 2021).
In the overall picture, Lake Nakuru has area-specific characteristics due to its shallow, alkaline nature, caused by the salinity of the volcanic soil. This has created a unique ecosystem that depends on high pH levels, which are currently subject to change. A key species, the flamingo, is becoming rarer in the area and moved to other lake ecosystems, such as Lake Elementaita and Lake Naivasha. The current trend shows an increased amount of fresh and often polluted water flowing into Lake Nakuru, which forms a threat for the vulnerable, alkine lake ecosystem.

Because Lake Nakuru does not contain fresh water, the city's residents rely on other water sources to meet its water needs. This also explains the near-total dependence on the groundwater reservoirs in the area and the critical situation in Nakuru as water demand rises alongside the growing population (Nillesen et al., 2024).



[Figure 42.] 'Groundwater and surface water interaction as illustrated using potentiometric surface and lake levels.' (Kiogora et al., 2021)



[Figure 43.] (Ground)water flows and resources on regional scale.

Water resources - Lake Nakuru basin

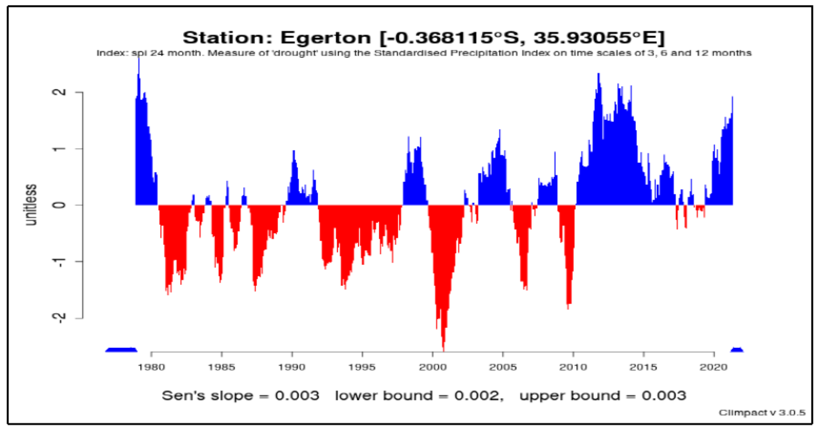
The Lake Nakuru basin is fed by several perennial and seasonal rivers, such as Njoro, Makalia, and Ngosur, as well as seasonal surface runoff from several discharge channels (Kiogora et al., 2021). Most of the surface outflow ends up in Lake Nakuru, as it is an endorheic lake system with no significant outlet seawards. In this system, water primarily leaves through infiltration or evaporation, as reflected in the water balance of the Lake Nakuru basin (figure 45). This closed system has had enormous consequences for the changing water levels of Lake Nakuru over the years. Seasonal fluctuations, increased rainfall patterns, and land-use changes have intensified surface inflow to Lake Nakuru (Kiogora et al., 2021; Obando et al., 2016).

As explained in several studies, the volume of surface runoff is determined by the interaction between climate and land-use changes and is highly sensitive to precipitation variability. The expected increase in heavier rainfall due to climate change poses a severe risk to livelihoods in the Lake Nakuru basin (Kimaru et al., 2019; Nillesen et al., 2024). During periods of drought in 1995 and 1996, the lake completely dried up. However, in the last decades, a significant increase in water levels between 2010 and 2021 has been observed in Lake Nakuru, with the total surface area estimated to have expanded by 39.47% during this period (Kiogora et al., 2021).

As the city of Nakuru rapidly grows, it increasingly encloses Lake Nakuru, leading to flooding in neighboring settlements along the lake's shores. Additionally, the area of Lake Nakuru National Park is shrinking due to the rising water levels, and experienced flooding has altered the land cover of the Lake Nakuru ecosystem over time. This situation threatens not only the citizens of Nakuru but also the wildlife of the national park. The park is completely fenced to control human-wildlife conflicts, but this further pressures species' habitats and increases trampling among wildlife in Lake Nakuru National Park (Onyango, 2020).

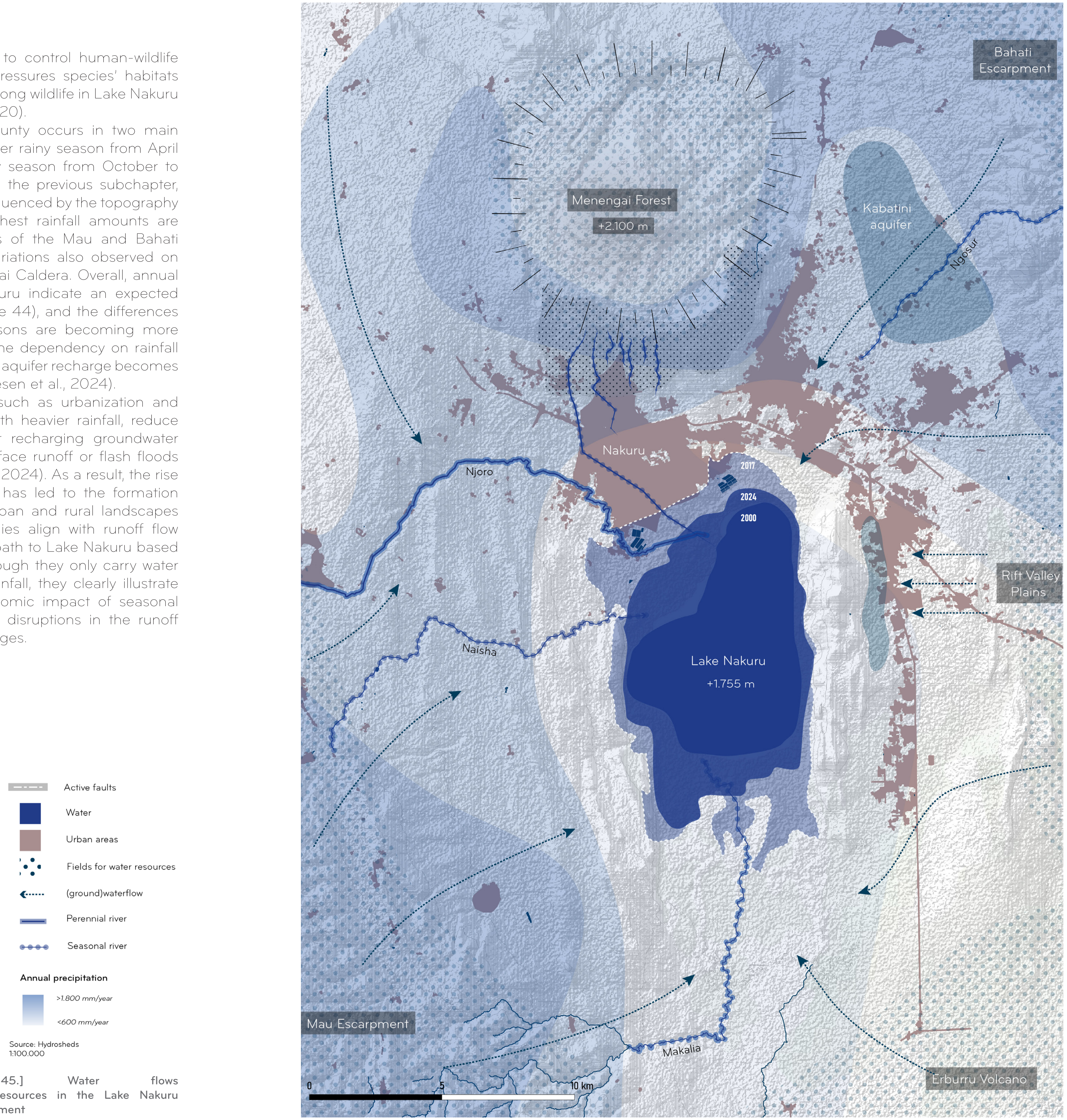
Precipitation in Nakuru County occurs in two main periods: a longer and heavier rainy season from April to May and a shorter rainy season from October to December. As explained in the previous subchapter, precipitation patterns are influenced by the topography of the landscape. The highest rainfall amounts are found in the upland areas of the Mau and Bahati escarpments, with slight variations also observed on the hillsides of the Menengai Caldera. Overall, annual rainfall projections for Nakuru indicate an expected increase in the future (figure 44), and the differences between dry and wet seasons are becoming more pronounced. As a result, "the dependency on rainfall for agricultural irrigation and aquifer recharge becomes increasingly uncertain" (Nillesen et al., 2024).

Rapid land-use changes, such as urbanization and deforestation, combined with heavier rainfall, reduce soil infiltration capacity for recharging groundwater reservoirs and increase surface runoff or flash floods downstream (Nillesen et al., 2024). As a result, the rise in seasonal surface runoff has led to the formation of eroded gullies in the urban and rural landscapes around Nakuru. These gullies align with runoff flow routes, seeking the fastest path to Lake Nakuru based on the area's elevation. Though they only carry water during periods of heavy rainfall, they clearly illustrate the power and socio-economic impact of seasonal runoff, which is caused by disruptions in the runoff chain due to land-use changes.



Category	SPI	Probability (%)
Extremely wet	2.00 and above	2.3
Severely wet	1.50–1.99	4.4
Moderately wet	1.00–1.49	9.2
Near normal	−0.99–0.99	68.2
Moderate drought	−1.00 to −1.49	9.2
Severe drought	−1.50 to −1.99	4.4
Extreme drought	−2.00 and less	2.3

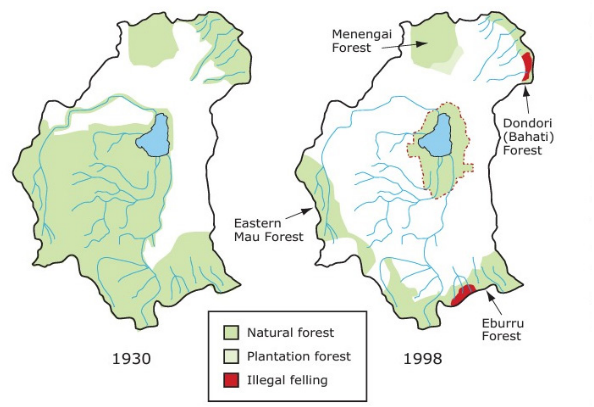
[Figure 44.] 24-Month Standardised Precipitation Index at Egerton University station" (Kiogora et al., 2021).



[Figure 45.] Water flows and resources in the Lake Nakuru Catchment

Vegetation

Before the rapid urbanization of recent decades, the valley of Nakuru functioned primarily as grazing land for nomadic communities and their livestock. Over the past 40 years, however, the landscape surrounding the city has undergone a major transformation—from a rarely settled, forested environment into a densely populated and intensively cultivated urban area (Raini & FlamingoNet, 2009).
Within the catchment basin, two major biodiversity zones can be identified: the forested upper slopes of the valley, including the Mau Forest Complex, one of Kenya's designated water towers, and the Lake Nakuru National Park at the bottom of the basin. Smaller, fragmented forest areas such as Menengai, Eburru, Bahati, and Dundori also play a crucial role in water catchment and biodiversity conservation. The areas between these ecological zones are now largely dominated by human activities such as agriculture and settlement expansion, and therefore hold relatively low ecological value. Nonetheless, they remain highly dependent on the ecosystem services and resources provided by the surrounding forested zones (Odada et al., 2006; Raini & FlamingoNet, 2019; Wetang'ula et al., 2014).
During the colonial period, much of the savannah and tropical forest within the Lake Nakuru Catchment was converted into large-scale agricultural and open landscape as part of the so-called "White Highlands," fundamentally altering the natural landscape (Duchhart & Wageningen University & Research, 2007). After the independency, the land was relocated to indigenous farmers from 1962 to 1967 and were sub-divided into smaller plots with the characteristic vegetated edges. Although, the intensive agricultural usage of the land still dominated the region. In the years after encroachment started in the forested areas, were forest was being replaced for settlements and cultivated land. In the period between 1970-2021 the natural forest cover degraded from 47% in 1970 to 8% in 2021, see figure 46. (Kiogora et al., 2021).
The resulting landscape between the natural reserves reflects the combined influence of long-standing indigenous land-use practices and colonial agricultural interventions (Duchhart & Wageningen University & Research, 2007). It has shaped a hybrid cultural and ecological landscape, characterized by a strong contrast in the scale of agricultural practices, differences that remain clearly visible in the landscape of Nakuru today.



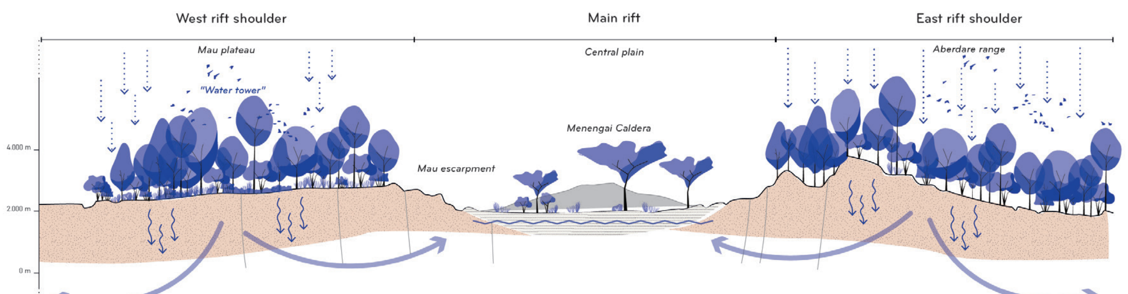
[Figure 46.] Deforestation between 1930 - 1998, mapped by Odada et al. (z.d.).

[Figure 48.] Vegetation types in the Lake Nakuru Catchment

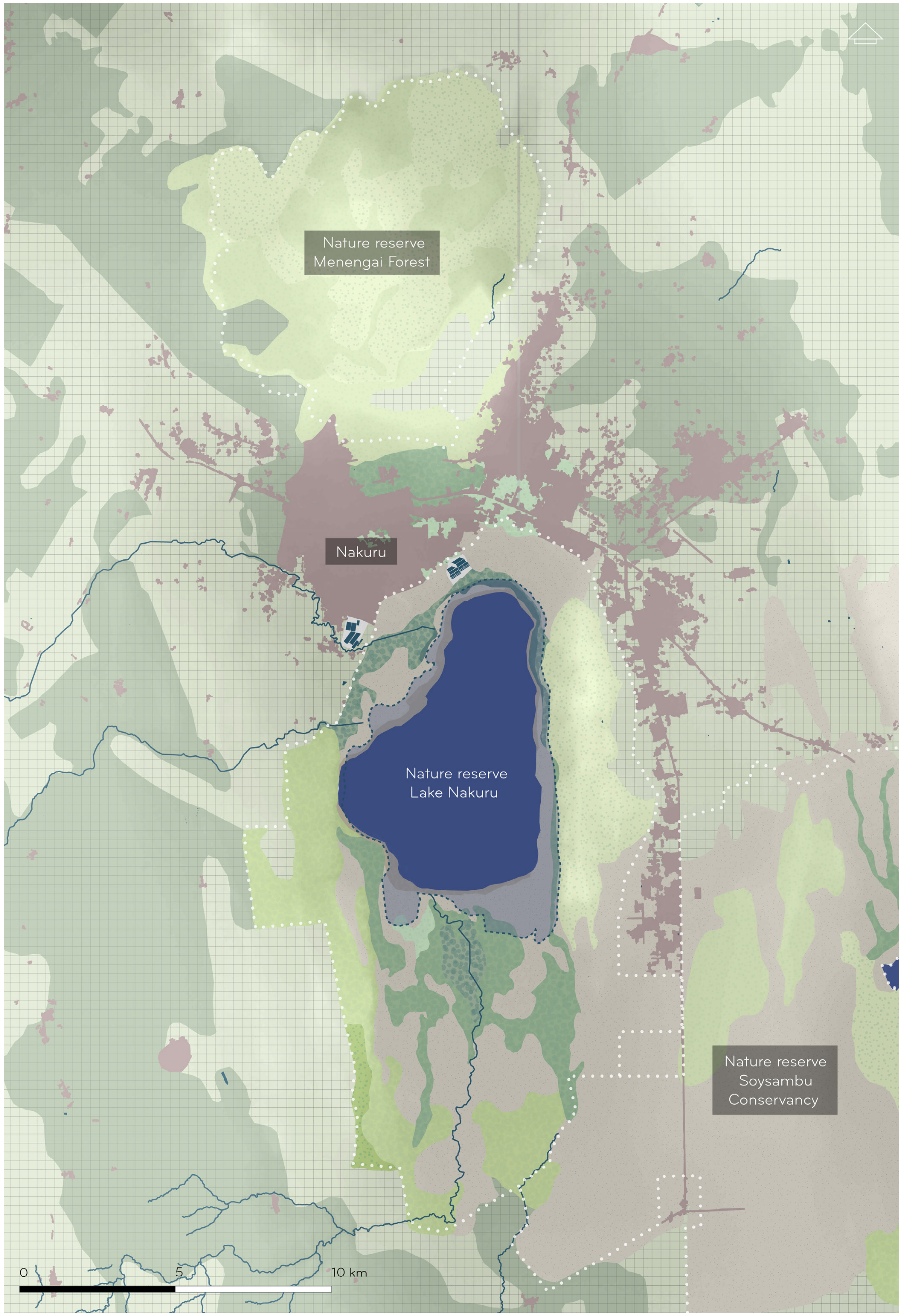
Box 3

Interaction between soil and drainage classes

Regarding the drainage in the Lake Nakuru basin, various drainage classes can be found in the area. The soil layers in the central plains surrounding Lake Nakuru have developed on sediment over time. As a result, the soil is deep, poorly permeable, calcareous, and saline.
In the open grasslands, the soils have formed from pumice layers and ash from recent volcanic activity, making them highly permeable.
Upstream, the soil types are well-developed, red, fertile, and extremely well-draining. These soils once supported the so-called 'dense tropical montane forests,' which have now almost entirely disappeared (Kiogora et al., 2021). This linkage between soil, drainage and vegetation is visualized in the section below of the Rift Valley (figure 47).



[Figure 47.] Section of Rift Valley illustrating the linkage between soil, drainage and vegetation.



Migration flow towards Nakuru

The highlands surrounding the Rift Valley, located within the Great African Lake System region, form the "Water Towers of Kenya" (figure 49). These areas receive significantly higher annual rainfall, experience a moderate climate, and have fertile soils, which has contributed to the expansion of extensive forested areas.

However, the climatic differences within Kenya are extreme, with over 80% of the land classified as arid or semi-arid, characterized by low soil fertility, fragile soils, and poor water infiltration and storage capacity (Obando et al., 2016). As a result, the availability of land rich in natural resources is limited and increasingly pressured by population growth and societal transitions, including the shift from pastoralism to mixed farming with livestock (figure 49).

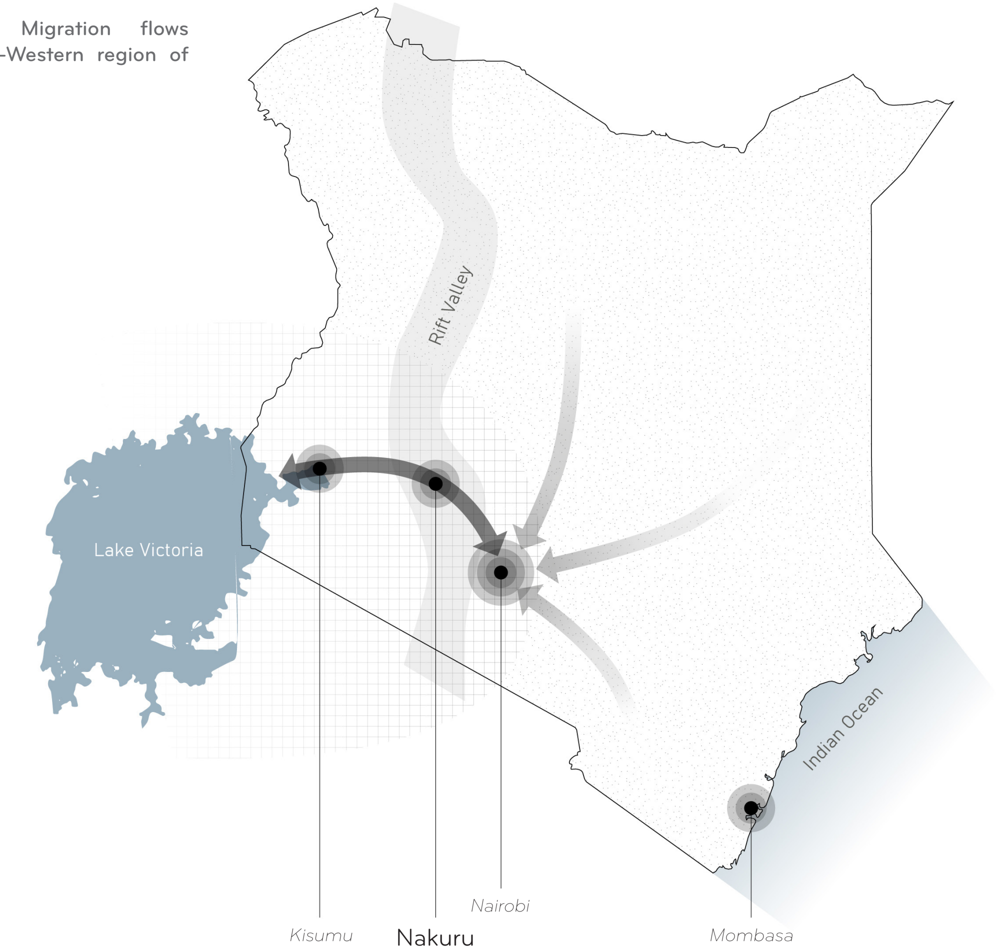
The favorable climate and abundance of natural resources have historically made this region, particularly the Rift Valley, an attractive location for human settlement. Around Nakuru, various prehistoric findings indicate early human presence in this area. For a long time, communities such as the Bantu-speaking groups and the Maasai lived in this region as nomadic pastoralists.

The appeal of the landscape was further reinforced during the colonial period when Nakuru became part of the so-called White Highlands. The fertile land attracted European settlers who introduced large-scale agriculture to the region. As part of Britain's expansion in East Africa and to facilitate intercontinental trade, the Uganda Railway was constructed, with "Nakuro" serving as a stop along the route . Shortly after the completion of the railway, Nakuru was formally incorporated into the White Highlands and continued to grow rapidly. By 1904, Nakuru had attained township status and became known for its agricultural productivity, abundance of natural resources, and rich wildlife (County Government of Nakuru, n.d.).

As illustrated in figure 50 and 51, the southwestern region of Kenya has the highest population density and the most extensive agricultural land, a pattern closely linked to the high annual rainfall. The favorable and productive climate has historically attracted people from surrounding areas, a trend that is reflected in the rapid urbanization of the region.

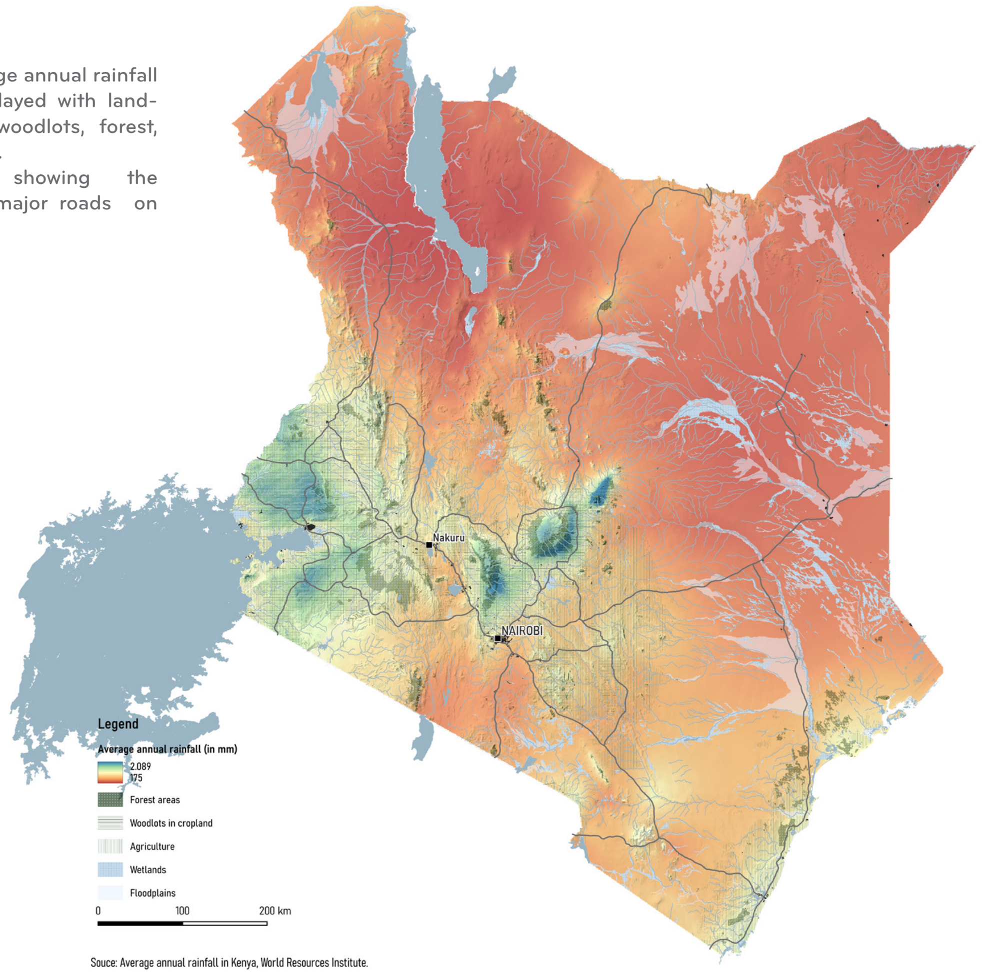
Nairobi, in particular, has evolved into a major global city over the past decades. However, this rapid expansion has also led to significant social and environmental challenges, prompting Nakuru, the next major city within this fertile region, to attract a growing number of new residents. Today, Nakuru has become the fourth-largest urban center in Kenya, following Nairobi, Mombasa, and Kisumu (County Government of Nakuru, n.d.).

[Figure 49.] Migration flows towards the South-Western region of Kenya.



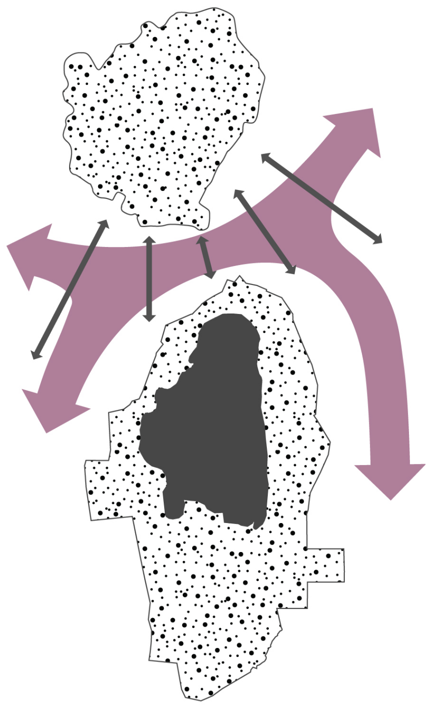
[Figure 50.] Average annual rainfall in Kenya combined overlayed with land-use types (agriculture, woodlots, forest, wetlands and floodplains).

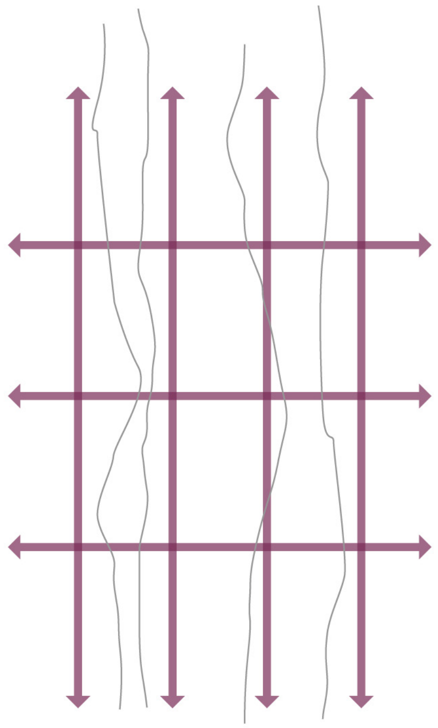
[Figure 51.] Map showing the population density and major roads on national scale.



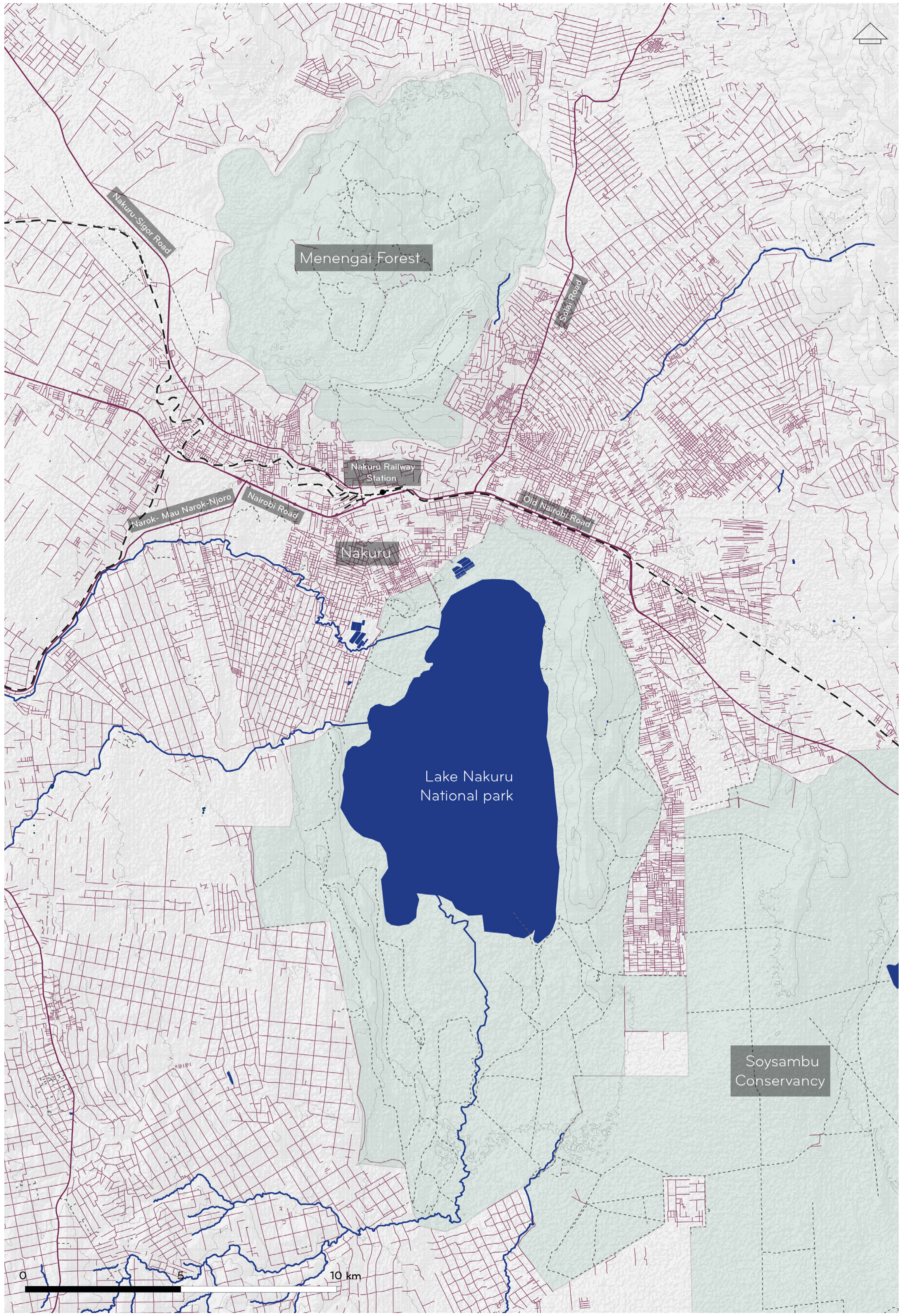
Infrastructural grid

As discussed in the previous chapter, infrastructure has shaped the foundation of Nakuru city., as it was founded after the installation of railway station "Nakuro". This continues for recent urban developments, as many projects still emerge along the main roads. The grid structure of the infrastructure aligns with the altitude of the terrain, and the drainage and sewer system follows this grid, accelerating runoff due to its orientation in relation to the lake (figure 52).
However, the main roads are positioned perpendicular to the slope of the Menengai Caldera, making them highly susceptible to damage from seasonal surface runoff during heavy rains (figure 53). As a result, they frequently sustain damage and require repairs (Nillesen et al., 2024)
Additionally, the current road network is inadequate to accommodate the city's rapid urban growth. Roads are heavily congested during peak hours, leading to severe traffic jams, hazardous conditions, and an increased risk of smog.





[Figure 52.] Orientation of infrastucture in relation to the surrounding nature reserves.
[Figure 53.] Infrastructure follows the contours of the landscape.



Water

Nature Reserve

Primary road

Secondary or residential road

Track

Railway

Source: Geofabrik
1 : 100.000

[Figure 54.] Infrastructural layer of Nakuru city.

Historical timeline

This timeline illustrates the historical evolution of Nakuru and the interrelations between vegetation, land use, hydrology, and population dynamics. It traces the shift from a biodiverse, resource-based landscape shaped by indigenous communities before colonization, to intensive agricultural and urban development under British rule, and finally to the present-day urbanized landscape. The diagram highlights how deforestation, land-use change, and urban expansion have progressively fragmented natural systems, resulting in current challenges of flooding, pollution, and water scarcity.

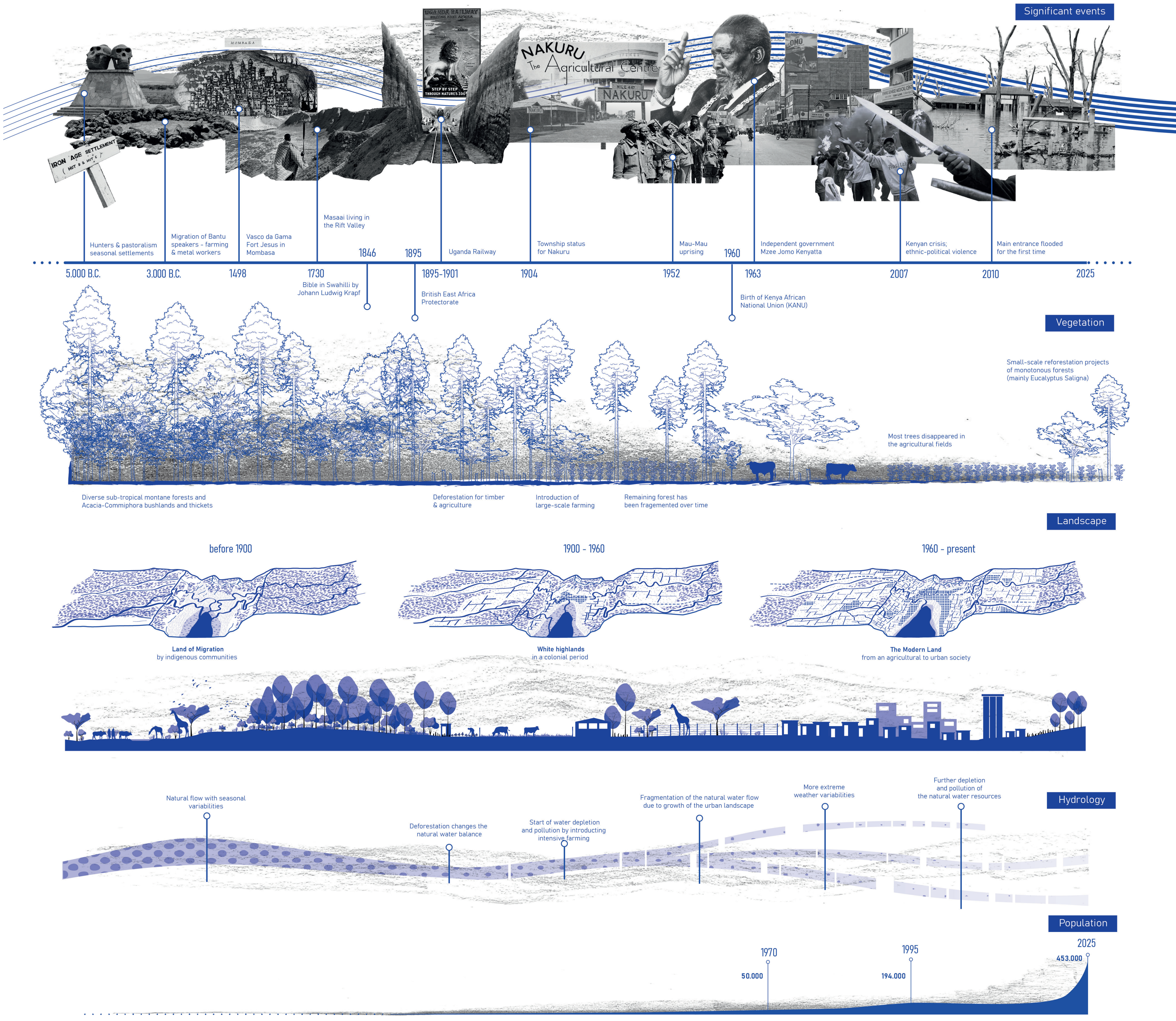
Before the colonial period, the area was sparsely populated, shaped by natural systems and rich biodiversity. Indigenous communities, such as the Maasai, practiced a nomadic lifestyle, relying on the seasonal availability of resources.

When the British colonial rule came around 1900, Nakuru was designated as part of the White Highlands. Intensive agriculture was introduced, supported by new infrastructure such as the Uganda Railway. Nakuru began as a railway station, described as station "Nakuro", and rapidly expanded into an urban center. This period marked the beginning of large-scale land-use change and depletion of natural resources.

After independence, the processes of deforestation, urban expansion, and intensified farming continued. Nature was increasingly fenced off into reserves, while agricultural fields took over the surrounding landscape. Together, these land-use changes progressively fragmented the ecological and hydrological cycle.

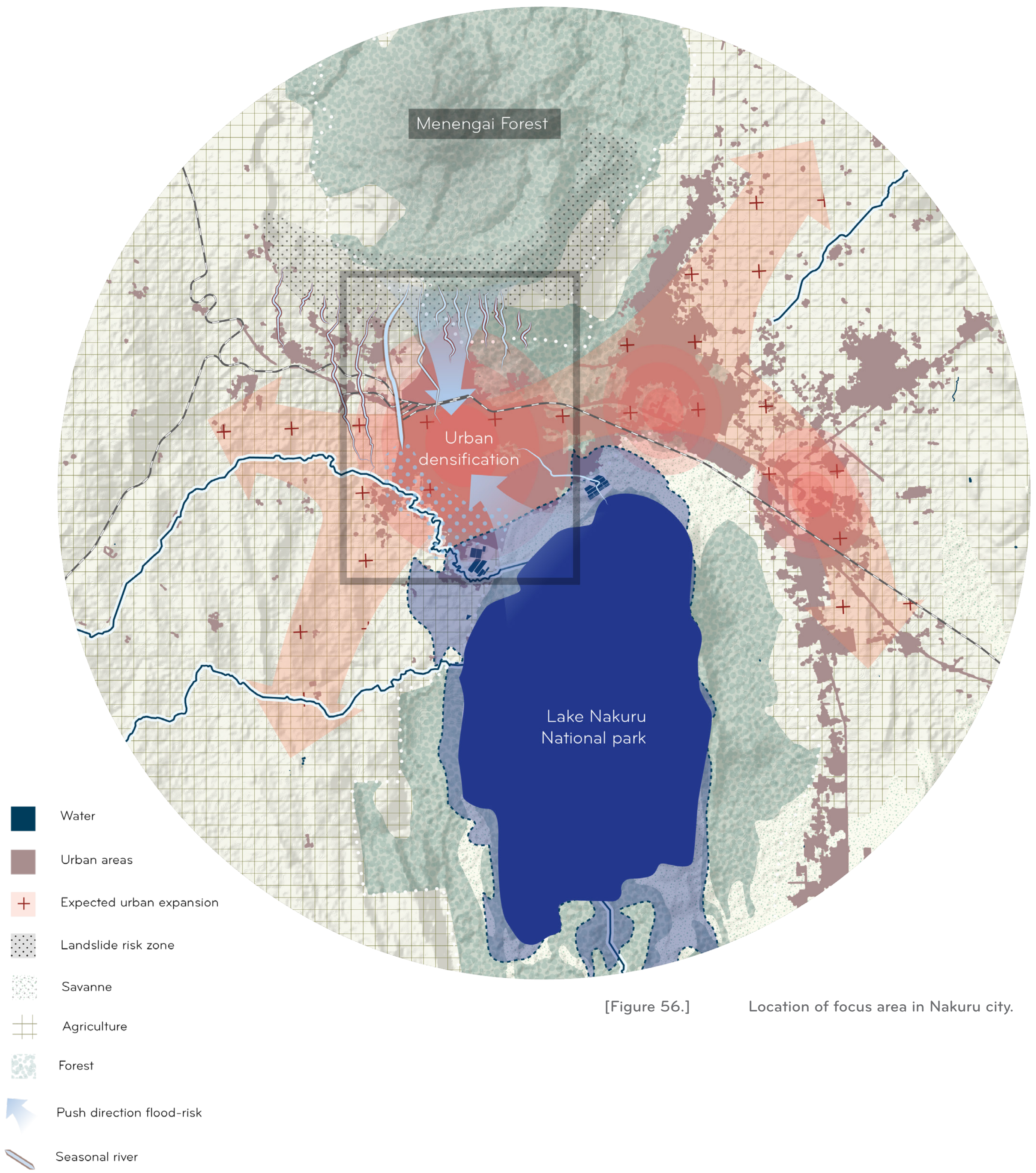
Today, Nakuru reflects the long-term impacts of these transitions, transforming from a biodiverse, resource-driven landscape into a rapidly urbanizing society facing critical ecological challenges.

(County Government of Nakuru, n.d.)

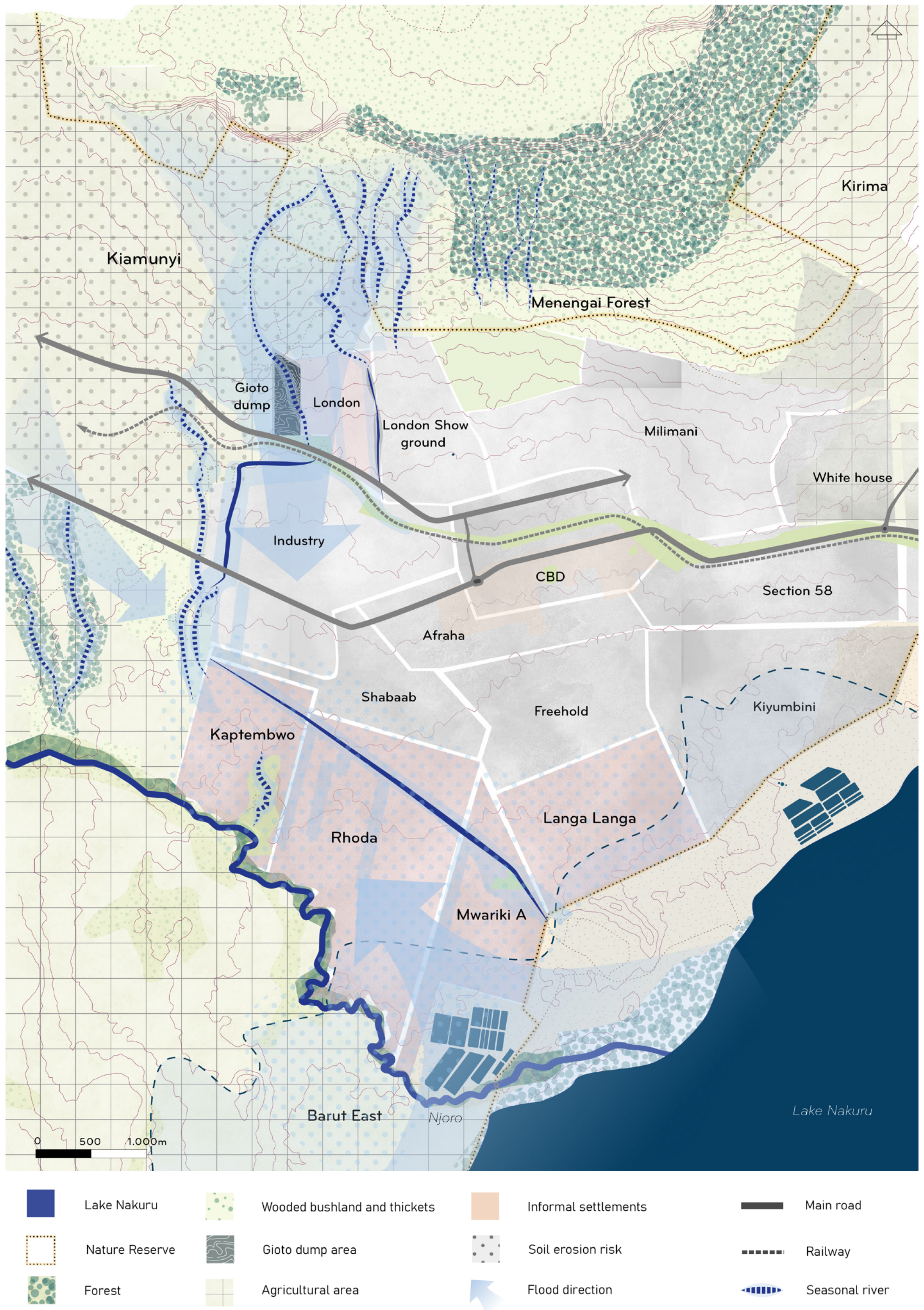


[Figure 55.] Historical development of Nakuru and transformation of its landscape layers.

The long-term transitions described in the previous chapter *Historical timeline* are urgently visible in the area highlighted in the map below, which has therefore been chosen as the focus of this research (figure 56). A sub-watershed emerges during the wet season and reflects many of the catchment-wide problems in a concentrated form: a disrupted ecosystem, an unbalanced water cycle, and seasonal runoff that causes both flooding and scarcity. This makes the area particularly relevant as a testing ground for a landscape-based spatial strategy aimed at recharging freshwater availability and strengthening social-ecological resilience, while mitigating the effects of surface runoff.
Future densification is expected to concentrate in this part of Nakuru City, even though it already faces high risks of flooding and water scarcity. Land-use changes, such as rapid urban growth, agricultural intensification, and deforestation, further exacerbate these risks. Several runoff hotspots lie within this region, intensifying problems for downstream communities that lack proper sewage and drainage systems. These communities are located in flood-prone areas, where risks arise both from upstream runoff and the rising water level of Lake Nakuru (figure 57). As a result, seasonal surface runoff contributes simultaneously to flooding and pollution during the wet season, and to water scarcity and groundwater dependency during the dry season.
In this chapter, the three fields of attention discussed by Tjallingii (1995), flow, area, and participants (see Chapter 3.6), will guide the site analysis of the sub-watershed. Together, they provide the basis for developing a comprehensive spatial strategy and context-specific design explorations to address the research question of this research.



[Figure 56.] Location of focus area in Nakuru city.



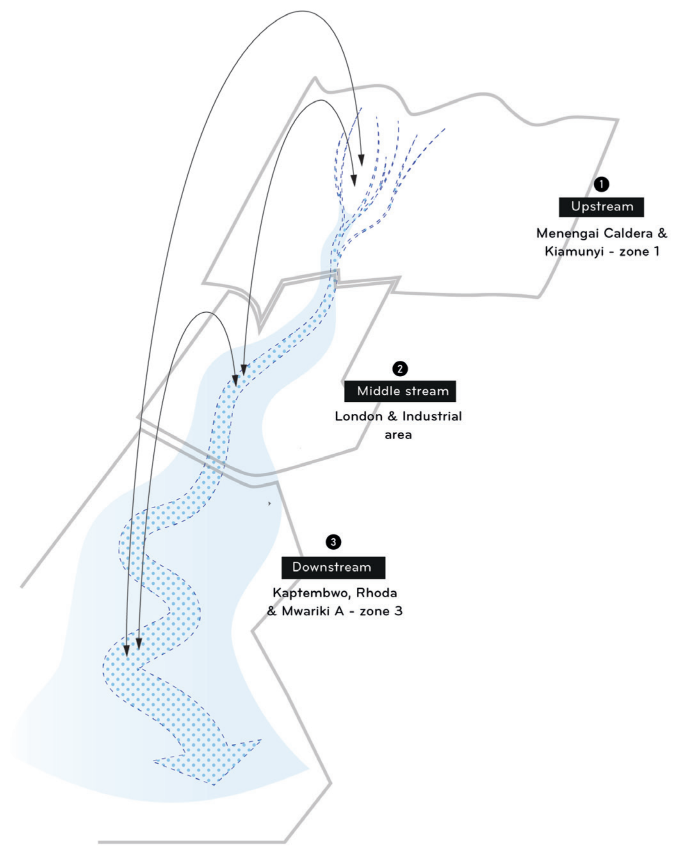
[Figure 57.] (Seasonal) sub-watershed affected by flood risks from two sides and where the highest densification is expected.

[Figure 59.] Collage overview of seasonal sub-watershed starting on the slopes of the Menengai Caldera (upstream) and ends in neighborhoods next to Lake Nakuru (downstream).

The focus area consists of a sub-watershed system, which will be analyzed to understand the links between seasonal water dynamics, ecological processes, and socio-cultural functions. In this report, it is referred to as a seasonal sub-watershed, to underline that water flows here are temporary and occur only during the wet seasons, within the larger catchment of Lake Nakuru. This definition is important to avoid confusion with permanent river systems and to highlight the seasonal dynamics that shape both ecological and social challenges.

Field observations and mapping revealed three distinct flow zones within the focus area, upstream, midstream, and downstream (figure 58), each with specific conditions and challenges. In the upstream zone, seasonal rivers originate on the slopes and can be traced through elevation profiles and satellite imagery. In the midstream urban areas, these flows are diverted into undersized sewer and drainage systems, where they become less visible but more disruptive. In the downstream zone, runoff accumulates and causes recurrent flooding, pollution, and risks for vulnerable communities.

By approaching the focus area as a seasonal sub-watershed, this chapter highlights the interconnected challenges across these zones. Problems downstream are directly influenced by developments upstream, and vice versa, showing the systemic interdependence within the area. This perspective reflects the Watershed approach of Hooijmeijer et al. (2022), which underlines the importance of interconnections between zones, an insight that will be crucial for developing the design strategy, -principles, and eventually context-specific interventions in this research.



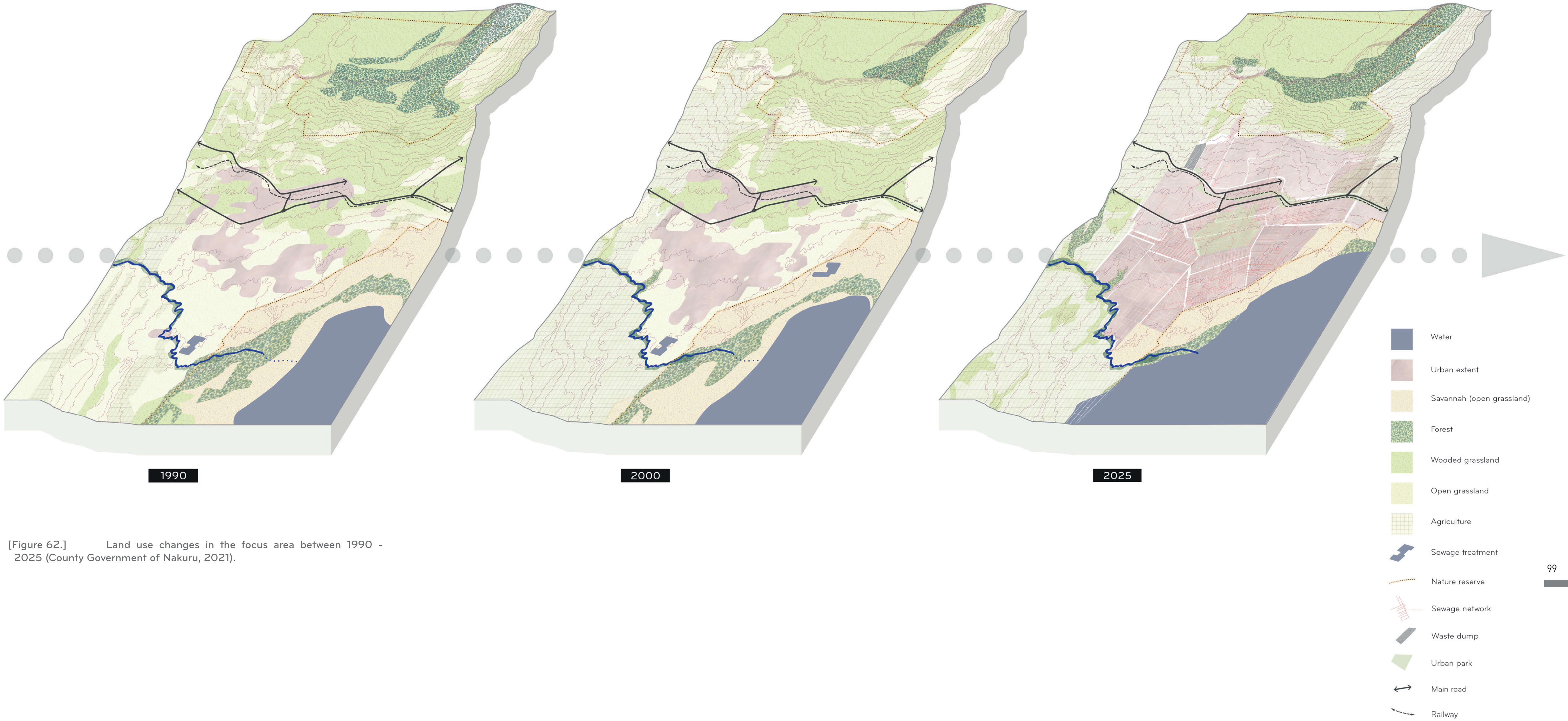
[Figure 58.] Defined flowzones within the seasonal sub-watershed

[Figure 60.] Seasonal runoff inlet on the slopes of the Menengai Caldera, where the first signs of gully formations appear.

[Figure 61.] (Illegal) logging of Menengai forest plots, which accelerates surface runoff in the upstream zone.

Site through time

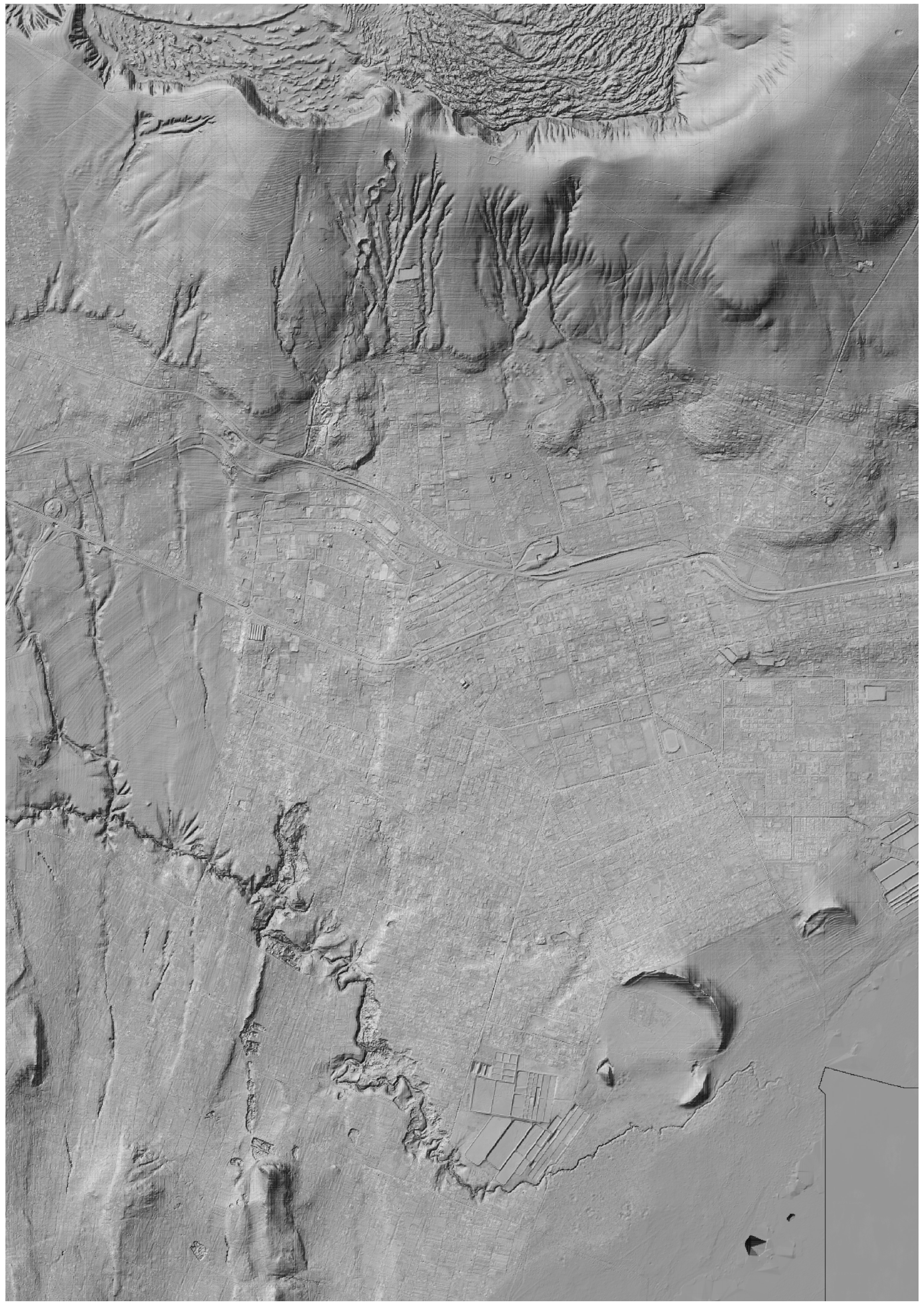
The focus area shows a clear trend of land-use transformation driven by rapid population growth and urbanization. Since Nakuru lies between the Menengai Caldera and Lake Naku-ru, the city's expansion has been forced east- and westward, creating a complex conflict between preserving nature reserves and meeting the demand for housing and infrastructure (Odada et al., 2006).
Between 1990 and 2000, large areas of forest cover on the slopes of the Menengai Caldera were lost due to logging, transforming into open grassland. Although parts near the ridge were later reforested, the majority of the landscape now consists of wooded bushland, agricultural plots, and expanding urban areas, and it has not recovered to its former extent (Kiogora et al., 2021). The Menengai Forest on the south-eastern side of the Caldera remains an essential resource for nearby communities, providing timber, char-coal, medicine, and grazing land (Wetang'ula et al., 2014). While this forest, under the pro-tection of the Kenya Forest Service, still contains patches of mature woodland, the western slopes are increasingly dominated by non-native eucalyptus species, often planted for timber but vulnerable to illegal logging.
Today (2025, see figure 62', uncontrolled urban densification and agricultural intensification have expanded impermeable surfaces and reduced infiltration capacity in both the up- and downstream regions. In the downstream zone, urban development has extended into flood-prone areas near Lake Nakuru and the Njoro River, while upstream construction has reached the unstable volcanic soils of the Menengai slopes. These changes fragment ecological systems and intensify hydrological risks, including flooding, erosion, and water scarcity, that directly affect both ecosystems and vulnerable communities.



[Figure 62.] Land use changes in the focus area between 1990 - 2025 (County Government of Nakuru, 2021).

Topography

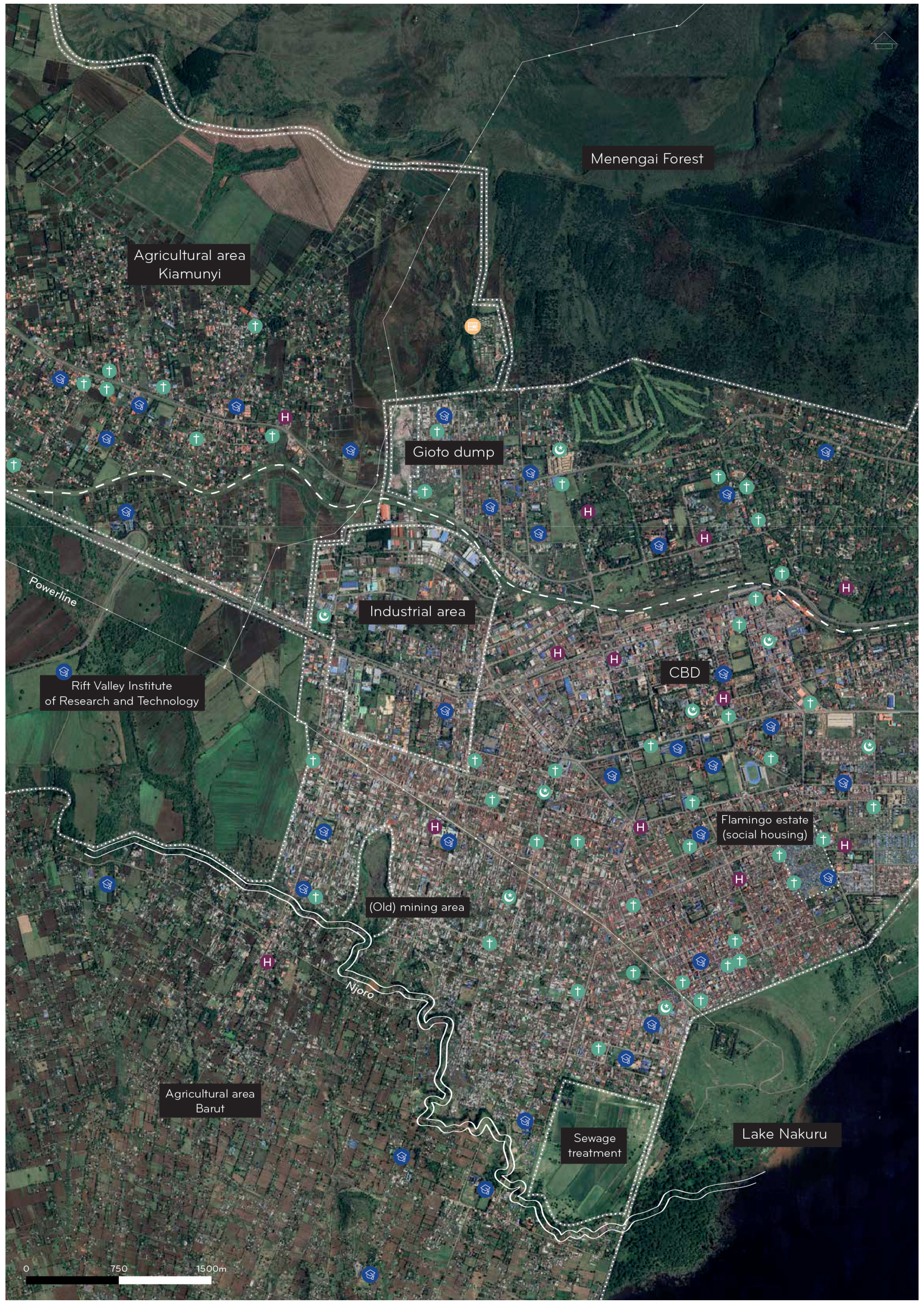
The maps illustrate the topography of the western part of Nakuru City and its surrounding agricultural hinterland, including the Njoro river. The city is enclosed by higher-lying terrain, where numerous gully formations mark the slopes of the Menengai Caldera. These gullies are seasonally water-bearing, revealing the instability and erosion-prone character of the volcanic slopes and the considerable risk of landslides in this area (Nillesen et al., 2024). The maps highlight how Nakuru has developed in a downstream position at the foot of the Rift Valley, where it is inherently exposed to the challenges of a low-lying and flood-prone landscape.



[Figure 63.] (Based on data from County Government of Nakuru).

Current landscape

The landscape surrounding Nakuru Town is strongly shaped by agricultural activities, which vary in scale and type. Parcels range from smallholder plots to larger farms, where livestock is kept alongside the cultivation of perennial and annual crops. To the north and south, nature reserves form distinct ecological zones that stand in sharp contrast to the neighboring densely populated residential areas.
Within this agricultural mosaic, the research fields of the Rift Valley Institute of Science and Technology are of particular importance. Beyond their academic role, these fields also function as key infiltration areas, contributing to the regulation of surface runoff and groundwater recharge.
In the urban fabric, two elements stand out: the elevated Gioto dumpsite and the adjoining industrial zone. Both exert a strong influence on the water chain, as they contribute to runoff contamination and intensify existing challenges related to flooding, pollution, and water scarcity.

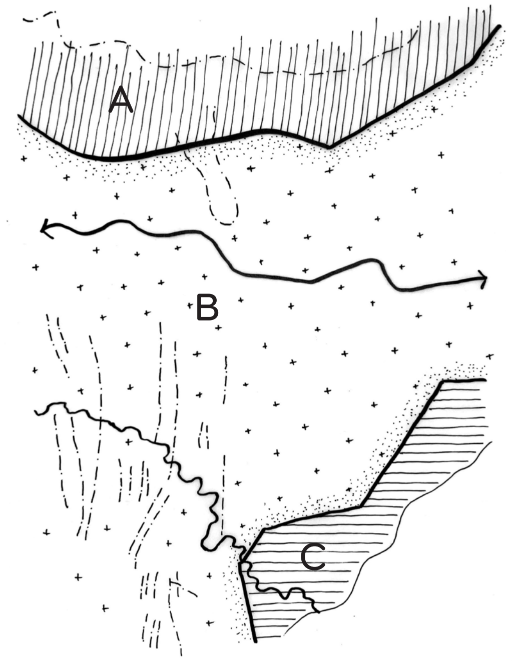


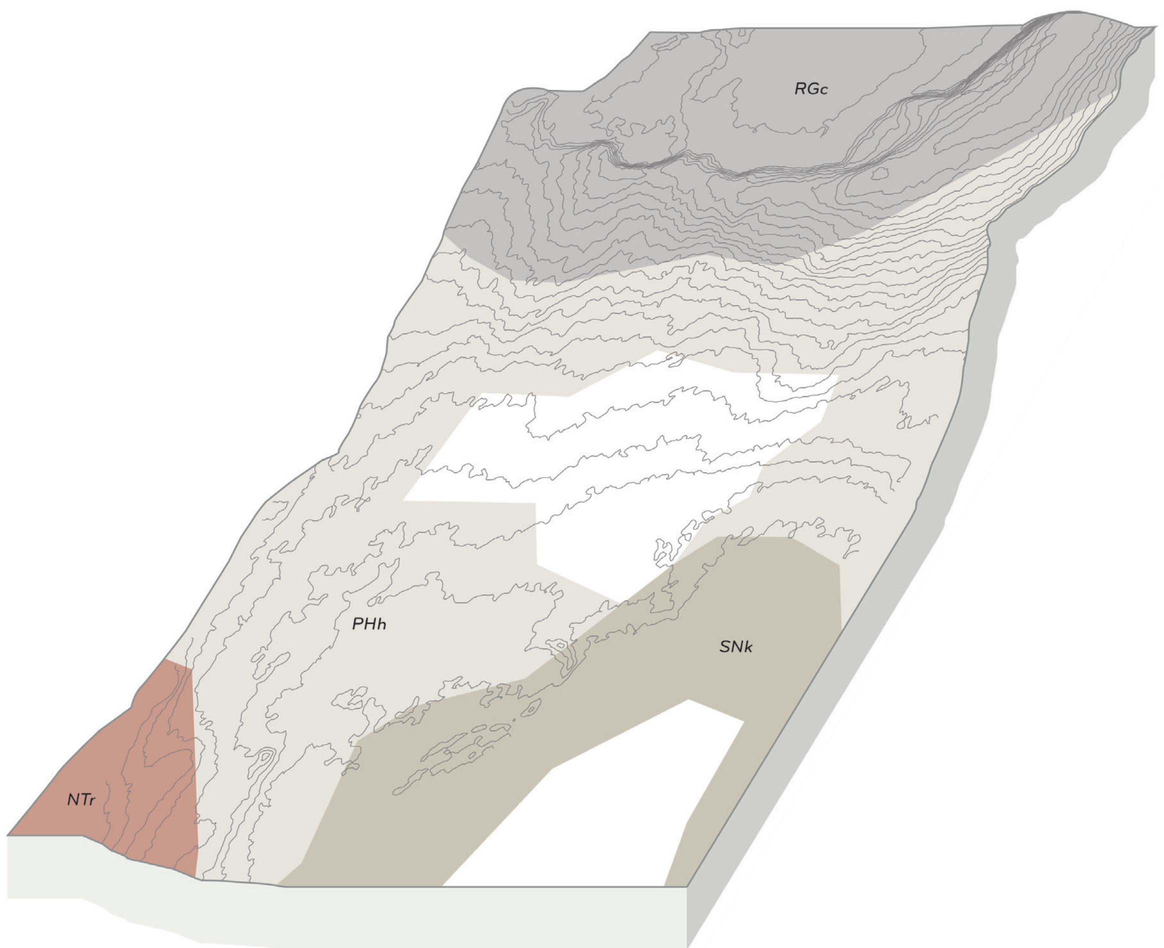
Civil institutions;
- School
- Hospital
- Prison
- Religious (mosque)
- Religious (church)

[Figure 64.] Relevant functions of spaces in the current landscape of Nakuru

Soil

- Zone A: Regosol;
  shallow, weakly developed soil, well-drained and mineral-rich; landsilde risk due to porosity, slope-gradient and deforestation
- Zone B: Phaeozem; well-drained, high natural fertility, excellent for agriculture
- Zone C: Solonchak; saline, poor drainage, high evaporation and low fertility
- Structure of the volcanic soiltypes allows for a high infiltration possibility to recharge the groundwater levels during wet seasons.
- Uncontrolled development near ridge formations and faults increases erosion of bare soil (Nillesen et al., 2024)

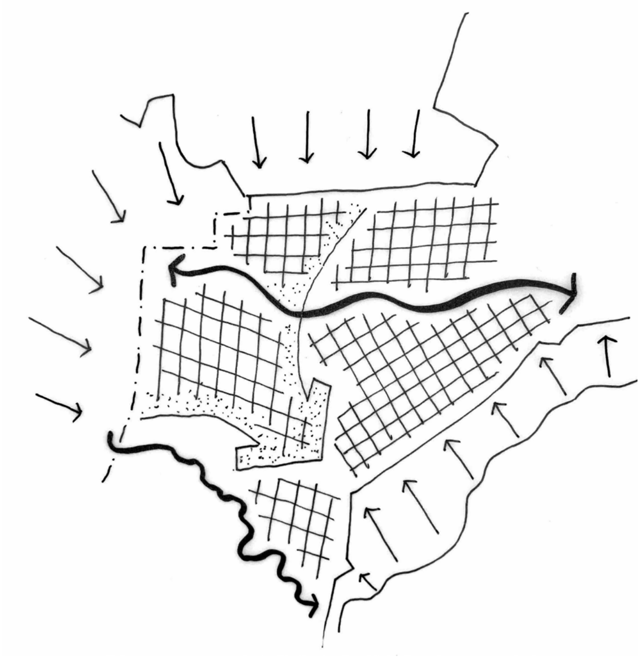


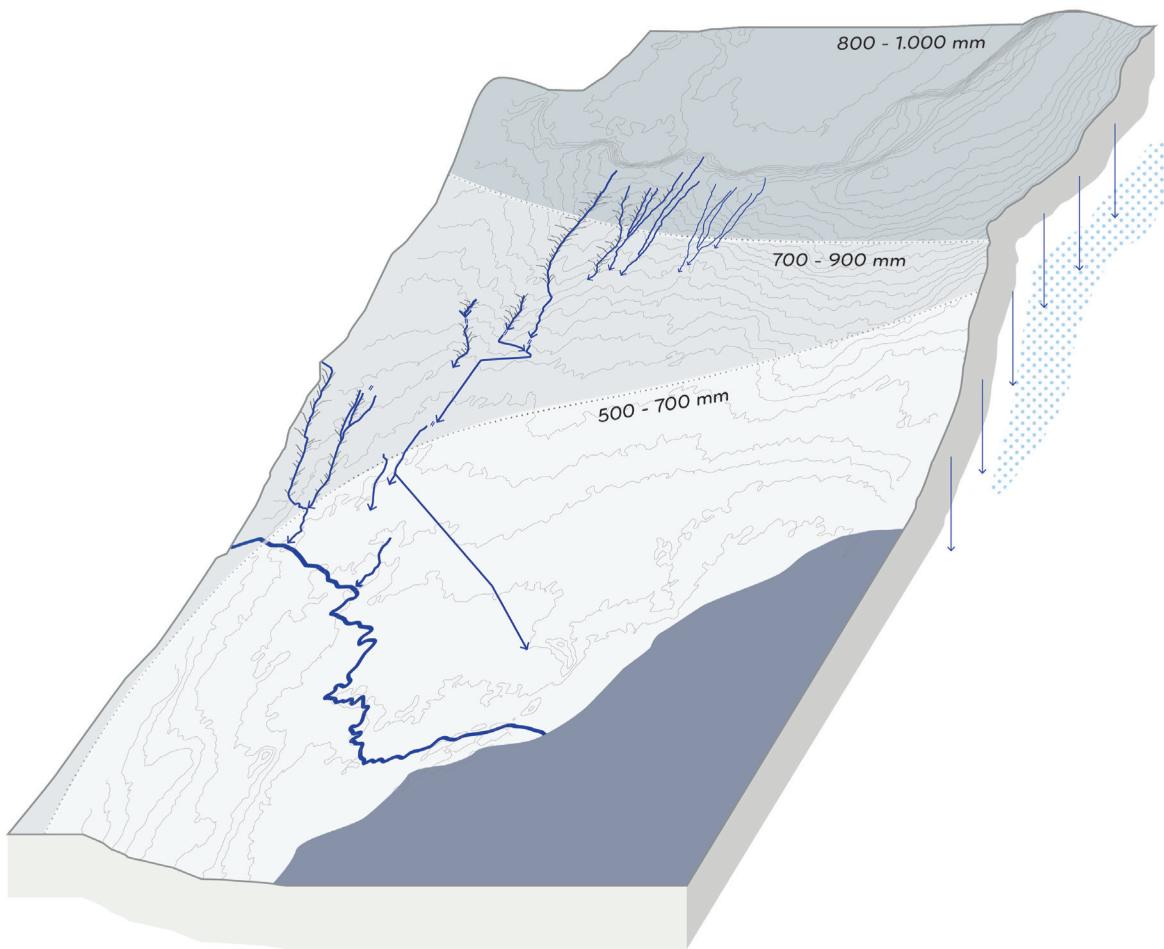


[Figure 65.] Soil layer

Hydrology

- Highest rainfall occurs uphill and is depositioned at the ridge of the Menengai Caldera.
- Eventhough the climate is changing to semi-arid, rain events that do happen are more extreme and intensified (Wetang'ula et al., 2014; Nillesen et al., 2024).
- 70% of the flood volume in urban context comes from external runoff (Schalkwijk, 2025) and gets lost on its way to Lake Nakuru by pollution and urban floodings, as it is not collected in an efficient way.
- Because of the high percentage of external runoff flowing from the surrounding agricultural hinterlands into the city, much of the fertile topsoil is eroded from the agricultural lands west of Nakuru, particularly in the Kiamunyi area and the fields of the Rift Valley Institute.
- Lake expansion is inevitable due to its endorheic character.
- Infiltration is possible in zones A and B.
- Urbanization increases impermeable surfaces, leading to more flash floods even without higher rainfall.

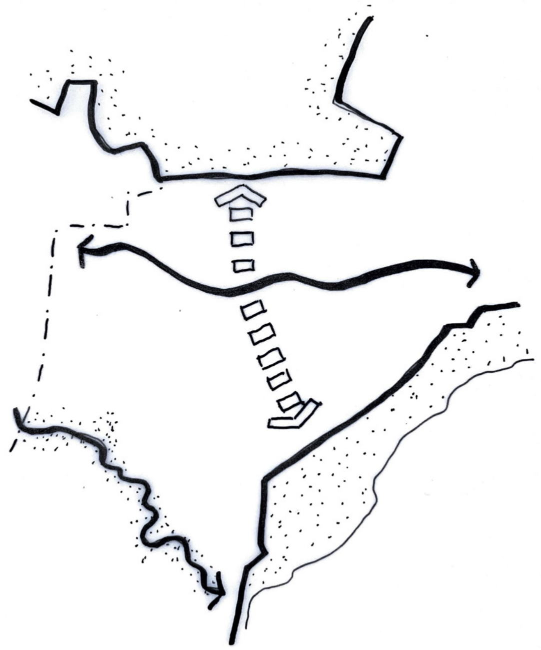




[Figure 66.] Hydrological layer

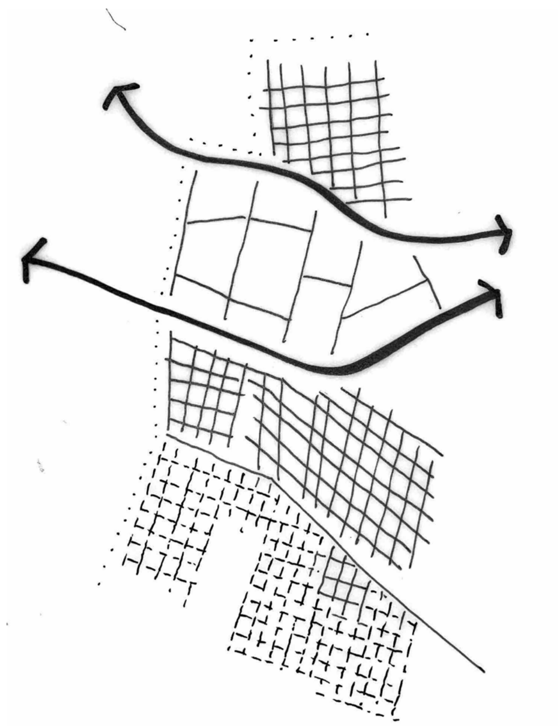
Ecology / Landuse

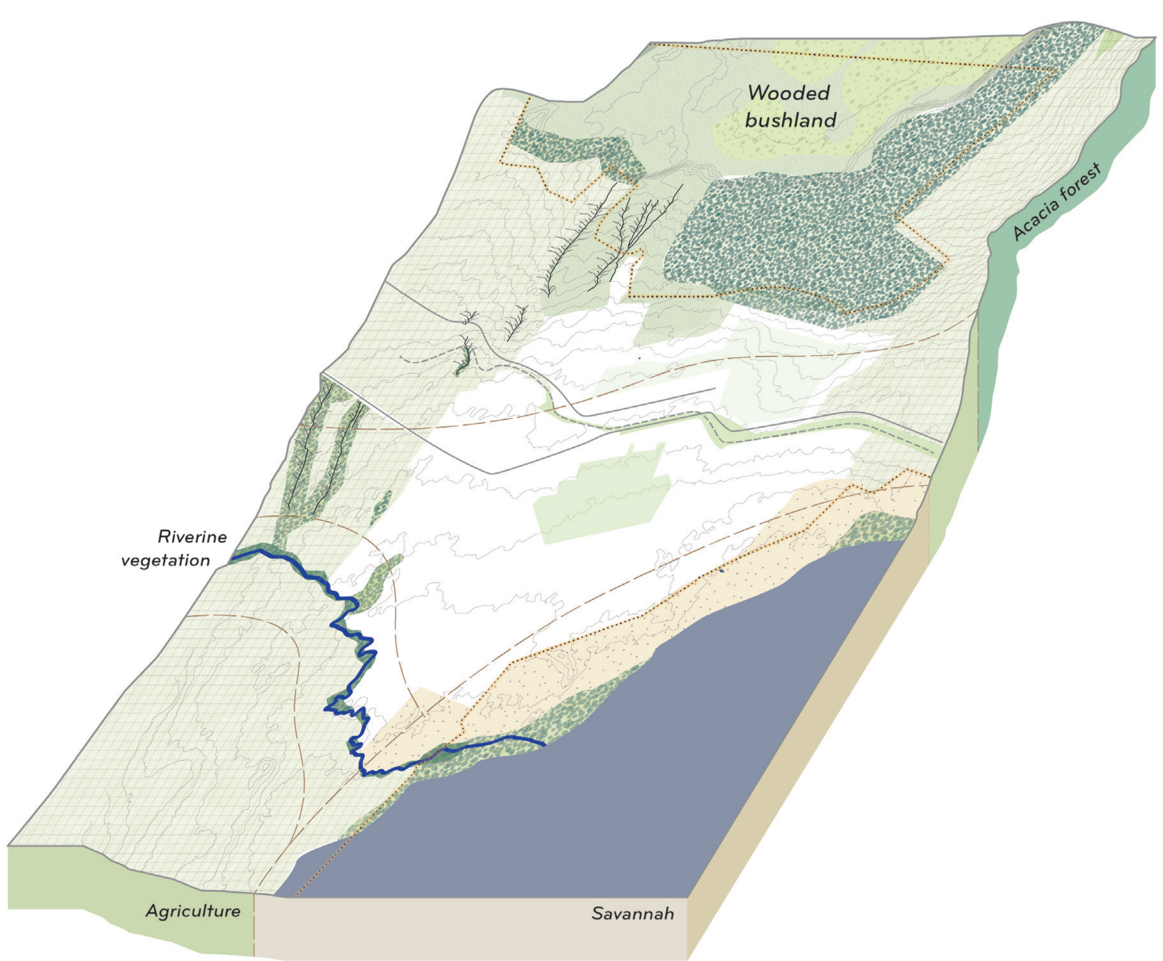
- Three clear ecological zones, with different ecotypes - savannah, riverine vegetation and wooded bushland - cut off and isolated by agriculture and urban areas
- Main use of the area surrounding the city and the nature reserves are different types of agriculture; perrenial crops, annual crops and livestock.
- Infrastructural lines could serve as a green corridor.
- Missing connections between the zones reduce ecological continuity, loss of biodiversity and environmental degradation.
- It increases risks on erosion, landslides, surface runoff and loss of habitats of flora and fauna.
- Gully formations can create dynamic ecological corridors, since they are highly dynamic for water and rarely accessed by people.



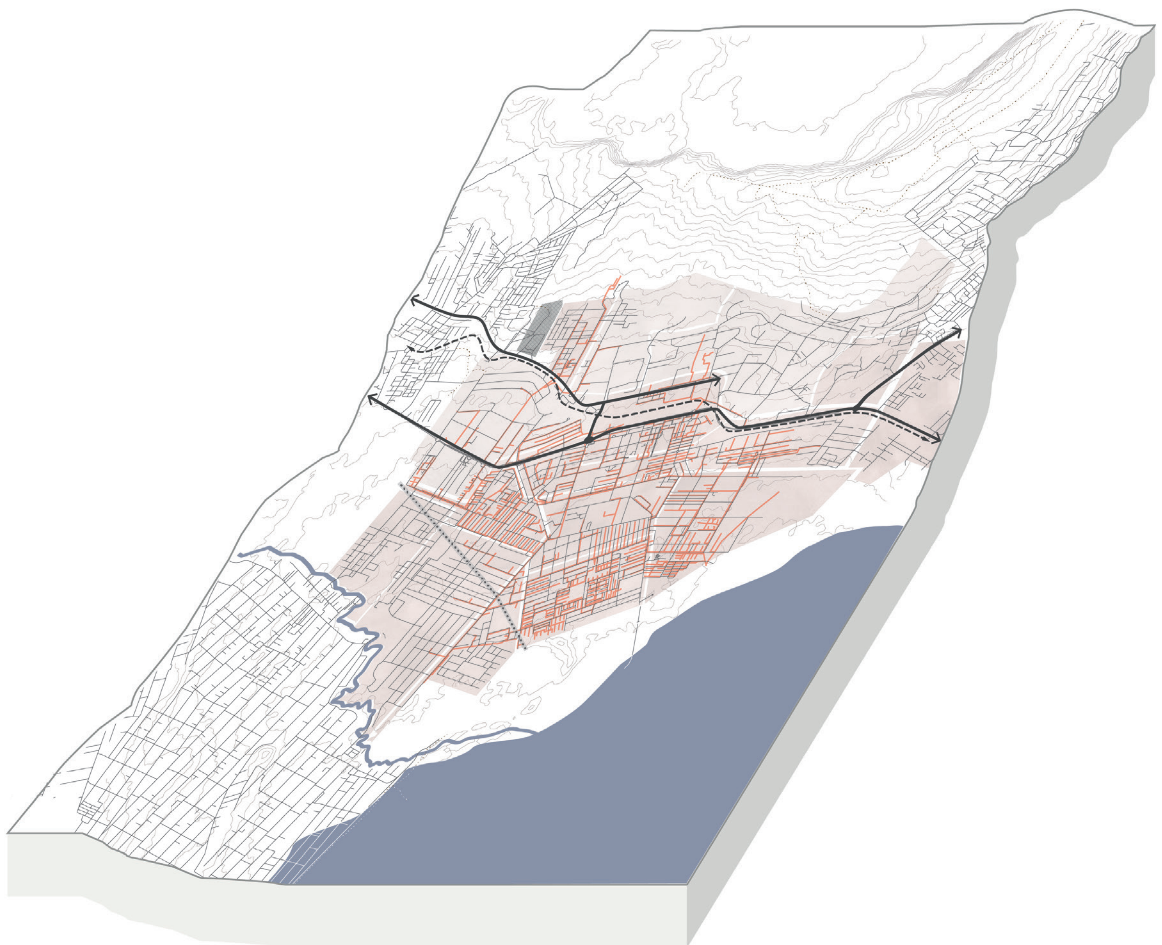
Network

- Two strong horizontal roads shape the area and lie perpendicular to the natural downhill runoff direction
- A grid is present all over the city but with different densities.
- Informal areas show a fine grid, with poor infrastructure and minimal or no sewerage (dotted lines).
- Industrial and wealthier areas have a wider grid.
- The grid structure speeds up the drainage downhill, causing urban flooding downstream, as does the drainage systems upstream located near to seasonal rivers at the hillside of the menengai caldera. The current drainage system is focussed on disponsing water as quickly as possible to Lake Nakuru, but effiency of the drainage system downstream is lower than upstream, causing bottlenecks like urban floodings and waste blockages.
- The electricity line on public ground is at the same time a runoff route with several floodings locations in the informal neighborhoods downstream.

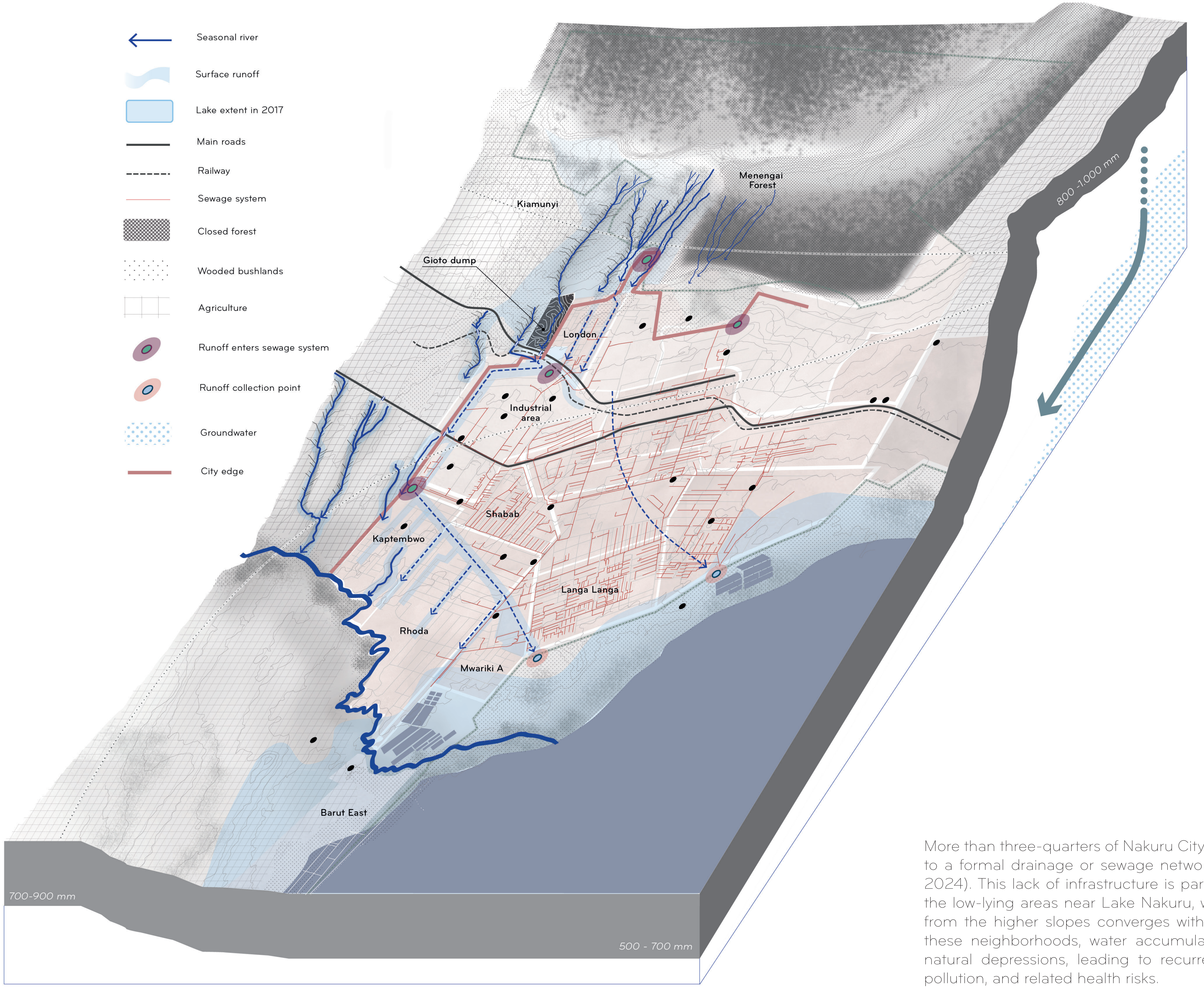




[Figure 68.] Ecology layer



[Figure 69.] Network layer



[Figure 70.] Overview of water-related issues in the seasonal sub-watershed

Coverage of sewage and drainage systems

More than three-quarters of Nakuru City is not connected to a formal drainage or sewage network (Nillesen et al., 2024). This lack of infrastructure is particularly critical in the low-lying areas near Lake Nakuru, where stormwater from the higher slopes converges with direct rainfall. In these neighborhoods, water accumulates by gravity in natural depressions, leading to recurrent waterlogging, pollution, and related health risks.

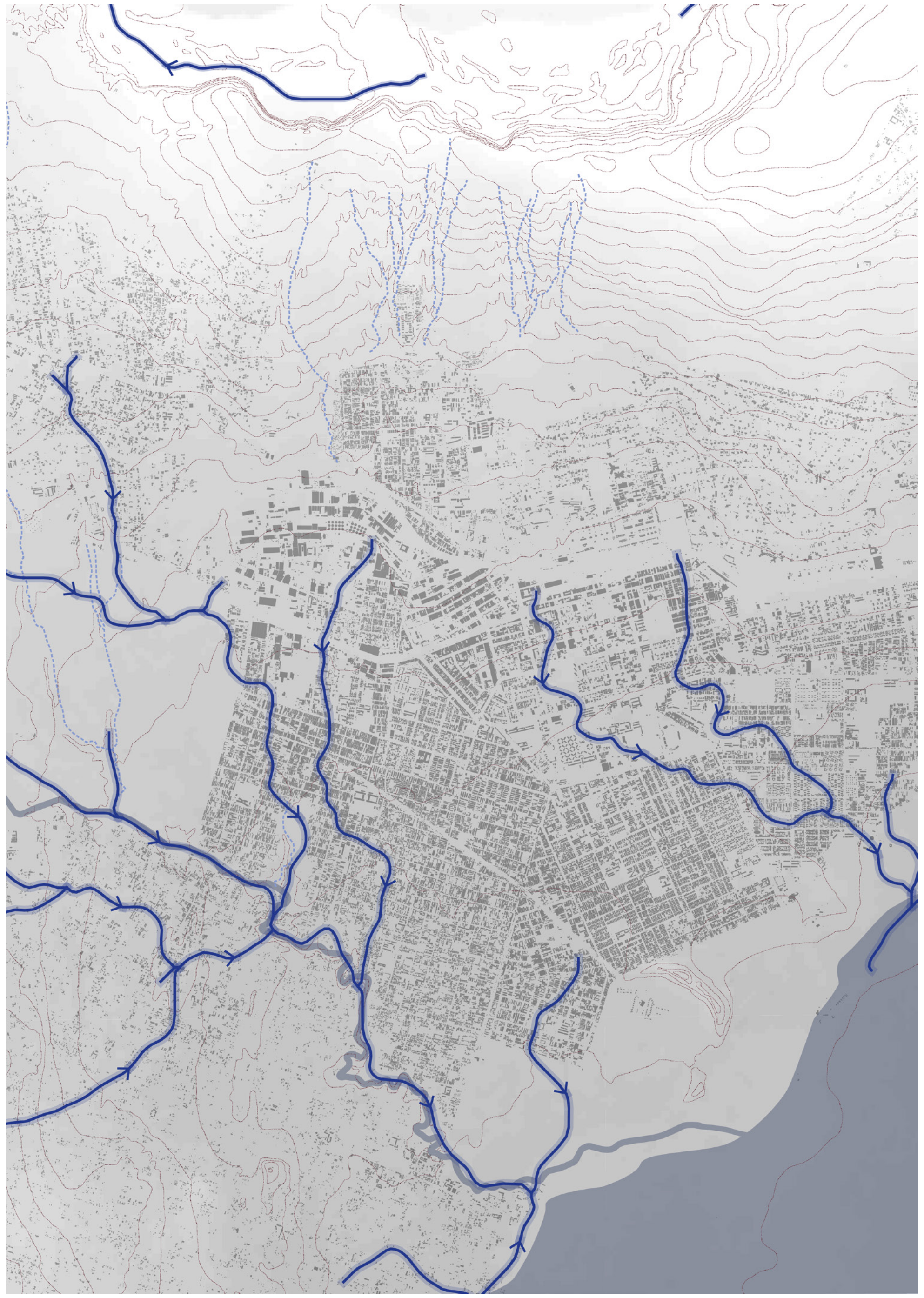
At the same time, water scarcity complicates the situation. Because there is little rainwater harvesting or storage capacity, residents depend heavily on groundwater and surface water. However, groundwater use is prioritized for industrial purposes, which further reduces the availability for local communities (Nillesen et al., 2024). The combination of absent drainage, limited water management, and competing groundwater demand intensifies both social and environmental vulnerabilities.

In response, community groups have started developing small-scale drainage systems. For example, in Kaptembwo, local residents are constructing drains towards the Njoro River. While this fosters ownership and shared responsibility, it also accelerates polluted runoff from upstream areas and channels it directly downstream. Without tackling the underlying causes upstream, such measures risk worsening the situation by transferring problems elsewhere.

As such, these interventions represent short-term fixes rather than systemic solutions. By collecting, treating, and reusing runoff within vulnerable neighborhoods, drainage could instead become part of a wider water strategy, simultaneously reducing flood risks and improving local water availability.

Runoff patterns

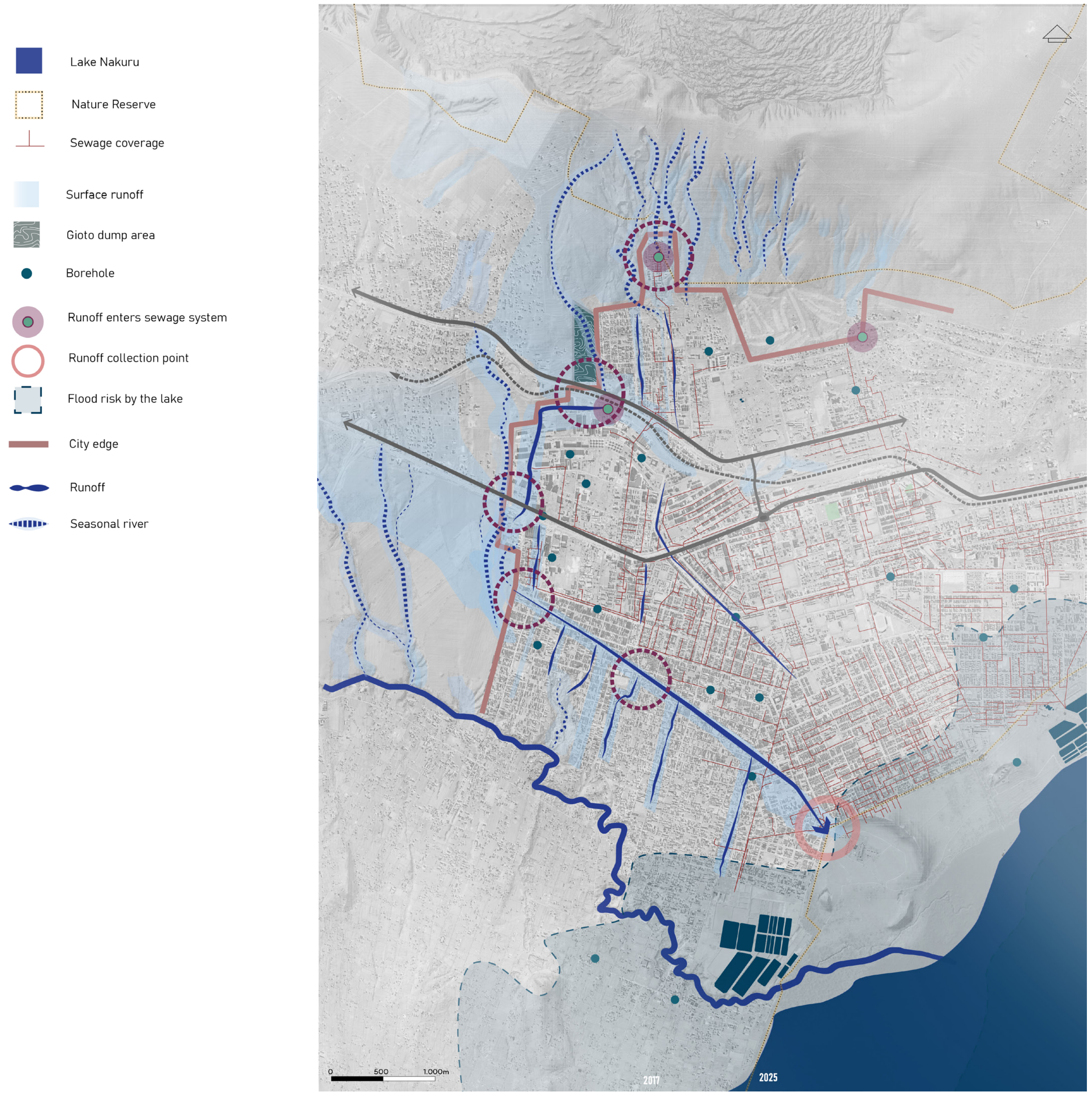
Runoff patterns within the seasonal sub-watershed were modeled by a GIS expert from NAWASSCO using a DEM of the region. The results show how several runoff lines begin in the agricultural hinterlands of Kiamunyi, pass through the urban fringe, and concentrate in downstream neighborhoods such as Kaptembwo, Rhoda, and Mwariki A. In these areas, the lack of sufficient drainage and sewerage causes water to accumulate in natural depressions, resulting in recurring flooding and contamination.
Field observations confirm that the mapped seasonal rivers on the slopes of the Menengai Caldera are interconnected with these runoff lines. Their traces downstream match the locations of urban flooding, showing how upstream flows intensify risks in vulnerable low-lying areas. This effect is particularly visible at the north-western edge of Nakuru, where many flooding incidents have been recorded. A large share of runoff enters the city from peri-urban catchments after heavy rainfall events. Schalkwijk (2025) notes that flows from the western peri-urban areas, including the research fields of the Rift Valley Institute of Science and Technology, are expected to affect large parts of Kaptembwo and Rhoda



[Figure 71.] Runoff lines and directions located in the focus area

Urban flooding locations

The map of urban flooding locations shows how runoff patterns translate into specific risks on the ground. The data is based on literature, field research, interviews with residents and experts, mapping, and photographic evidence, and is consistent with the flood locations documented by Schalkwijk (2025) and Nillesen et al. (2024).
Most flood-prone sites are concentrated at the city's edge. Schalkwijk (2025) classified these as pluvial flood risks, caused by surface runoff during or immediately after extreme rainfall events. In Nakuru's water system, approximately 70% of total flood volume comes from such external runoff.
Upstream, landslides and severe soil erosion already endanger communities in Kiamunyi and London. Here, runoff also flows through the Gioto dump site, where uncontrolled waste disposal and inadequate drainage lead to polluted flows moving downstream. Further downstream, these contaminated and accelerated waters combine with additional runoff entering Kaptembwo from the west. As a result, informal neighborhoods such as Kaptembwo, Rhoda, and Mwariki A face severe flood risks. The consequences are visible in abandoned dwellings and in community-made embankments, built in attempts to block overland flows (figure 76).



[Figure 72.] Overview of (urban)flooding locations

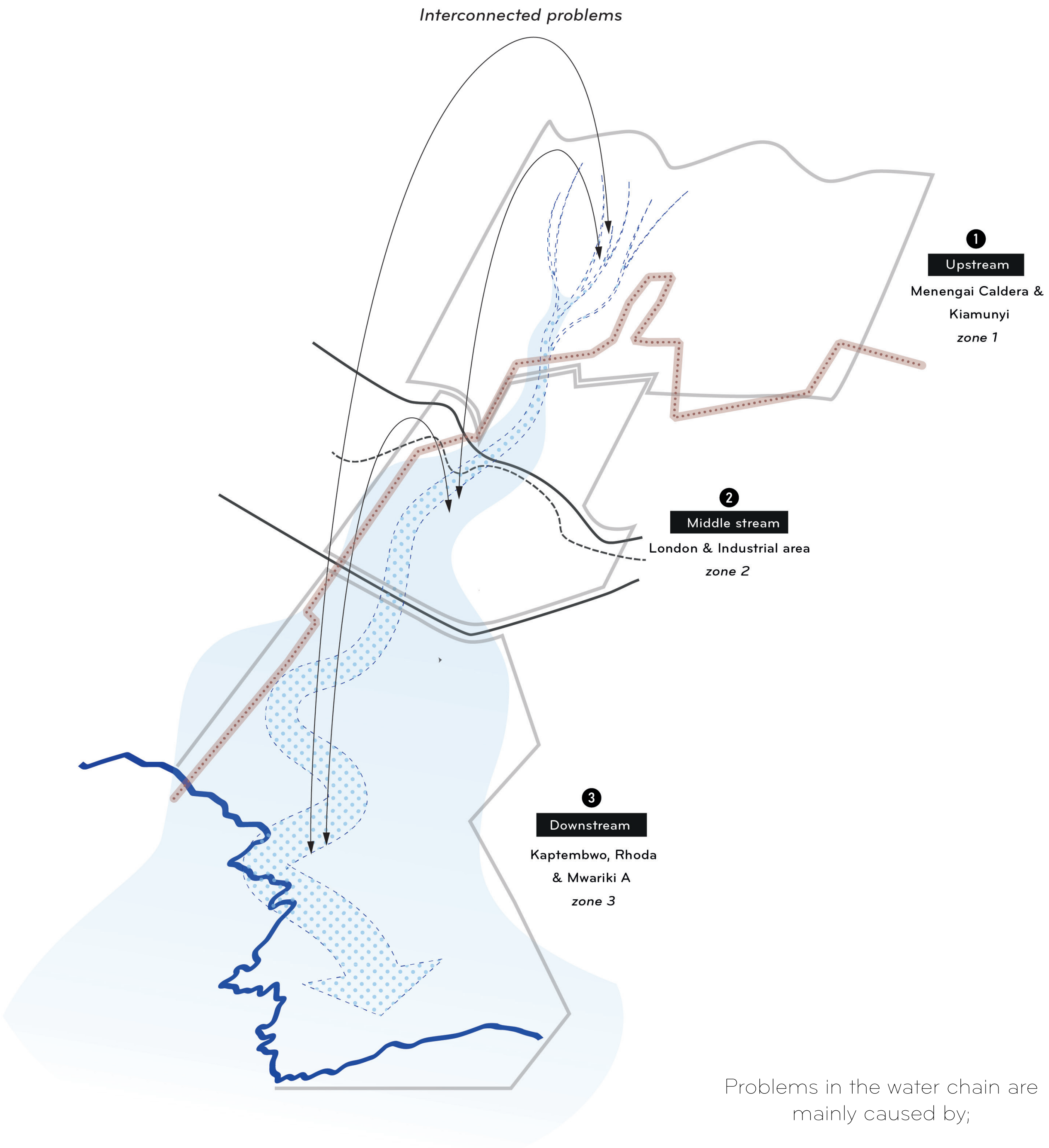
[Figure 73.] Soil erosion at the hillside of the Menengai Caldera (photo by author)

[Figure 74.] Sewage blockages due to waste discharge in drainage channels at the Pondamali market, located in informal neighborhood Mwariki A. (photo by author)

[Figure 75.] Closed community borehole due to water scarcity, Kiamunyi area (photo by author)

[Figure 76.] Flooded area, abandoned dwellings caused by excessive surface runoff from upstream catchments. The community constructed an improvised embankment in an attempt to block the overhand flow (photo by author)

Defining flowzones



[Figure 77.] Overview of defined flowzones within the seasonal sub-watershed

Problems in the water chain are mainly caused by;

too much
(flooding)

too polluted
(environmental degradation)

too little
(scarcity)

Tjallingii, 1995

Following a critical water flow downstream

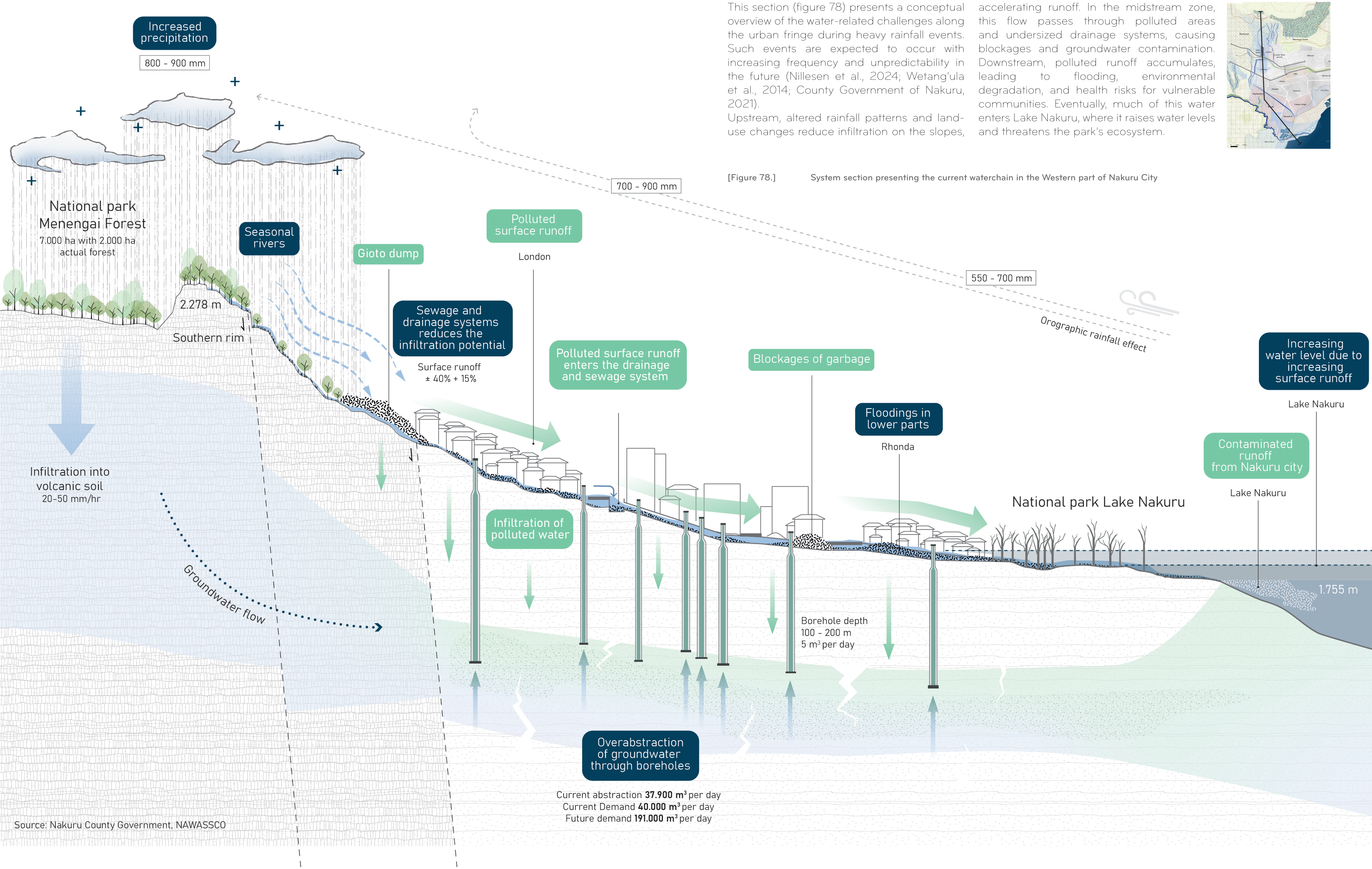
The second field of attention, as outlined by Tjallingii (1995), concerns the sustainable, long-term management of water chains, here applied to the seasonal sub-watershed under study. Such chains are often disrupted by conditions of too little, too much, or too polluted water (Tjallingii, 1995), all of which are present in the focus area. In many urban contexts, disruptions are addressed through short-term measures such as adding more water to the chain or accelerating its removal, as described in the Ecodevice model by Van Wirdum and Van Leeuwen (see Chapter 3.5). These approaches, however, shift problems to future generations, often resulting in new critical situations such as dehydration of surrounding areas, increased flood risks, or health hazards caused by pollution (Tjallingii, 1995).

This subsection, Flow, examines the water chain in detail. It shows that surface runoff is in many cases the primary source of critical situations. As highlighted in the previous subsection, Area, many of these challenges occur along the urban fringe on the western side of Nakuru and are interconnected, forming a chain of related problems. However, these water-related issues manifest differently across the upstream, midstream, and downstream zones, each requiring specific attention.

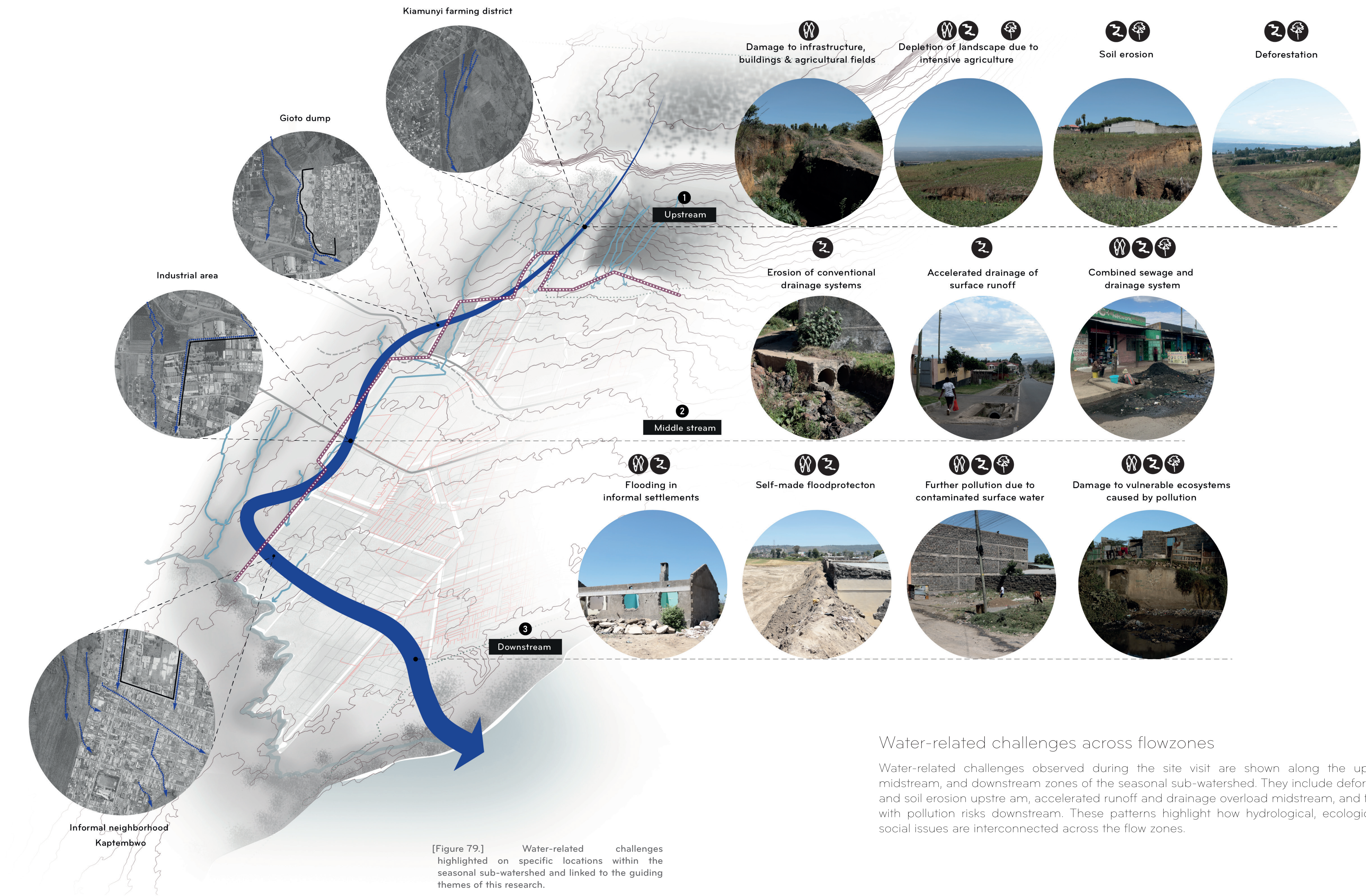
System section - along the city edge

This section (figure 78) presents a conceptual overview of the water-related challenges along the urban fringe during heavy rainfall events. Such events are expected to occur with increasing frequency and unpredictability in the future (Nillesen et al., 2024; Wetang'ula et al., 2014; County Government of Nakuru, 2021).
Upstream, altered rainfall patterns and land-use changes reduce infiltration on the slopes, accelerating runoff. In the midstream zone, this flow passes through polluted areas and undersized drainage systems, causing blockages and groundwater contamination. Downstream, polluted runoff accumulates, leading to flooding, environmental degradation, and health risks for vulnerable communities. Eventually, much of this water enters Lake Nakuru, where it raises water levels and threatens the park's ecosystem.

[Figure 78.] System section presenting the current waterchain in the Western part of Nakuru City



Source: Nakuru County Government, NAWASSCO



[Figure 79.] Water-related challenges highlighted on specific locations within the seasonal sub-watershed and linked to the guiding themes of this research.

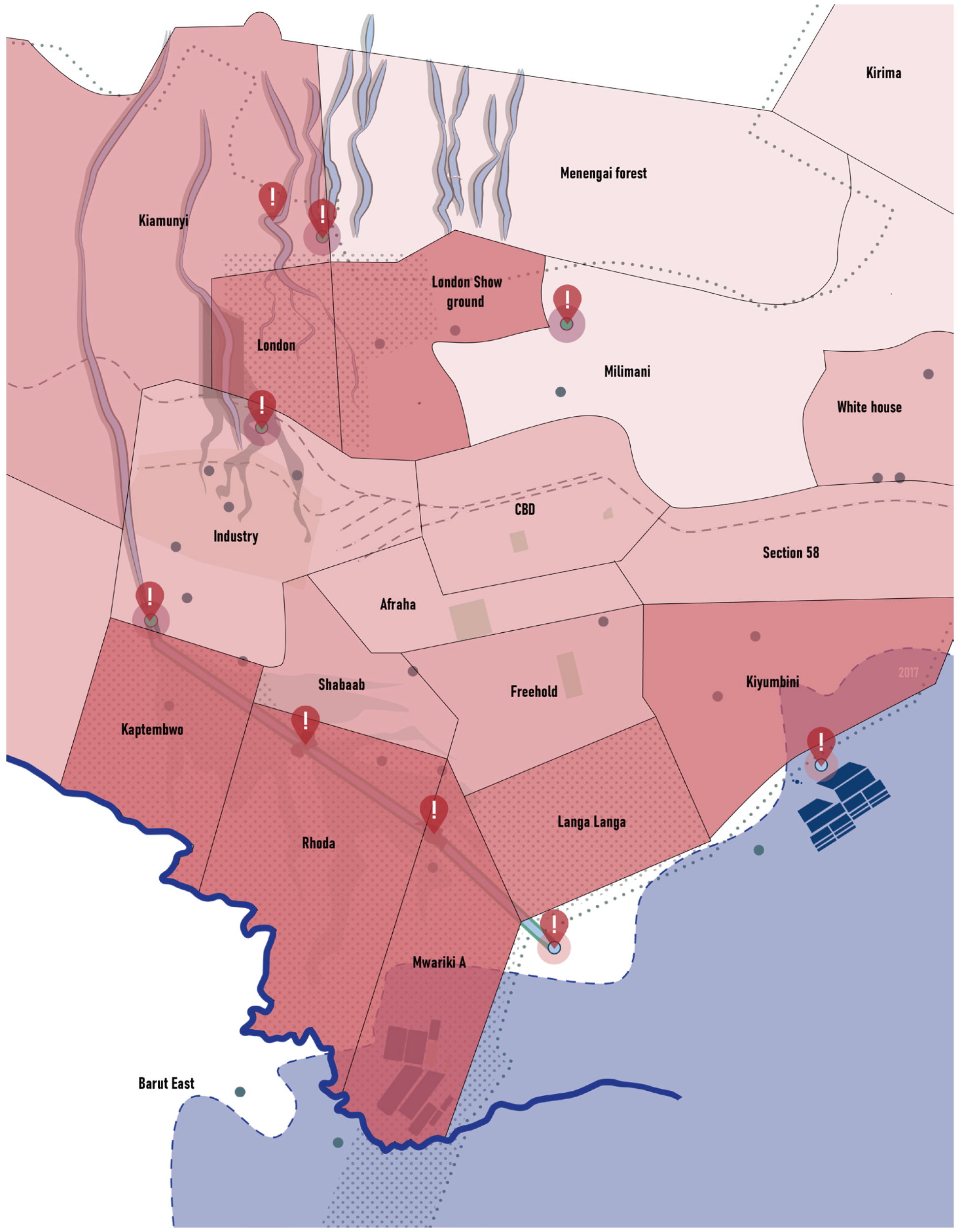
Water-related challenges across flowzones

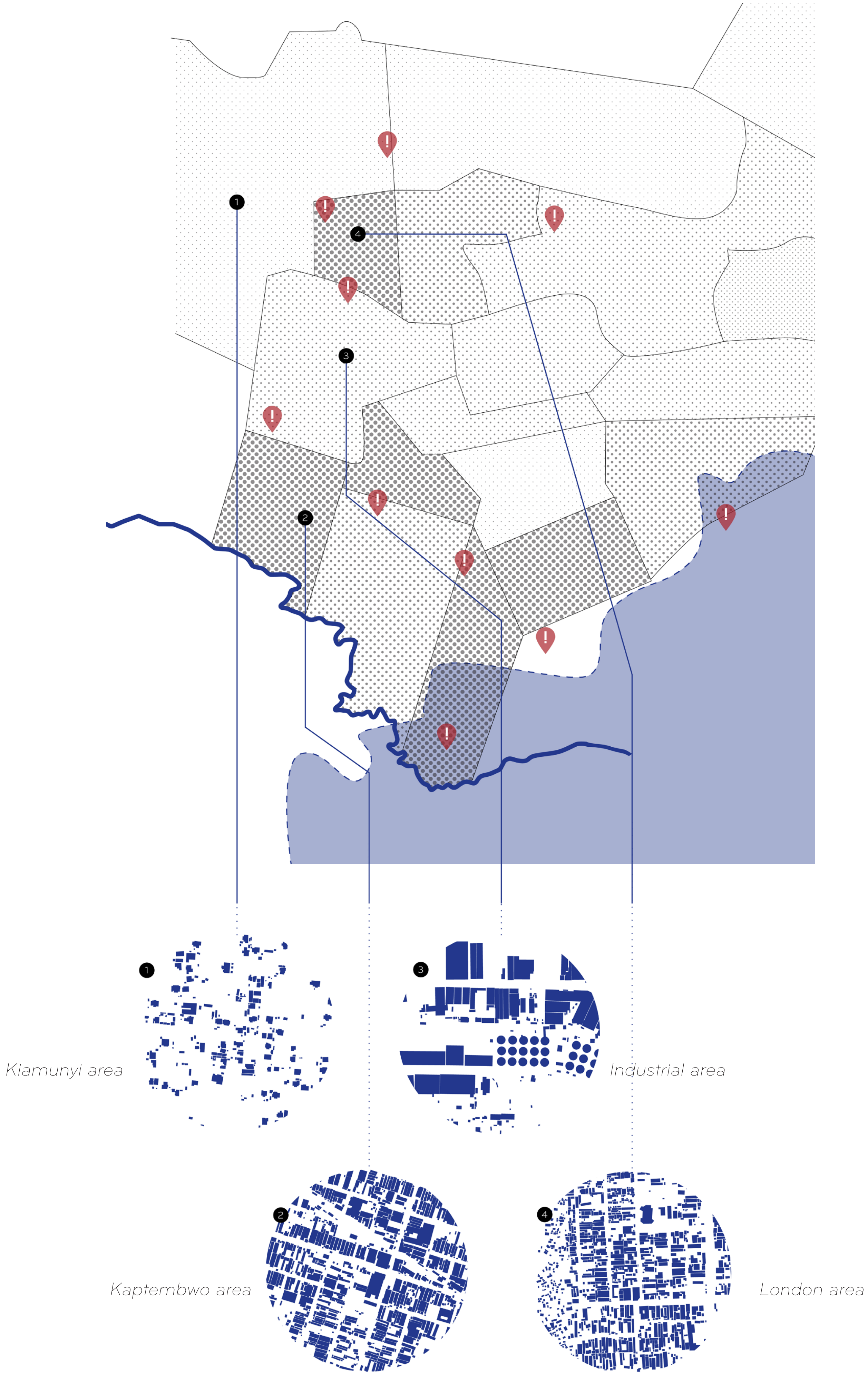
Water-related challenges observed during the site visit are shown along the upstream, midstream, and downstream zones of the seasonal sub-watershed. They include deforestation and soil erosion upstre am, accelerated runoff and drainage overload midstream, and flooding with pollution risks downstream. These patterns highlight how hydrological, ecological, and social issues are interconnected across the flow zones.

The third pillar of Ecopolis, Participants, addresses the socio-cultural dimension of the seasonal sub-watershed, with a focus on community participation and interaction. After analyzing the Area and Flow of the water chain, it becomes possible to assess which parts of the focus area are most severely affected by the challenges of too little, too much, and too polluted water (figure 80). A key factor in this assessment is the density of neighborhoods and the degree of informality.

Building density offers a proxy for population density within the focus area (figure 81). The lowest-lying and most densely built neighborhoods can largely be categorized as informal settlements. Informal settlements are unregulated and unplanned areas where housing does not meet building codes or regulations and where residents often lack formal land tenure (Tom et al., 2022). As a result, these areas typically suffer from inadequate infrastructure, limited social services, and insufficient water access, which makes them highly vulnerable to flood risks (Dawson et al., 2008).

In Nakuru, rapid urban growth over recent decades has produced a city largely inhabited by low-income households, with more than half of the population classified as poor (Mokaya et al., 2016). Within the Kaptembwo area, for example, access to adequate water supply is particularly limited, while sewerage and drainage coverage remain very low (Mokaya et al., 2016). These conditions reveal a critical situation in which the most vulnerable communities are disproportionately exposed to pollution, flooding, and water scarcity.





[Figure 80.] [Left] Assessment of neighborhoods within the seasonal sub-watershed, indicating levels of exposure to water-related challenges

[Figure 81.] [right] Estimated building density per neighborhood within the focus area, used as a proxy for population pressure and vulnerability

Stakeholder analysis

Expertise and contextual knowledge were gathered through the Water as Leverage workshop, a scenario workshop at Egerton University, and on-site interviews with residents' associations, governmental institutions (NAWASSCO and the County Government of Nakuru), and local academic and research institutions (Rift Valley Institute and Egerton University). A detailed overview of these activities can be found in Appendix.

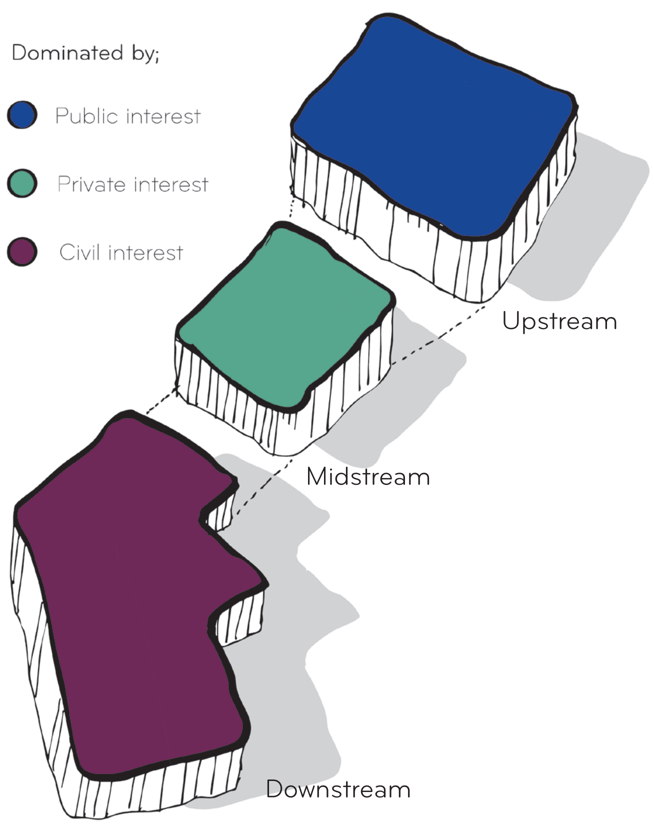
Based on these inputs, a stakeholder analysis was developed, distinguishing three main groups of interest: public, civil, and private (figure 83). As highlighted in interviews with officials, local experts, and residents, very little land in and around Nakuru town is owned by the government. Many services are instead organized through community groups, which follow a bottom-up approach and exercise considerable influence over how space is used and managed. This is an essential factor to integrate into design principles and interventions to ensure feasibility and implementation.

On-site research further revealed the frequent occurrence of the "strategy of the commons" (see Chapter 3.5). Public land, where available, is often used for small-scale farming or trade, forming a crucial part of the informal economy. This makes stakeholder dynamics highly fluid: in many cases, ownership and land-use responsibilities are unclear and poorly documented. As a result, the analysis is based on a combination of local expertise, knowledge, and observations made in the field (see Appendix).
Given the disrupted water chain in Nakuru, interventions will ultimately be required at multiple scales. Here, the connection between local residents (bottom) and governmental actors (top) is of great importance. Large-scale interventions require financial backing, which can only be realized through government institutions and NGOs. Identifying the location of public land is key to targeting these efforts. However, in areas dominated by private or civil interests, interventions must be designed with a bottom-up perspective to align with the needs of local stakeholders.

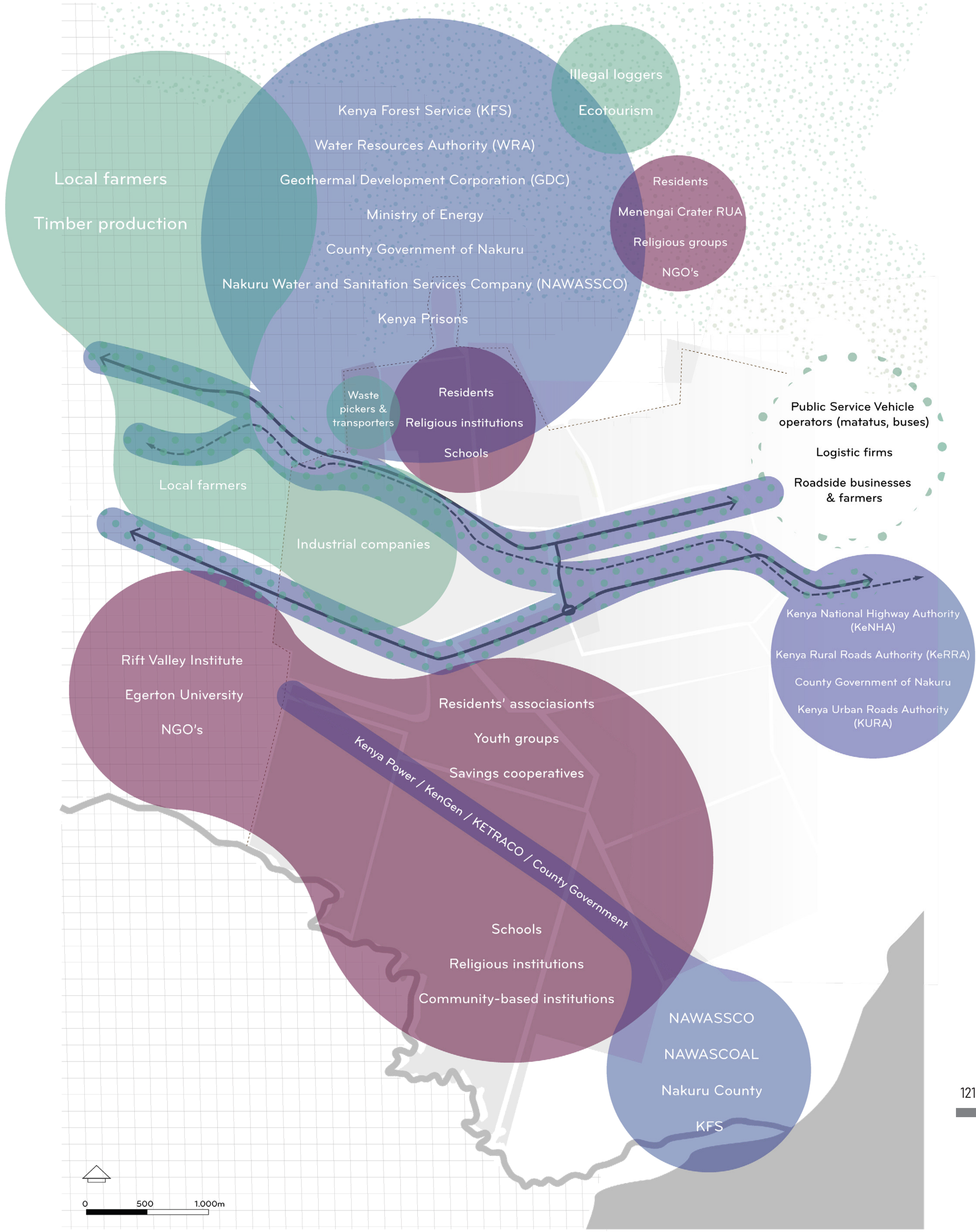
In conclusion, the stakeholder analysis shows that public, civil, and private interests overlap with the three flow zones of the seasonal sub-watershed (figure 82). This alignment creates an opportunity to develop design strategies that both reflect hydrological realities and respond to the social and institutional context of each zone. By connecting stakeholder interests to resilience principles, the analysis provides a foundation for interventions that are context-specific, feasible, and widely supported. Embedding strategies within existing governance structures and community practices increases their long-term effectiveness and acceptance.

To further clarify:
- Upstream: Public actors (such as KFS, NAWASSCO, and the Geothermal Development Corporation) dominate, given their control over forested slopes, water resources, and energy development. Design strategies here should focus on large-scale ecological restoration, forest protection, and water retention measures supported by institutional frameworks.
- Midstream: Industries and infrastructure providers play the central role, as this zone includes the industrial area, waste sites (such as Gioto dump), and critical sewerage and drainage infrastructure. Here, strategies must address pollution control, infrastructure upgrading, and better management of industrial and urban runoff to reduce downstream risks.
- Downstream: Civil interests—local residents, community associations, and informal groups—are most prominent. Here, interventions must directly address the vulnerabilities of informal neighborhoods, co-designed with residents to reduce flood risks, improve water access, and strengthen community resilience.

Together, these differentiated roles ensure that interventions are tailored to the realities of each flow zone, building a coherent framework for the transition toward the design strategy and specific interventions.



[Figure 82.] Illustrating the main interest per flowzone



[Figure 83.] Stakeholer analysis of the seaonal sub-watershed showing relevant participants in the urban system

The field visit to Nakuru provided essential insights into the socio-ecological dynamics of the focus area that could not be obtained from remote data sources alone. Observations on site revealed how local communities engage with their landscape through spatial structures and initiatives that influence water flows, infiltration, and ecological resilience.

This chapter is divided into two parts. First, the role of spatial structures such as vegetation, agroforestry, terracing, and check dams is discussed, showing how they contribute to delaying runoff and enhancing infiltration capacity. Much of the knowledge presented in this chapter is based on information shared by the Rift Valley Institute of Science and Technology and Egerton University.

Second, four local initiatives are analyzed, each situated in a distinct position within the seasonal sub-watershed. These initiatives illustrate context-specific practices that address water-related challenges while reflecting cultural and ecological interactions in the area.

The insights from the field visit form a crucial foundation for the subsequent design strategy and principles. By connecting observed practices to the broader framework of this research, they provide locally grounded knowledge that ensures the proposed interventions are both ecologically effective and socially embedded.

Learning from local knowledge; spatial structures for delaying water and reducing soil erosion

In the focus area, two critical landscape issues, soil erosion and surface runoff, were identified in the previous chapters as key challenges affecting both ecological and social systems. During the field visit, local experts and residents frequently emphasized how these problems can be mitigated through spatial interventions that work with the landscape rather than against it. Insights from interviews and literature highlight two main categories of such interventions: vegetation-based measures, including agroforestry and reforestation, and contour-based measures, such as terracing and check dams. Both approaches use spatial structures to slow down water, enhance infiltration, and stabilize soil. The following sections discuss these strategies in more detail, drawing on observations from the field and knowledge shared by local academics and literature.

Vegetation-based measures

In the hilly areas surrounding Nakuru, soil erosion caused by excessive surface runoff presents a persistent environmental challenge. It results in the loss of fertile topsoil rich in organic matter and nutrients, damages built-up areas, and threatens local livelihoods. As emphasized by several local experts, this problem can be mitigated by slowing down water flow along slopes through runoff barriers or by maintaining continuous vegetation cover. Vegetation therefore functions as a key spatial principle for controlling surface runoff, stabilizing soil, and enhancing infiltration capacity, highlighting its relevance to this research.

The effectiveness of this principle, however, largely depends on species selection. As observed during the field visit to the Rift Valley Institute of Science and Technology, introduced Eucalyptus trees develop deep vertical roots that extract groundwater but provide limited lateral stabilization. In contrast, native Acacia species form extensive horizontal root systems that effectively anchor the soil and better withstand climatic extremes. Their rooting structure makes them particularly suitable for erosion control and water retention in Nakuru's semi-arid environment (Appendix – Interview with Rift Valley Institute of Science and Technology). Additionally, the rather transparent canopy of Acacia species stimulates lower vegetation layers, closer to the ground and thereby reduces the overland flow even further (figure 84).

In addition to their structural role, trees also influence microclimatic conditions. As described by Belsky et al. (1989), tree canopies intercept solar radiation and rainfall, generating local temperature and moisture variations that support surrounding vegetation. The broad, parasol-like crowns of native trees observed on site extend this microclimatic effect by providing shade and enhancing moisture retention, an essential function in the semi-arid climate of Nakuru. Soils beneath tree canopies are typically more fertile and biologically active than those in open grasslands, as demonstrated in studies from Kenya's Tsavo region (Belsky et al., 1989).

Building on these insights, three spatial applications of vegetation are particularly relevant for reducing erosion and slowing runoff in the study area.

First, planting along contour lines, for example, through hedgerows or vegetative strips, reduces the velocity of surface flow and increases infiltration on sloped terrain. This approach is widely practiced by local farmers and was frequently discussed during the field visit.

Second, riparian vegetation, consisting of trees and shrubs along perennial or seasonal watercourses, stabilizes riverbanks and slows the concentration of runoff. These linear green corridors also enhance habitat connectivity and water retention (Schmitt et al., 2018; Bennett et al., 2024; Owen et al., 2015). However, there is a constant tension over the use of these fertile zones, as they provide valuable resources for charcoal production and timber, and are increasingly attractive for urban development and agriculture (Schmitt et al., 2018).

[Figure 84.] Effect of different tree species on runoff routes; Eucalyptus trees (left) and Acacia trees (right)

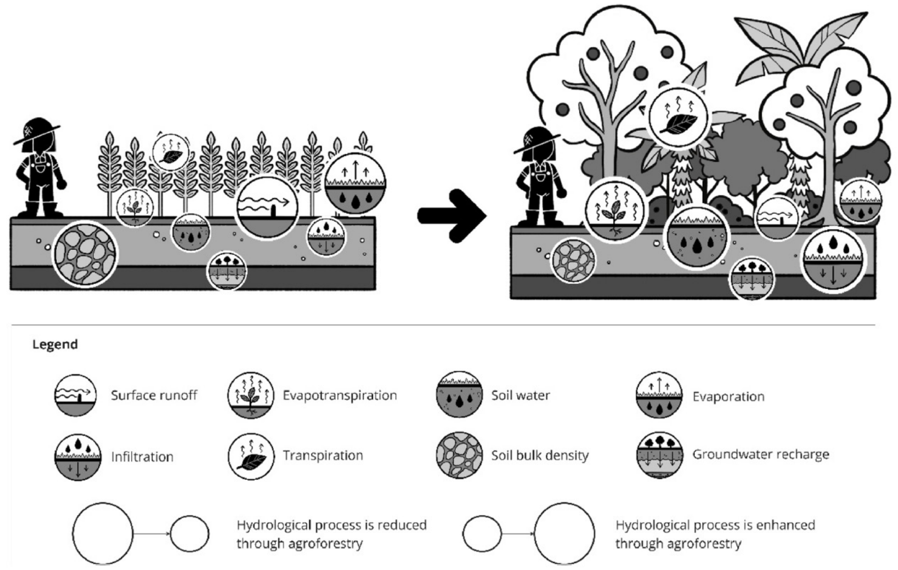
To partly address this conflict, agroforestry systems, as the third spatial intervention, integrate productive and ecological functions by combining perennial tree crops, such as guava, avocado, or mango, with annual crops. This approach strengthens soil structure, supports biodiversity, and regulates local hydrology. Literature widely recognizes its potential to "enhance biodiversity, prevent soil degradation, and mitigate flooding and droughts, while promoting sustainable development of (rural) communities" (Janzen et al., 2023). Studies show that under agroforestry systems, surface runoff and evaporation decrease while infiltration and evapotranspiration increase, as illustrated by Janzen et al. (2023) in figure 85. Although yields may initially decline, the long-term benefits to soil health, ecosystem services, and community resilience make agroforestry a sustainable strategy for erosion control, water management, and local livelihoods.

In summary, these three vegetation-based interventions, contour planting, riparian reforestation, and agroforestry, share the common objective of delaying water flow and stabilizing soil, yet each contributes differently to hydrological functioning, ecological restoration, and local livelihoods. When applied in combination and adapted to local conditions and community needs, they embody the guiding principles of this research: integrating water, ecology, and culture into a resilient and context-specific landscape strategy.

Contour-based measures

Beyond the role of vegetation, shaping the landscape itself is another important way to slow down runoff and reduce soil erosion. By working with the contours of the terrain, water flow can be interrupted, spread out, and given more time to infiltrate, thereby reducing the risk of erosion and downstream flooding. Two key strategies stand out and are well-recognized both on site and in literature: terracing and check dams. Terracing transforms steep slopes into stepped surfaces that reduce overland water flow, capture water, and provide more stable ground for cultivation while preserving the topsoil. Check dams, or gully plugs, are small barriers constructed across gullies or seasonal streams to trap sediments, slow down flows, and promote groundwater recharge.

Terracing is recommended on slopes where conventional contour farming is no longer sufficient to prevent erosion. According to Hussein et al. (2016), terraces are most effective on slopes between 5% and 20%, depending on soil and rainfall conditions. Their study shows that terraces help slow down surface runoff and increase infiltration when designed with gentle channel gradients that allow water to move gradually across the slope. These principles provide useful guidance for applying terracing in semi-



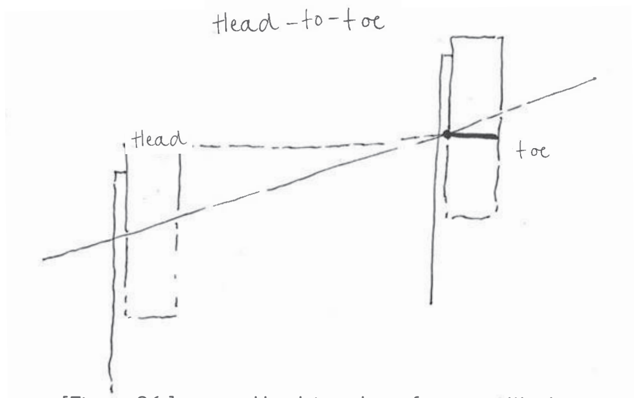
[Figure 85.] Schematic overview of the effect of agroforestry systems on hydrology and soil (visual by (Janzen et al., 2023))

arid landscapes where soil erosion and water scarcity are closely linked.

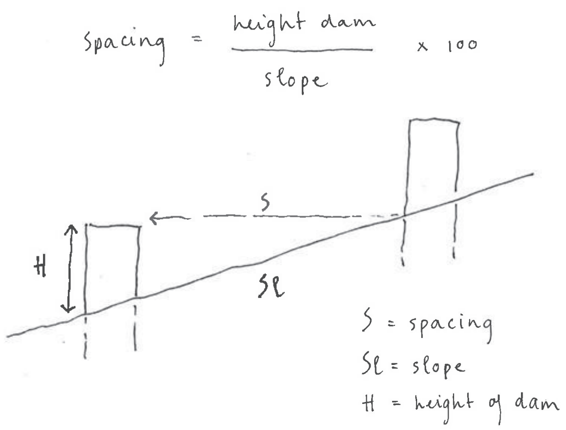
Check dams complement this approach by stabilizing gullies and controlling concentrated runoff. As described by Castillo et al. (2014), the optimal distance between consecutive dams follows the head-to-toe principle, meaning that the toe of the upstream dam aligns with the crest of the downstream dam (figure 86 and 87). This conservative design ensures a stable sediment wedge and a gradual reduction of the gully slope, enhancing both effectiveness and safety. Castillo et al. (2014) states that a V-notched weir in check dams as a design feature that allows controlled water discharge during runoff events (figure 88). The narrow V-shape concentrates low flows toward the center, ensuring continuous drainage while still promoting sediment deposition behind the dam. This design helps maintain hydraulic efficiency and prevents erosion or overtopping, making the structure both stable and self-regulating under varying flow conditions. In practice, check dams are most effective on slopes between 2% and 20%, depending on soil and flow conditions. Field studies in northern Ethiopia have shown that check dams combined with vegetation significantly delay runoff, reduce peak flow by 8–17%, and enhance infiltration and groundwater recharge (Guyassa et al., 2017). Together, these findings highlight that careful spacing and integration with vegetation improve both the hydraulic stability and ecological performance of check dam systems.

Both measures have proven effective in erosion-prone regions worldwide, such as terracing on China's Loess Plateau (see Chapter 3.7) and check dam systems in semi-arid northern Ethiopia (Guyassa et al., 2017) and have also been observed in practice during the field visit.

In conclusion, the previous sections about vegetation- and contour-based structures, based on insights from interviews with local experts and supporting literature, demonstrates how spatial structures can effectively reduce erosion, delay runoff, and enhance infiltration in Nakuru's semi-arid landscape. These examples offer valuable guidance for the slopes surrounding Nakuru, where erosion and surface runoff are key concerns. Within this research, both vegetation- and contour-based measures form an important foundation for strengthening resilience across scales and flow zones (upstream, midstream, and downstream) and are integrated into the design strategy and design explorations presented in later chapters. Building on this foundation, the following subchapter explores four local initiatives that further illustrate how community-driven and local practices already contribute to water regulation, ecological restoration, and social resilience in the Nakuru region and are based on these vegetation- and contour-based measures.

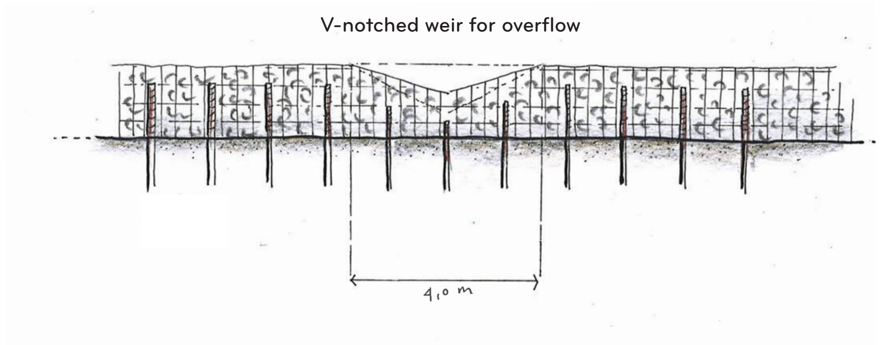


[Figure 86.] Head-to-rule for positioning checkdams on a slope (Castillo et al., 2014).



[Figure 87.] Formula to determine the spacing between checkdams (Castillo et al., 2014).

[Figure 88.] V-notched weir in the middle of checkdam to control water discharge during rainfall events (Castillo et al., 2014).



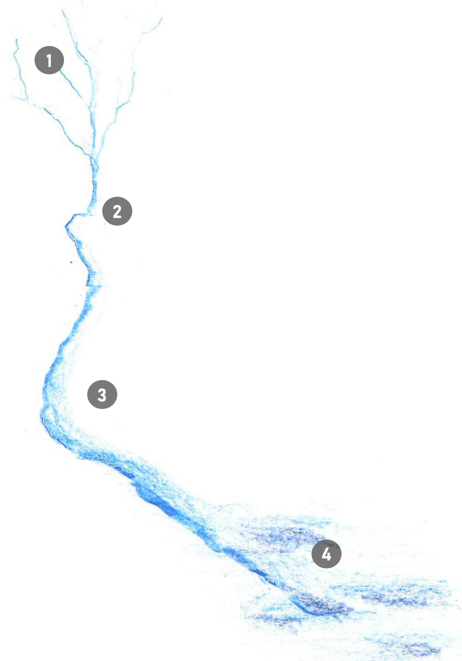
Learning from local initiatives

As part of the field visit, four local initiatives near Nakuru have been analyzed that serve as inspiration for the design principles developed later in the designing phase (chapter 5). These initiatives illustrate how communities have engaged with their landscape over time, creating places that not only contribute to the functioning of the water system but also hold significant social, communal, or ecological value.

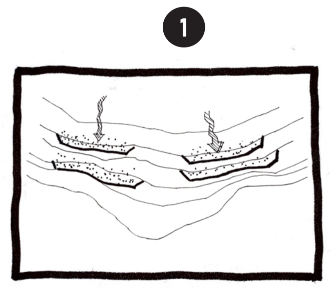
As Duchhart (2007) emphasizes, analyzing local case studies is essential for understanding how context-specific practices can inform broader design strategies.

In line with this perspective, the selected initiatives are more than isolated examples: they provide insights into how traditional knowledge and small-scale practices can support systemic resilience and help to create an understanding of the socio-cultural layer of Nakuru.

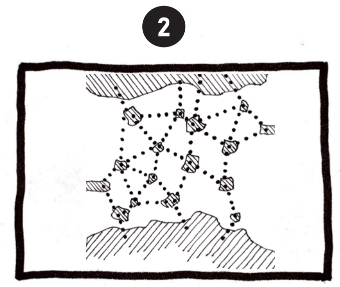
As visualized in figure 89, each initiative is situated within a specific part of the seasonal sub-watershed—upstream, midstream, or downstream. Together, they demonstrate how context-specific practices can strengthen resilience by contributing to a healthier natural and water balance across the urban system.



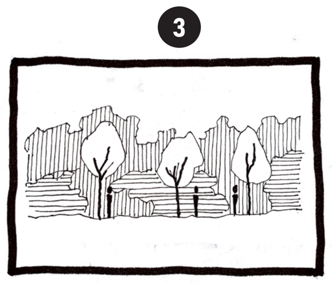
[Figure 89.] Postion of local intiatives in the seasonal sub-watershed on the Western-side of Nakuru.



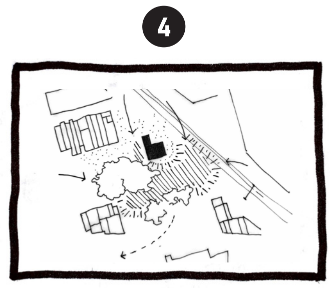
Agricultural terraces for soil stabilization and delaying surface runoff - upstream



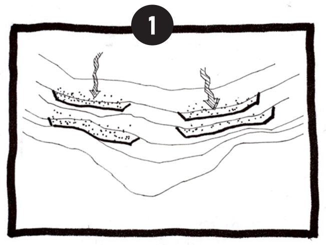
Local waterponds for retention with a communal function - upstream / midstream



Agroforestry; considering the water system and natural dynamics - midstream



Water retention area near communal spaces (churches or schools) in informal neighborhoods - downstream

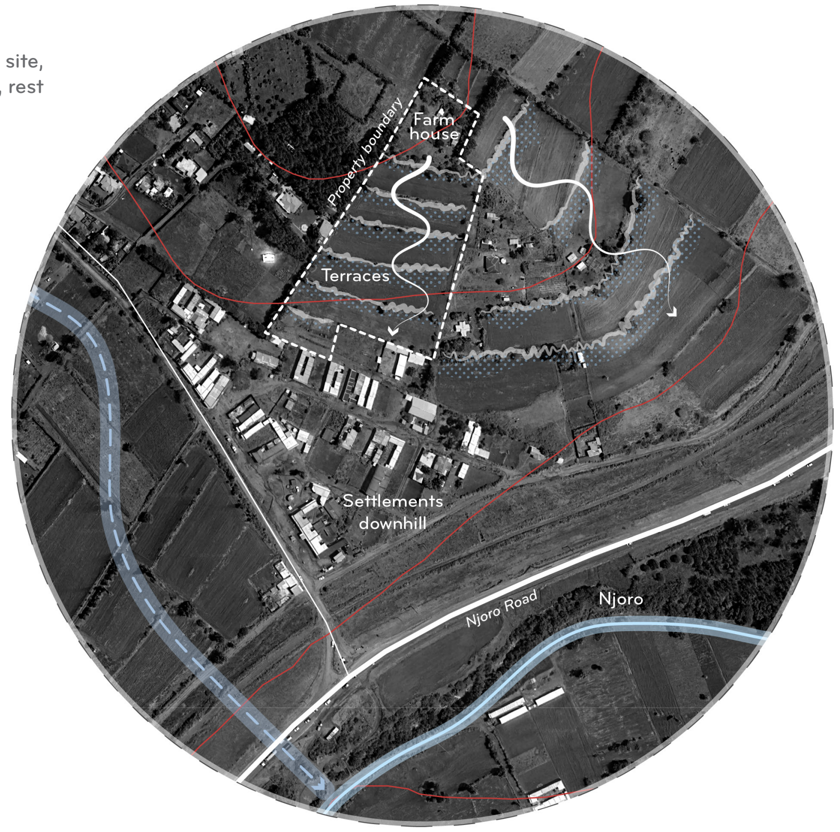


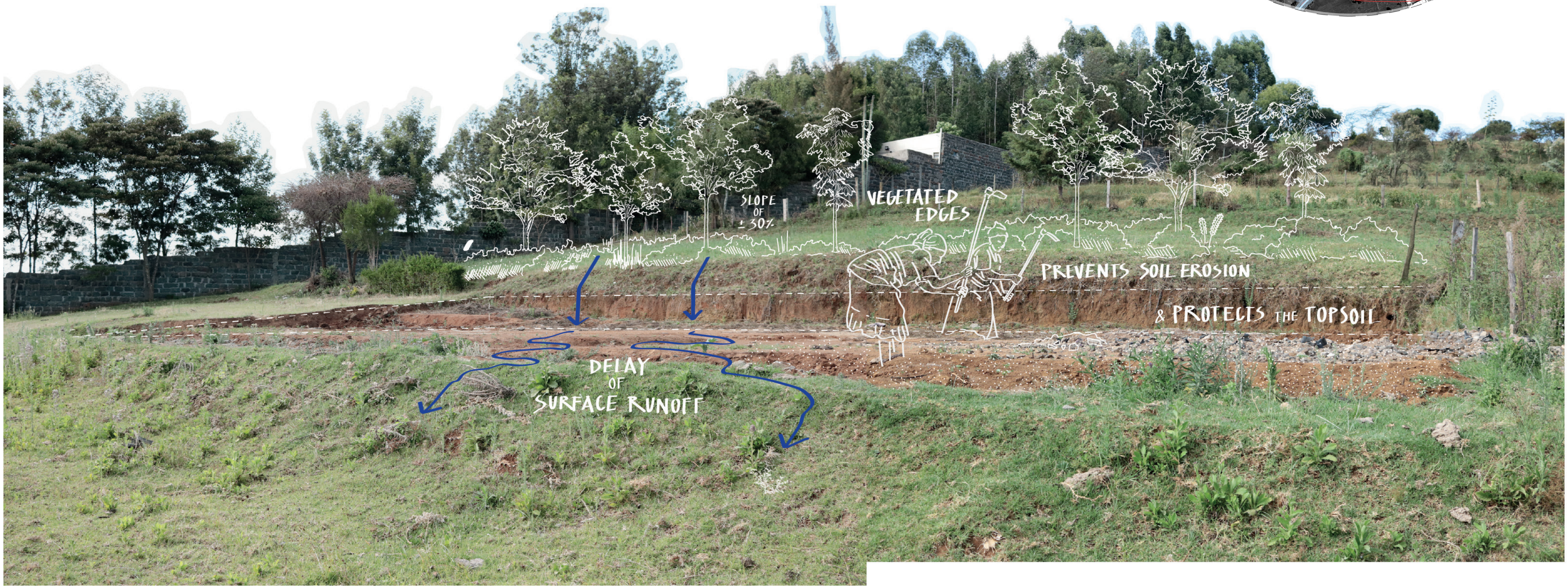
Agricultural terraces for soil stabilization and delaying surface runoff - upstream

This terrace system is located in the upper region of the study area, on a steep slope of approximately 30%. The terraces were constructed manually over generations and are cultivated with a variety of crops.
A key characteristic of this system are the vegetated edges that stabilize and anchor the soil, while providing shade and helping to retain moisture within the cultivated plots. Contouring the land with additional vegetation slows down surface runoff even further, while retention ditches integrated along the terraces allow for the capture and storage of both water and organic matter (Holzer, 2004).
According to the landowner, the system functions effectively under local climatic conditions, reducing overland water flow and protecting the settlements located downhill from flooding.

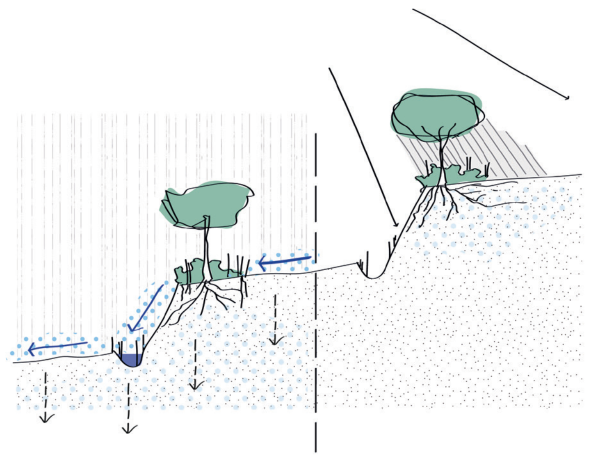
Through this combination of traditional knowledge and adaptive practice, the terrace system demonstrates how small-scale agricultural structures can play a vital role in soil stabilization, water retention, and climate resilience in the upper catchment.

[Figure 91.] Context of agricultural terraces on site, farmhouse uphill, , terraces delaying water in the middle, rest of the settlement downhill.

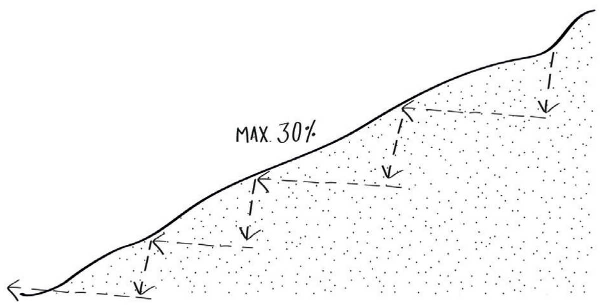




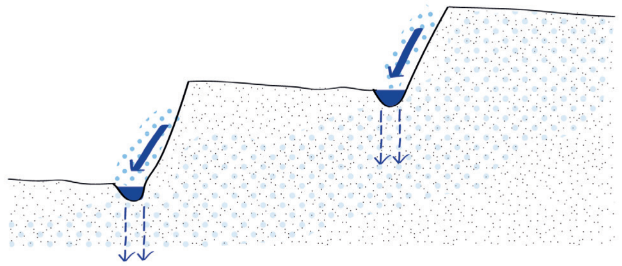
[Figure 90.] Collage of the terracing, located near Nakuru, showing the effects and elements of the terrace system on the landscape.



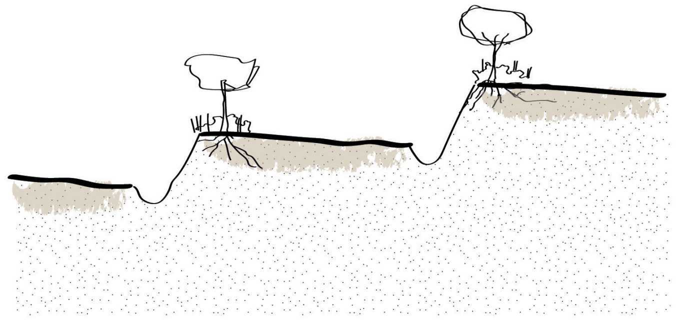
Vegetation at the edges for stabilization and shade



Suitable for slopes up to 30%



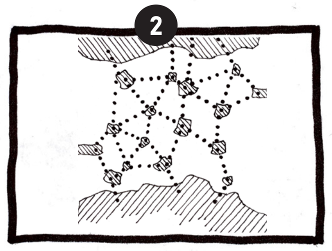
Retention ditches can provide an additional delaying function



Protects the top soil of being washed away

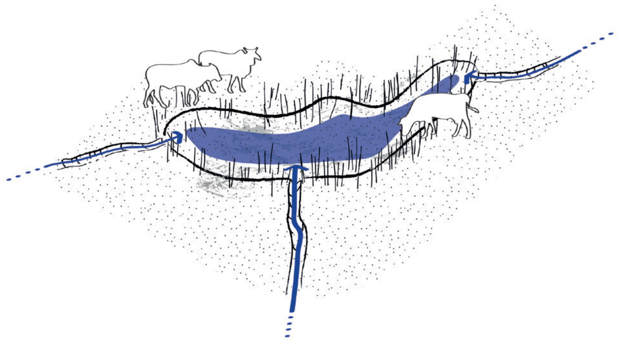
(1) Soil profile; (2) Vegetated edges of the terraces, to increase the delay of surface runoff (3) Slope of approximately 30% in between terraces;
(4) Lastest terrace made by the farmers familiy owning the land and living uphill.

This retention pond is located along a natural runoff line on the hillside of the Menengai Caldera. Strategically positioned along this route, it captures surface water through handmade inlets that guide runoff into the pond. The site is framed by a small wooded plot, where a large tree provides shade that reduces evaporation and enhances infiltration of the stored water.
According to local residents, the pond is frequently used to provide water for livestock after rainfall events and is accessible to nearby community members. A closer examination of the site revealed that one side of the pond has a gentler slope, likely shaped intentionally to improve accessibility for animals.
Through its design and position, the pond demonstrates how small-scale, community-managed structures can retain water effectively while supporting both ecological functions and local livelihoods.

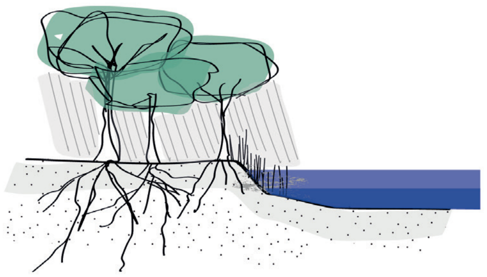


Local waterponds for retention with a communal function - upstream / midstream

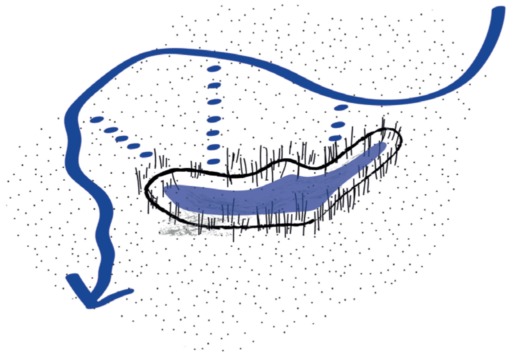
[Figure 92.] Collage of the commual water pond, located on the hill of the Menengai Caldera. It shows how the area functions and how it contributes to the local system.



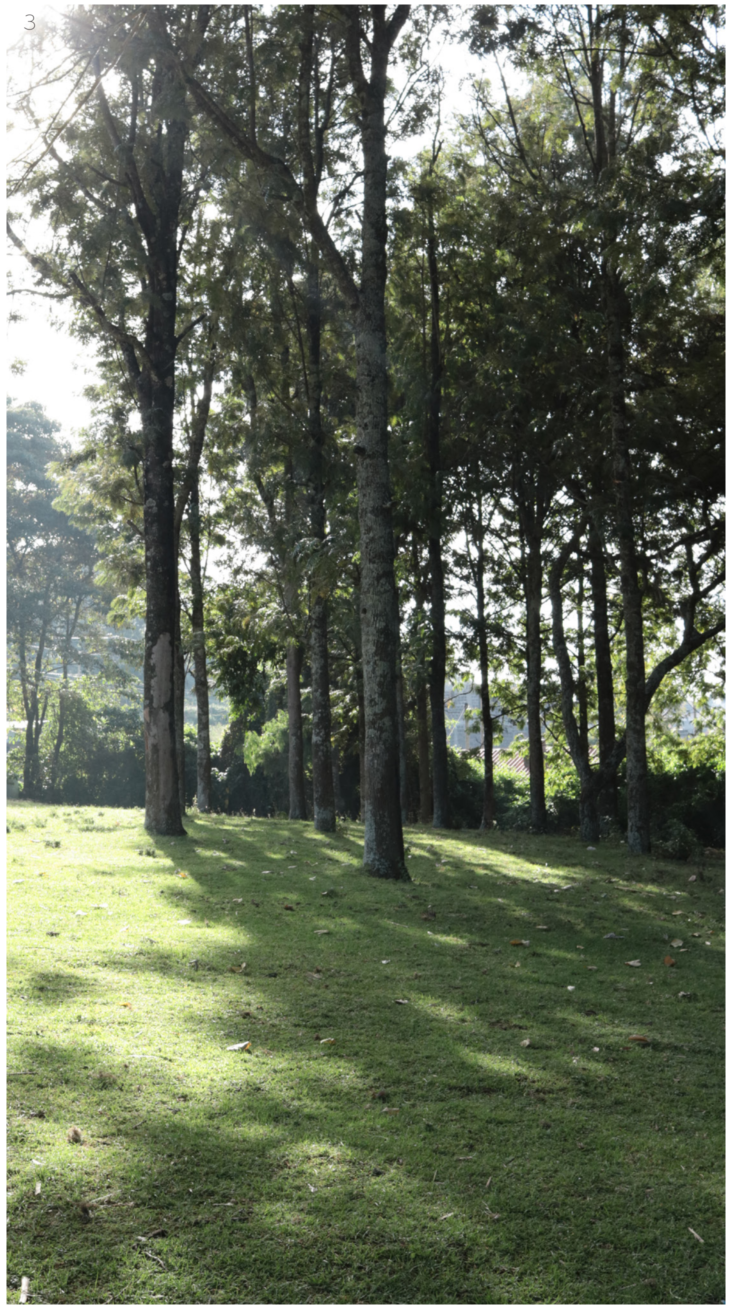
Designing easy access points allows livestock to reach water safely



Trees for shading to reduce evaporation

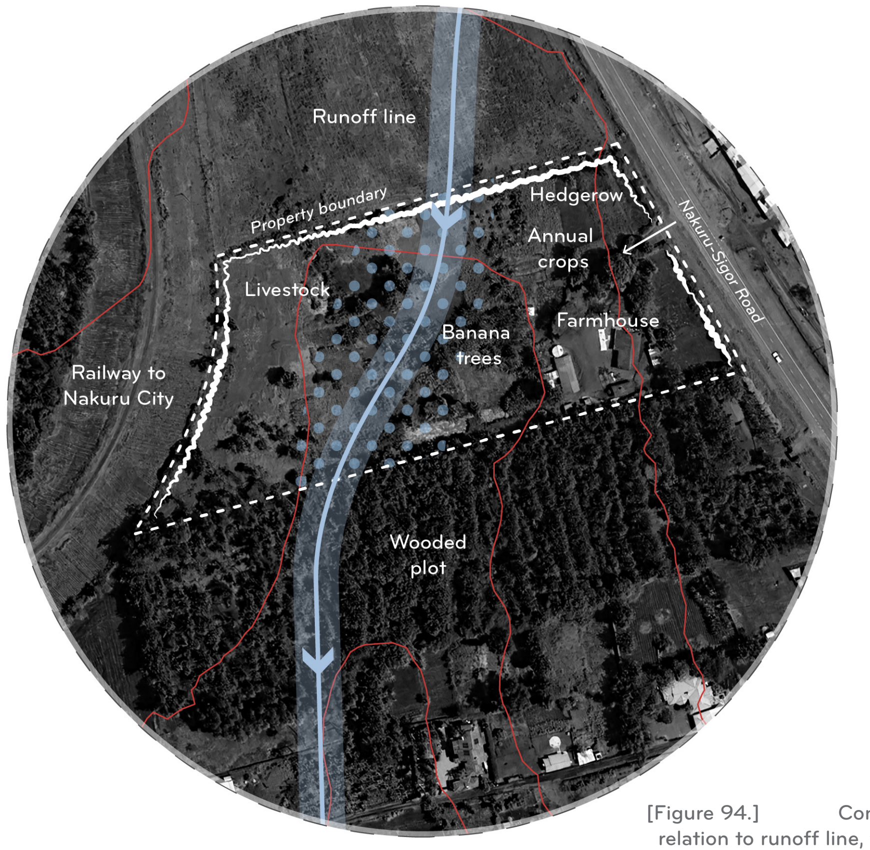


Located on runoff routes, water enters by gravity

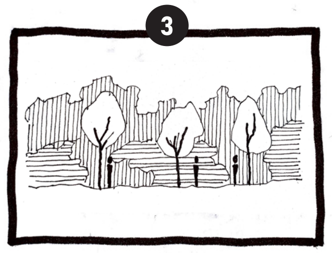


(1) Runoff enters the waterpond through drainage ditches; (2) Slower edges to create an easy acces for livestock; (3) Surrounded by a forested plot, provides shading, therby reducing evaporation and increasing the moisture in the soil; (4) Water retention pond has an estimated depth of two meters.

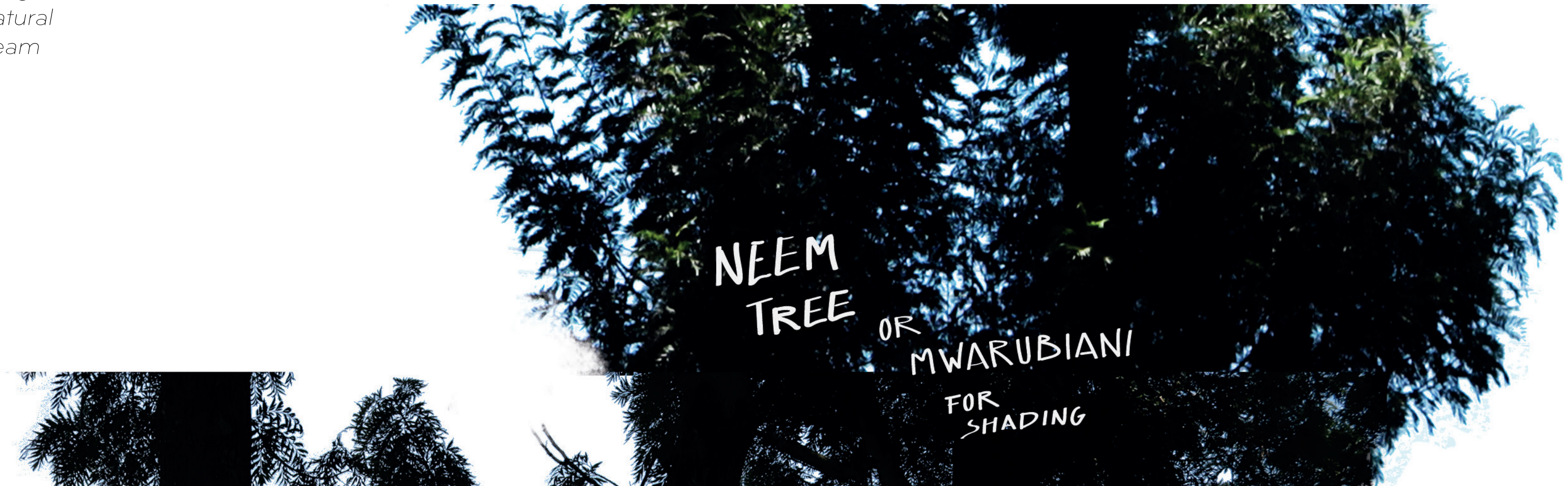
This agroforestry plot is located in the midstream zone on a gentle hillside near Nakuru City. During the dry season visit, neighboring plots had completely dried out, while this farm remained productive through the use of intercropping and the integration of natural vegetation.
The plot is structured according to soil moisture availability, combining both perennial and annual crops in a way that follows the local topography. The lower, wetter section, positioned along a runoff line, supports a banana plantation, while the upper, drier areas are planted with annual crops and Napier grass for livestock fodder.
Across the entire plot, a mixed hedge encloses the field, with seed and multipurpose trees (in this case Neem trees) are distributed throughout the plot to provide shade, improve soil moisture retention, and support biodiversity.
This integrated system demonstrates how agroforestry can enhance resilience to seasonal extremes while maintaining agricultural productivity in the midstream landscape of Nakuru.



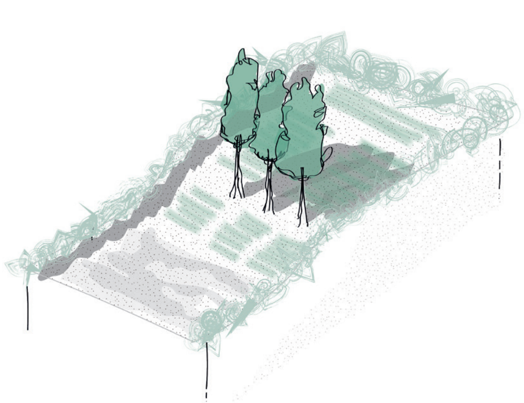
[Figure 94.] Context of agroforestry plot, in relation to runoff line, flowing through the farm.



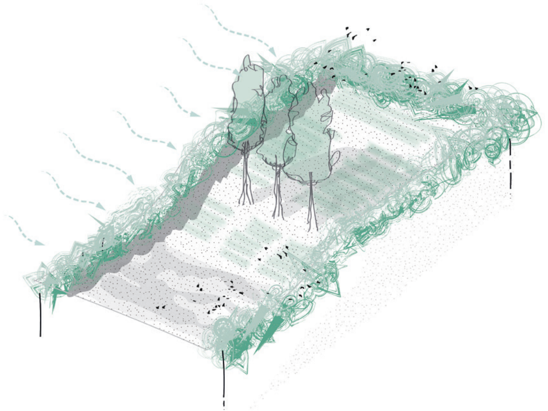
Agroforestry; considering the water system and natural dynamics - midstream



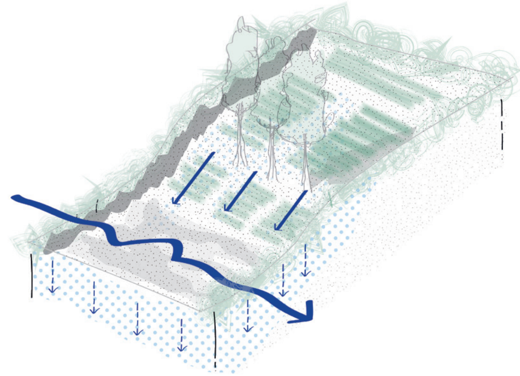

[Figure 93.] Collage of the agroforestry plot near Nakuru city. It illustrates the cropping activities and important landscape elements, like the Neem trees in the middle of the plot.



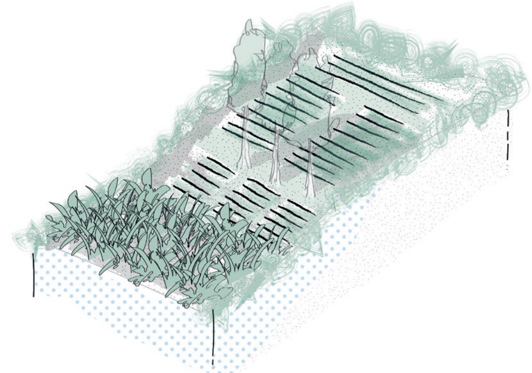
Native trees in the fields for shade



Edge of hedgerows for wind protection and support for biodiversity

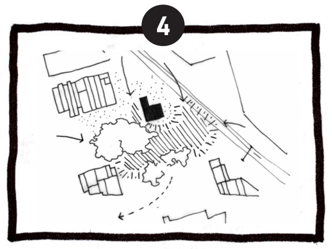


Runoff harvesting enhances soil moisture and field water supply



Promote perennial cropping and intercropping systems for resilient and diverse production

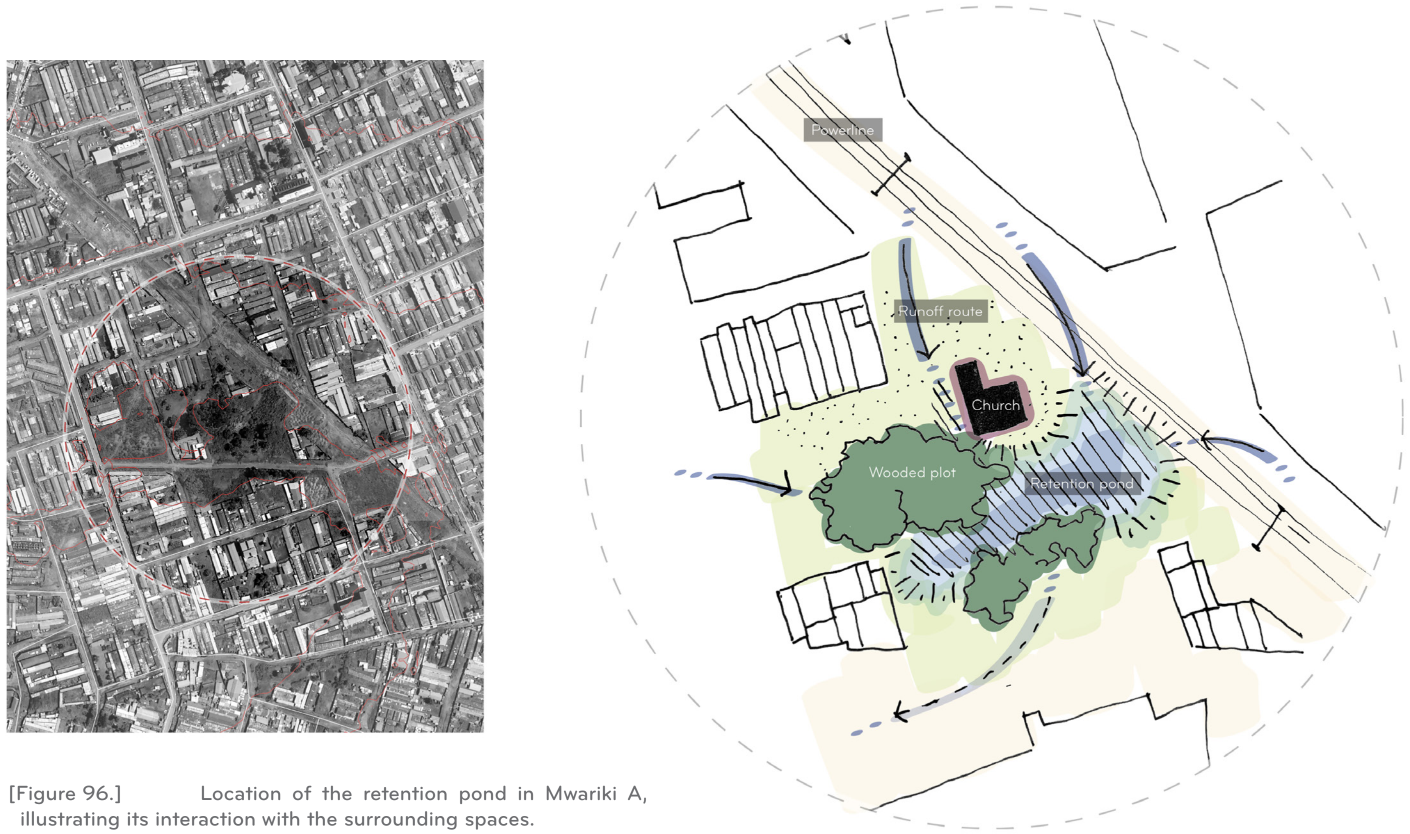
(1) Overview of agroforestry plot;, (2) Practices of intercropping, mixing perrenial and annual crops in a field; (3) Tall, multipurpose and native trees (Neem trees) planted in the middle of the field to provide shade and increase the moisture in the soil; (4) Owner of the agroforestry farm, standing in front of the entry to the agricultural fields behind.



Water retention area near communal spaces (churches or schools) in informal neighborhoods - downstream

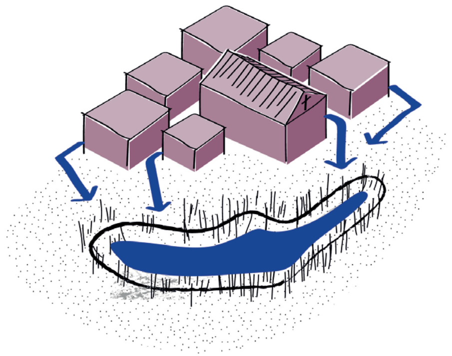
This pond is located behind a church in Mwariki A, a downstream informal neighborhood. It is not man-made but formed by a natural depression that has remained largely untouched, now functioning as a retention area during heavy rainfall events.
Runoff from surrounding plots collects here, reducing the risk of urban flooding in adjacent areas. Along its edges, several crops are cultivated, benefiting from the moisture and shade of the site. Because the pond lies next to a church, a key communal space, it reaches many residents and fosters everyday interaction between people and water, raising awareness of local hydrological dynamics.
Over time, the wet conditions and absence of disturbance have allowed a variety of plant species to establish, including a small wooded area that has evolved into a pocket of high ecological value.

The site is situated along a powerline corridor on public land, which protects it from encroachment (figure 94). These public spaces could be further connected into a water-retaining corridor, linking natural depressions like this one to form a system of green buffers. Such an approach could lower flood risks by restoring natural drainage routes while creating new spaces for water storage, vegetation growth, and community use

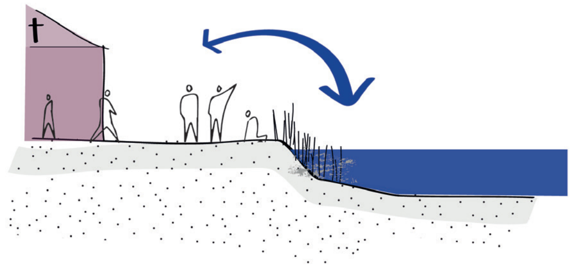


[Figure 96.] Location of the retention pond in Mwariki A, illustrating its interaction with the surrounding spaces.

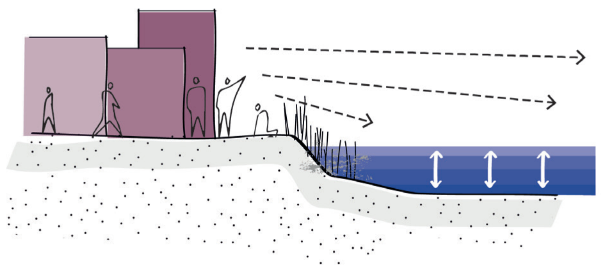
[Figure 95.] Collage of the water retention pond next to a church in Mwariki A, illustrating the impact of the retention space on its surrounding landscape.



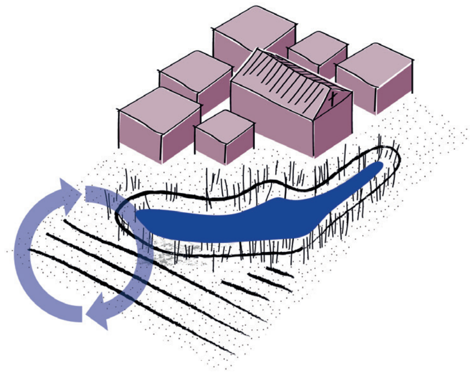
Seasonal runoff storage prevents flooding of neighboring fields



Public spaces as a possibility for interaction between human and water



Making seasonal variabilities visible to create awaraness



Function- and community-driven interventions rooted in local use and priorities

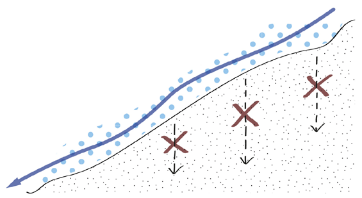
(1) Overview of the water retention pond; (2) Production of cale next to the retention pond and church; (3) Laundry hanging to dry in the frontgarden of the church, farming of diverse crops in the back; (4) Diverse wetland vegetation found in the lower parts of th retention pond, contributing to bidiversity in the area; (5) Surface runoff and drainage channel of neighboring plots are connected to the retention area, with an estimated depth of four meters.

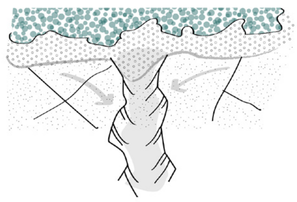
The site analysis reveals a landscape where ecological processes, hydrological dynamics, and socio-cultural realities are tightly interwoven. Seasonal surface runoff dominates Nakuru's water system, accelerated by deforestation, urban expansion, and fragile volcanic soils. This disrupted flow chain manifests as erosion upstream, infrastructural overload midstream, and recurrent flooding and water scarcity downstream. These patterns confirm the first Ecopolis pillar, flows, as the primary driver of systemic challenges in the region.
The second pillar, area, highlights how spatial development has intensified these risks. Expansion into natural drainage lines, fragmented ecological zones, and inadequate infiltration capacity have left little room for water buffering or ecological continuity. The seasonal sub-watershed exemplifies how upstream land-use changes translate directly into downstream vulnerabilities, particularly for the most exposed communities.
The third pillar, participants, shows the central role of local actors in shaping and managing space. Community groups, residents' associations, and informal initiatives often compensate for limited governmental capacity. These bottom-up efforts, together with institutional knowledge from universities and research institutes, demonstrate how locally rooted practices can inform broader strategies. Yet, the analysis also makes clear that fragmented responsibilities and unclear land ownership complicate coordinated action.
Findings from the field visit further deepen this understanding by showing how these dynamics manifest in practice. On-site observations and interviews revealed how local communities actively engage with their environment through small-scale, adaptive measures such as agroforestry, terracing, check dams, and communal retention ponds. These interventions, though modest in scale, demonstrate how locally embedded practices already contribute to delaying runoff, enhancing infiltration, and strengthening ecological and social resilience. They illustrate the potential of combining local knowledge with spatial design to build upon existing strengths within the landscape.
Taken together, the site analysis provides a multi-scalar understanding of Nakuru's socio-ecological landscape. It identifies both the vulnerabilities that must be addressed, erosion, flooding, pollution, and scarcity, and the opportunities embedded in local initiatives and institutional frameworks.
These insights provide the foundation for the design principles and strategies in the next chapter, ensuring that the proposed interventions are rooted in ecology, aligned with spatial dynamics, and embedded in local communities.

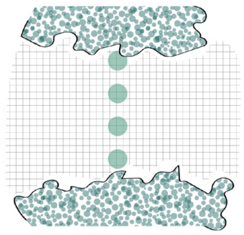
FLOW - Water flows and chains (Hydrological functioning)
In the seasonal sub-watershed, (seasonal) water flows are highly unstable. Heavy rains generate rapid runoff from the Menengai slopes, while dry periods leave communities dependent on groundwater. Pollution from waste disposal, agriculture, and inadequate sewage systems further degrades water quality. Instead of being managed in a circular chain, flows are often displaced downstream or postponed to future generations. Restoring the water chain here requires delaying runoff, improving infiltration, and creating cleaner cycles of use and reuse.

AREA - Spatial and ecological character
The sub-watershed is defined by steep slopes upstream, midstream industrial areas with limited capacity to manage runoff, and low-lying downstream neighborhoods that are densely populated and flood-prone. Land-use changes, like deforestation, urban expansion, and agricultural intensification, have reduced infiltration and fragmented ecological processes. This has weakened the natural capacity of the landscape to buffer floods, filter water, and sustain biodiversity.

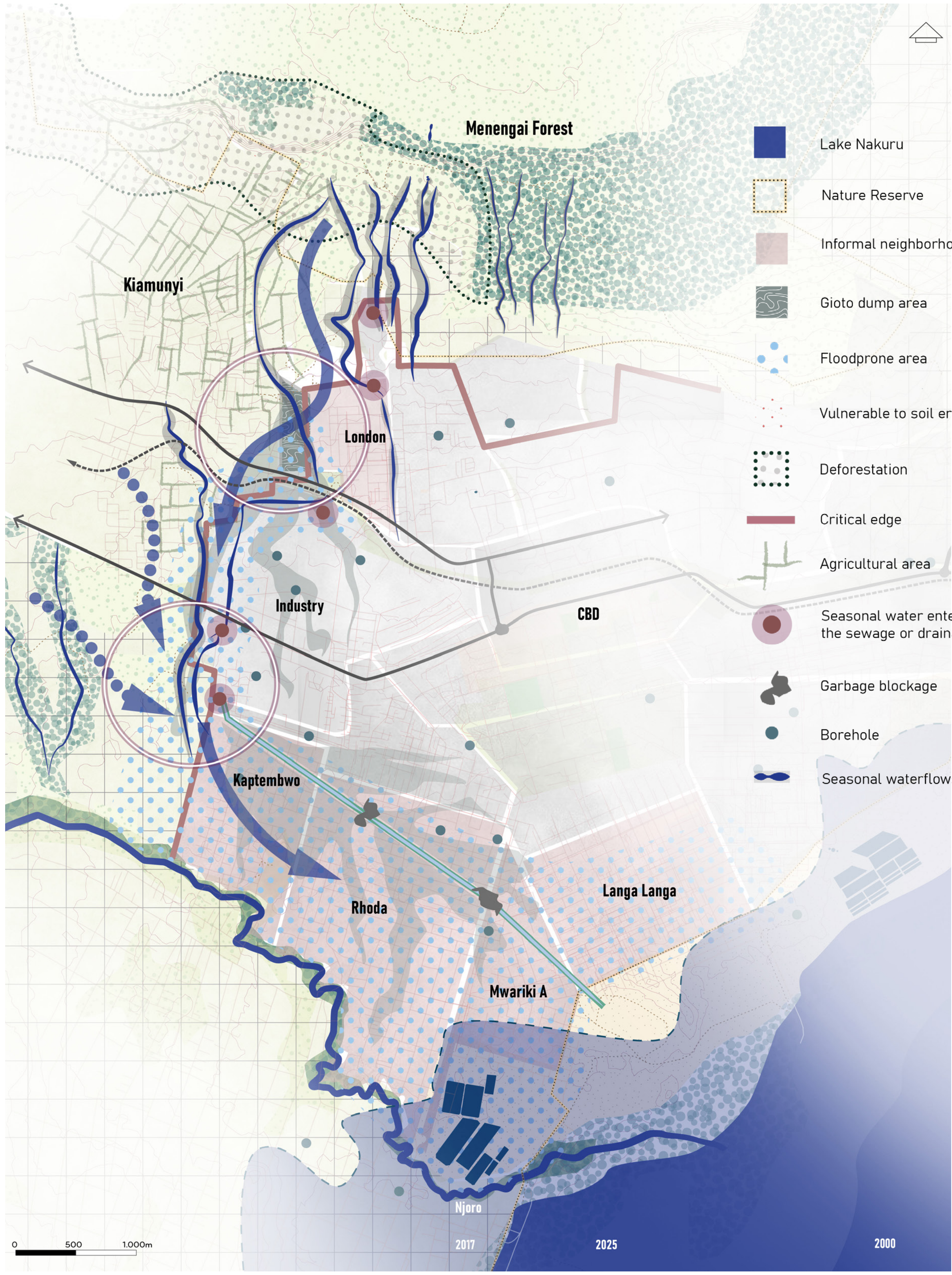
PARTICIPANTS - Social dimension and governance
The socio-cultural dimension of the sub-watershed is diverse but unevenly equipped for water-related risks. Downstream informal settlements are most vulnerable, facing flooding and pollution without adequate infrastructure. Midstream industries and institutions strongly influence water and land management, while upstream areas depend on farming and forest use under pressure of land degradation. Local initiatives exist but remain fragmented. Interventions across scales should encourage shared responsibility among these groups to strengthen socio-ecological resilience in Nakuru City.


Lack of infiltration possibilties for surface runoff

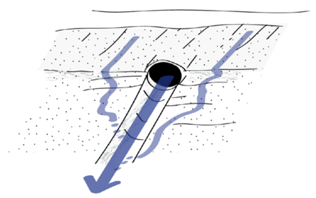

Risk of soil erosion due to deforestation and intensive agriculture

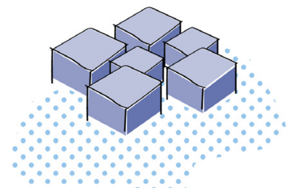

Fragmentation of natural areas

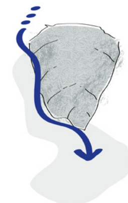
[Figure 97.] Landscape challenges



[Figure 98.] Overview of the found landscape challenges on site on the Western part of Nakuru City.


Runoff is rapidly drained through the drainage system along infrastructure


Vulnerable communities positioned in floodprone areas


Surface runoff gets polluted by waste disposal

Runoff inlet at the ridge of the Menengai Caldera, small gully formation are starting to shape the landscape (photo by author)

Designing

PART III

Native acacia tree in between eucalyptus trees - “last man standing” (photo by author)

Chapter 5. Design strategies and principles

5.1. Introduction

The design strategies and principles presented in this chapter are based on the theoretical framework and the findings from the site-analysis of the seasonal sub-watershed presented in the previous chapter. While the theoretical framework provided a theoretical strategy to approach the guiding lenses (water, ecology, and culture) and methodological tools such as the Ecopolis model (Tjallingii, 1995), the site analysis revealed how these themes manifest in Nakuru's landscape through seasonal water flows, ecological conditions, and socio-cultural dynamics.
This chapter addresses the second research question: What design principles and strategies are suitable for recharging the freshwater availability in the socio-ecological context of Nakuru City? It translates insights from theory and analysis into actionable design guidance. First, an overarching design vision and strategy are formulated at the sub-watershed scale, establishing a systemic framework to address the challenges of seasonal runoff, freshwater recharge, and ecosystem restoration. The strategy is then unpacked into layers (water, ecology and cutlure) that correspond with the guiding lenses of this research. Each layer is discussed and accompanied by suitable design principles that guide its implementation.
By linking theory and analysis, this chapter aims to developa a coherent spatial framework for context-specific, landscape-based interventions that aim to be ecologically effective, spatially coherent, and socially embedded.

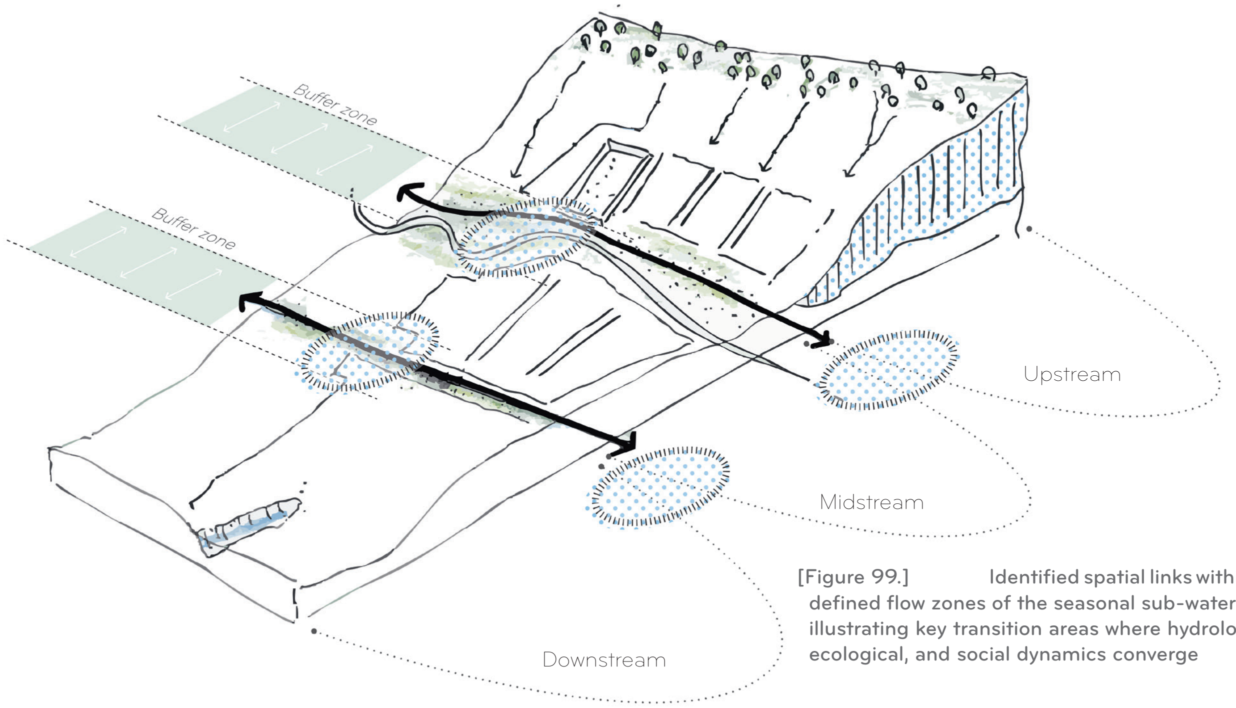
5.2. Design vision

Spatial links

From the analysis, two critical areas within the seasonal sub-watershed have been identified where water, ecological, and socio-cultural challenges converge. In this research, these are referred to as spatial links. They represent points where interventions can have the greatest systemic impact, both on restoring the water balance and on strengthening Nakuru's urban ecosystem.
These areas are defined by several conditions:
- They are highly exposed to flooding, erosion, and pollution, directly affecting multiple stakeholder groups.
- Processes occurring in these locations strongly influence the wider seasonal sub-watershed.
- They provide space and opportunity for interventions to function as buffer zones.
- They hold significant potential to recharge groundwater, mitigate runoff, and enhance social-ecological resilience.

Spatial link 1 is located at the transition from the steep upstream slopes—where seasonal rivers originate and severe erosion occurs—towards the Gioto dump and adjacent infrastructure. Here, runoff interacts with critical land uses: agricultural fields in Kiamunyi, the waste-pickers' activities in London, and the Nakuru-Sigor road and railway, which are particularly vulnerable to flooding and erosion.

Spatial link 2 is positioned along the city's edge, where large volumes of external runoff, partly from the Rift Valley Institute's grounds, enter the downstream neighborhoods after extreme rainfall (Schalkwijk, 2025). This runoff causes destruction, pollution, and recurrent flooding in Kaptembwo, Rhoda, and Mwariki A—while during dry periods, the same areas face acute water scarcity and dependence on groundwater kiosks. These dynamics intensify contamination and environmental degradation, in stark contrast with the proximity of Lake Nakuru National Park and the Njoro River, which remain essential sources of water for daily activities.



[Figure 99.] Identified spatial links within the defined flow zones of the seasonal sub-watershed, illustrating key transition areas where hydrological, ecological, and social dynamics converge

Functional zones

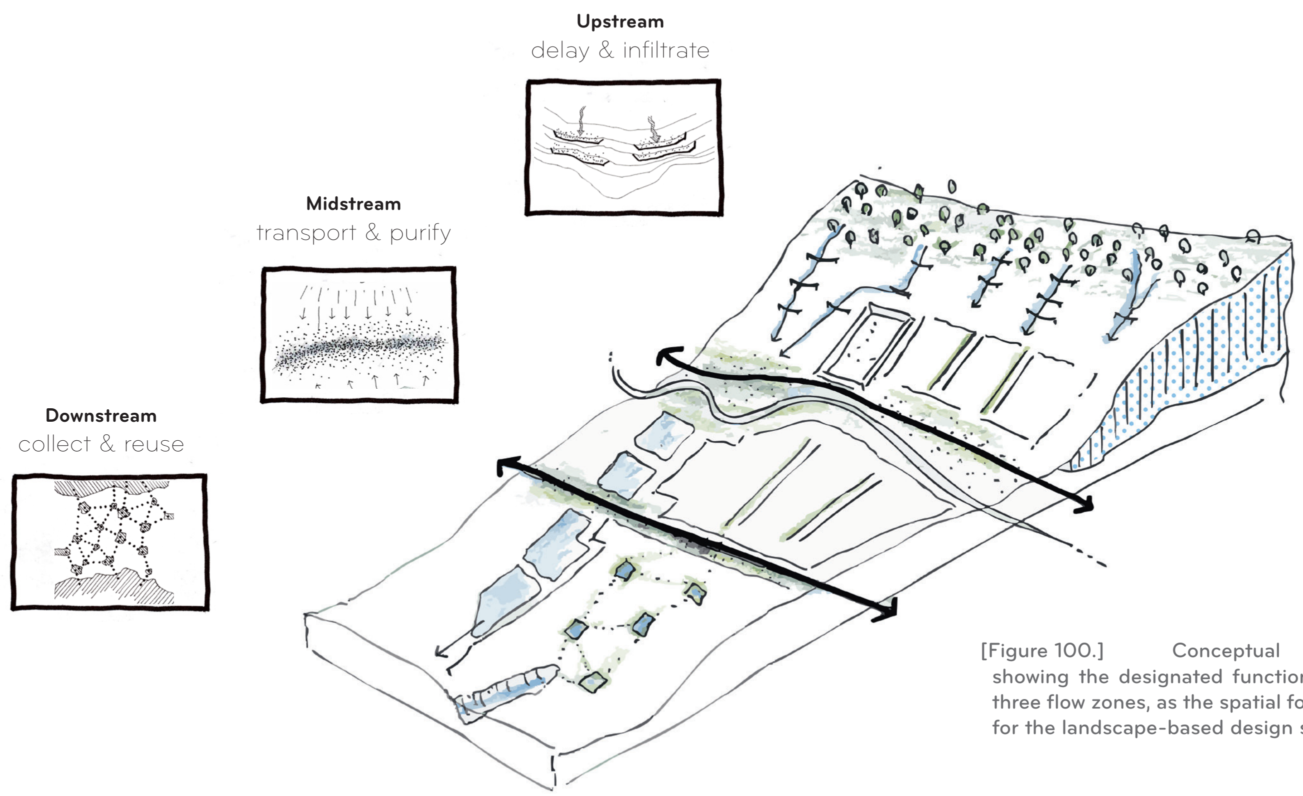
As part of the design vision, functions are designated to the flow zones based on their characteristics identified in the analysis (Chapter 4). These functions respond to abiotic and biotic conditions such as soil composition, slope steepness, vegetation cover, and hydrological behavior, as well as to land use patterns, existing infrastructure, and socio-cultural dynamics. By aligning the functions with these conditions, the design vision strengthens the ecological and social resilience of the seasonal sub-watershed and focuses on recharging groundwater while minimizing the impacts of seasonal water flows.

Upstream
The steep slopes of the Menengai Caldera and surrounding highlands are highly prone to erosion, as confirmed in the analysis of soil degradation and runoff dynamics. At the same time, the soils here have significant potential for water infiltration, and the ecological value of the Menengai Forest can be promoted by integrating gully formations as ecological corridors combined with reforestation. The designated function in this zone is to delay and infiltrate. Interventions such as terracing, agroforestry, and check dams reduce surface runoff, stabilize soils, and enhance infiltration, addressing erosion risks while supporting agricultural productivity and promoting ecological restoration. Research by Schalkwijk (2025) confirms that terracing and reforestation are effective in reducing runoff, particularly when implemented at larger scales. While small-scale applications remain limited in impact, scaling up these measures—as proposed in this design vision—can significantly strengthen ecological and hydrological resilience.

Midstream
In the midstream zone, water flows interact strongly with infrastructure and industrial land uses. The analysis highlighted how drainage channels, polluted runoff, and waste blockages are critical challenges in this zone. The designated function is to transport and purify. Interventions focus on guiding water safely through urban areas, integrating constructed wetlands and green retention corridors that reduce pollution loads while maintaining hydrological connectivity.

Downstream
The downstream neighborhoods, including Kaptembwo, Rhoda, and Mwariki A, are characterized by dense informal settlements in flood-prone areas. The analysis emphasized their vulnerability to flooding, pollution, and inadequate infrastructure. In this context, the designated function is to collect and reuse. Retention areas near communal spaces, water harvesting systems, and stormwater reuse can reduce flood risks while providing much-needed water resources to vulnerable communities. Evidence from Schalkwijk (2025) demonstrates that retention areas are the most effective intervention in reducing flood volumes, making their implementation relevant for this zone.

Together, these designated functions translate the analytical findings into a coherent design vision. They establish a framework in which interventions across the flow zones complement one another: upstream measures reduce pressures, midstream strategies improve water quality and flow, and downstream interventions enhance resilience and water availability for the most vulnerable groups. Across all zones, retention areas emerge as a particularly effective measure (Schalkwijk, 2025). Their integration at multiple locations throughout the watershed creates a unifying backbone for managing seasonal flows, buffering extreme events, and securing freshwater availability. In this way, seasonal water flows can be transformed from a challenge into a potential solution for the area's water-related problems.



[Figure 100.] Conceptual diagram showing the designated functions of the three flow zones, as the spatial foundation for the landscape-based design strategy

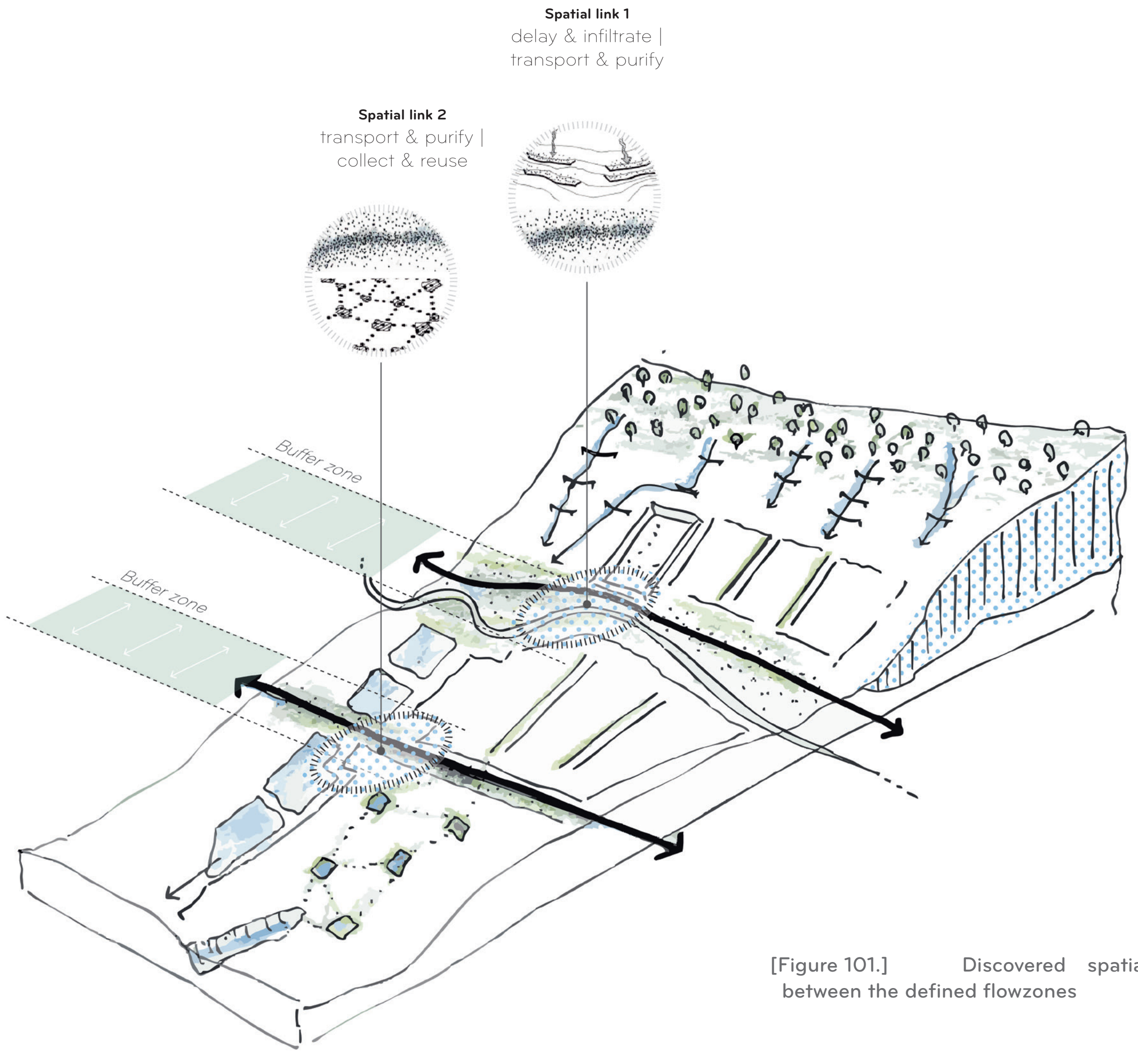
The design strategy builds directly on the flow zone functions and the identification of two spatial links. While the functional zones define the roles of upstream, midstream, and downstream areas, the spatial links highlight where these roles overlap and where interventions can generate the greatest systemic impact. Together, they provide the framework for positioning landscape interventions that strengthen ecological processes and local involvement, reduce floodrisks, and enhance water availability.

Spatial Link 1: Upstream–Midstream
At the transition from the steep upstream slopes to the midstream urban fringe, erosion, polluted runoff, and vulnerable infrastructure converge. This link therefore combines the upstream focus on delaying and infiltrating with the midstream need to transport and purify. Proposed interventions include terracing and agroforestry to stabilize soils, ecological corridors along gully formations, and retention systems that reduce erosion and pollution before water enters the city.

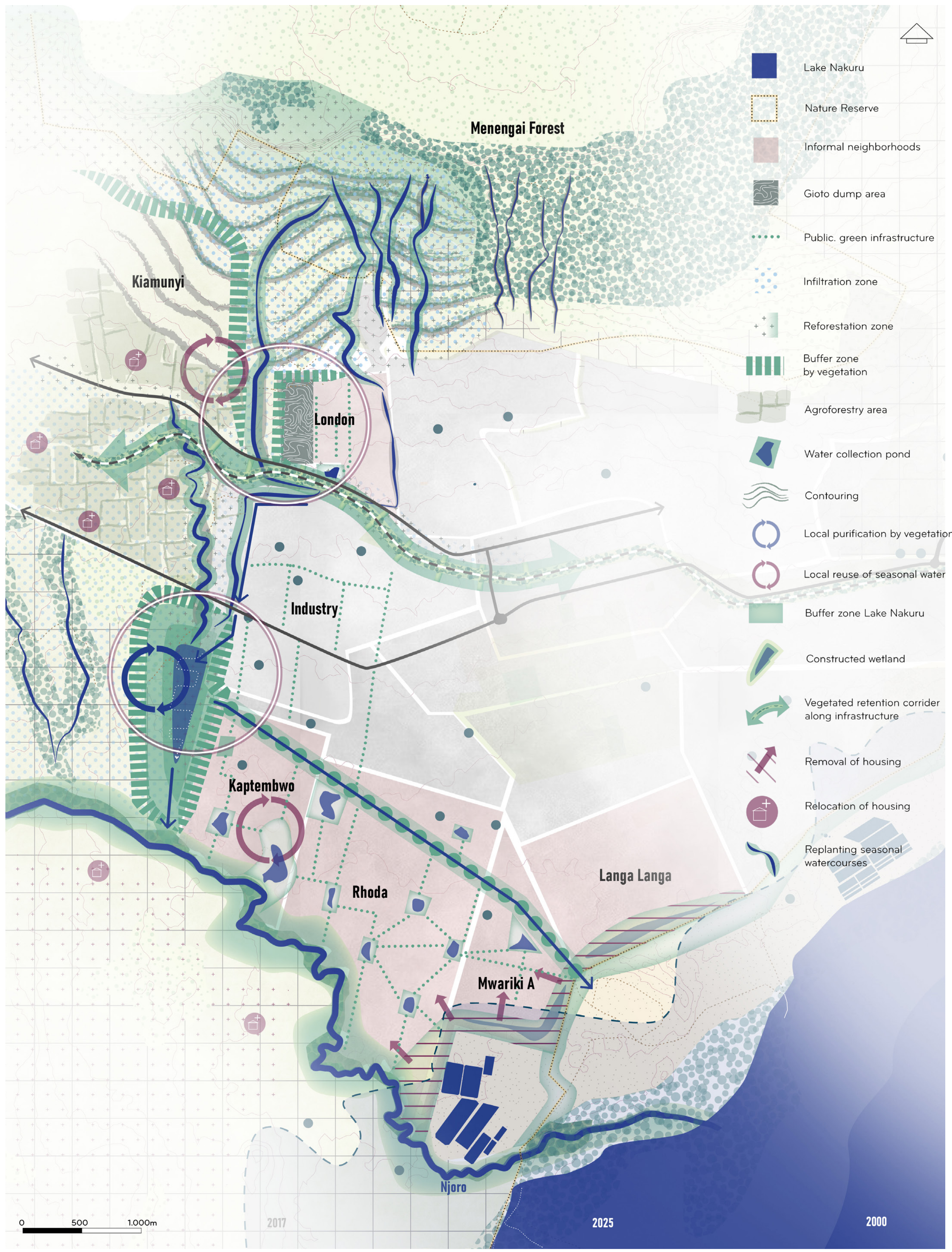
Spatial Link 2: Midstream–Downstream
Along the city edge, runoff from peri-urban catchments enters dense downstream neighborhoods, where flooding and water scarcity are most acute. This link integrates the midstream function of transport and purify with the downstream goal of collect and reuse. The strategy proposes wetlands to buffer and filter runoff, complemented by smaller retention areas near schools and churches that combine hydrological, ecological, and communal functions.

Overall Strategy
The map of landscape potentials (right) visualizes how these interventions fit within the broader design strategy: reforestation and ecological corridors in the upstream, infrastructural retention and purification systems in the midstream, and communal water storage and reuse in the downstream. In extreme cases, such as Mwariki A, where exposure to multi-directional flood risks is unsustainable, the strategy also anticipates long-term relocation to safer areas within the watershed on higher grounds.

By working across flow zones and anchoring interventions at the spatial links, the strategy translates the analytical findings into an integrated and context-specfic spatial framework. It demonstrates how seasonal water flows can be managed not only to reduce risks but also to restore ecological functions and provide new opportunities for communities at the Western part of Nakuru city.



[Figure 101.] Discovered spatial links in between the defined flowzones



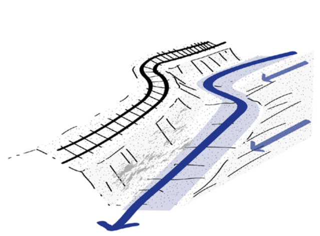
[Figure 102.] Discovered spatial links in between the defined flowzones

Water

The water layer forms the backbone of the design strategy, linking the designated functions of the flow zones, delay and infiltrate upstream, transport and purify midstream, and collect and reuse downstream, into one coherent system. It addresses the imbalance between wet and dry seasons by redistributing, storing, and reusing seasonal flows across the sub-watershed, aiming to strengthen runoff management, groundwater recharge, and water quality throughout the year.
In the upstream zone, interventions focus on slowing and guiding runoff before it accelerates downslope. Existing infrastructural lines such as roads and drainage corridors are repurposed as contouring elements that delay and direct water, turning these structures into part of the hydrological network. Vegetated buffers and terraced slopes further enhance infiltration and stabilize soils, supporting the designated function of "delay and infiltrate."
Moving midstream, where water flows intersect with dense urban and industrial land uses, the focus shifts to purification and separation. Here, polluted runoff is intercepted at the source, especially near the Gioto dump and industrial zones, to prevent contaminants from spreading through the watershed. Constructed wetlands and natural depressions are integrated along drainage lines to filter and cleanse runoff, aligning with the "transport and purify" function of this flow zone.
In the downstream areas, where runoff naturally accumulates, the strategy emphasizes retention and reuse. Multifunctional retention zones, such as ponds, wetlands, and reactivated peri-urban plots, are designed to collect and store seasonal water while supporting productive and communal uses. These spaces provide essential buffers against flooding and

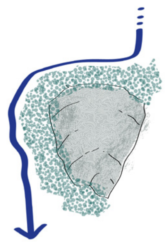
[Figure 103.] Design principles for the guiding lense "water"

1



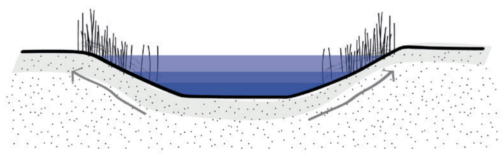
Infrastructural lines for slowing down and transporting runoff

2



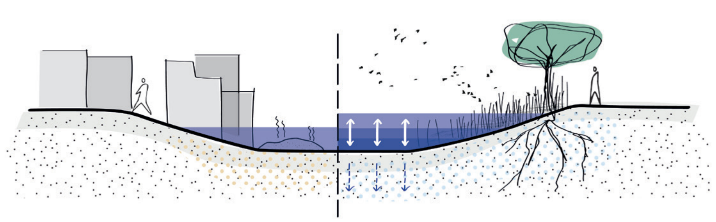
Disconnect runoff from main waste resources

3



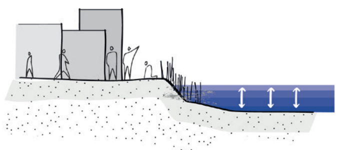
Slow edges that sustain cyclic flooding

4



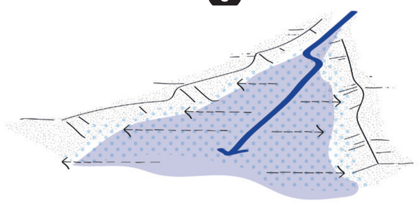
Reactivating abandoned places for retention and infiltration

5



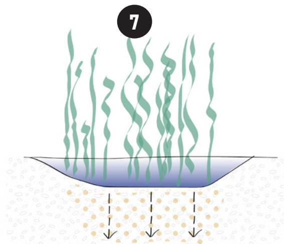
Allowing cyclic flooding in urban areas

6

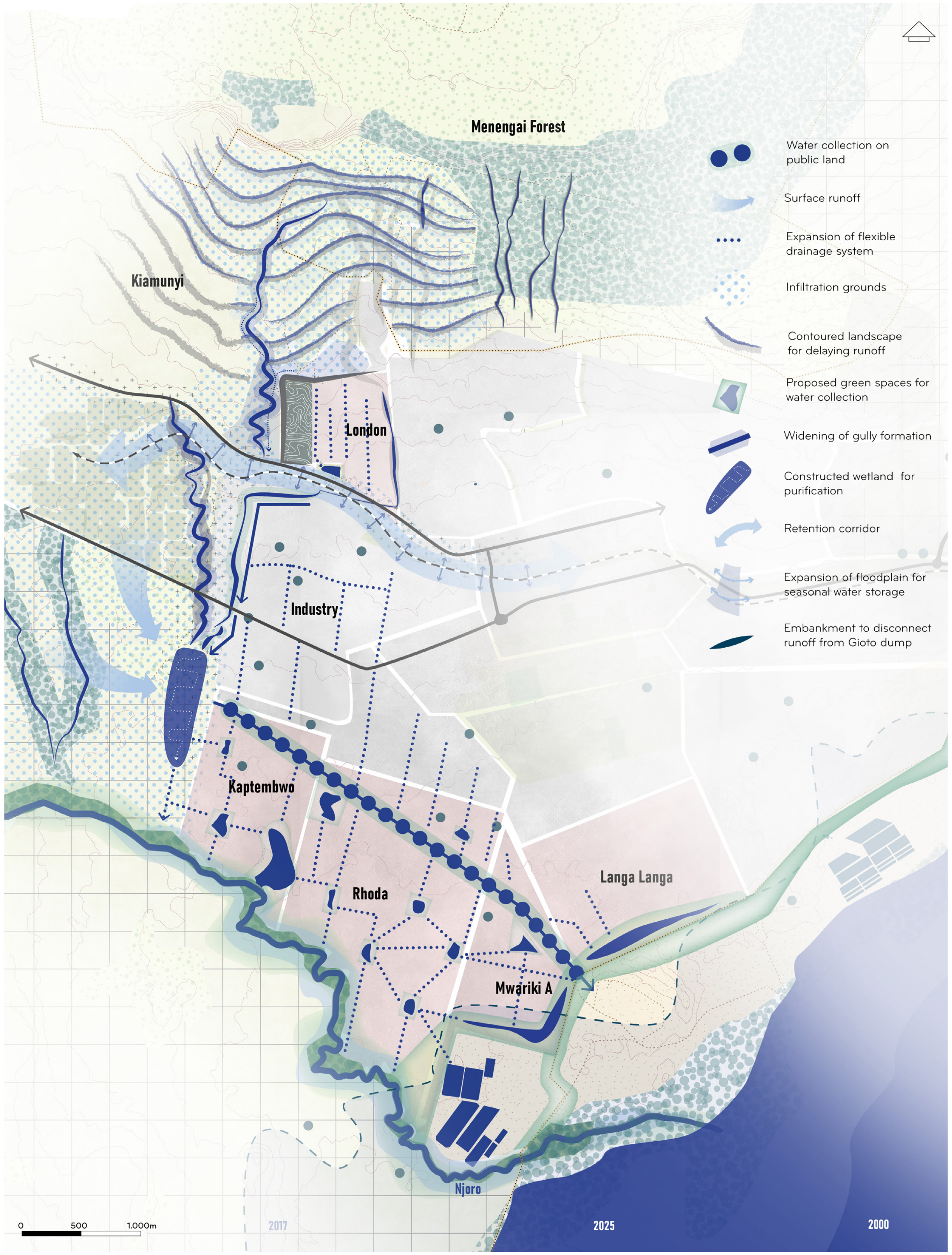


Expanding floodpains for seasonal water storage

7



Integrating wetlands in urban context for local treatement of runoff and waste water



[Figure 104.] Overview of the water layer of the design strategy

Ecology

The ecology layer focusses on strengthening the connection between soil, vegetation, and water across the seasonal sub-watershed. It builds on existing natural structures to restore degraded landscapes, enhance biodiversity, and create spaces for water retention and habitat regeneration. Gully formations are transformed into ecological corridors that stabilize soils and guide vegetation succession, while natural depressions and underused plots are reimagined as multifunctional zones supporting both ecological and social functions.

In the upstream areas, steep volcanic slopes are reforested with native species that delay runoff, stabilize soils, and recharge groundwater. Eroded agricultural zones are gradually withdrawn from cultivation to allow natural regeneration, while surrounding farmland is restructured through agroforestry and terracing. These landscape-based practices align production with natural processes, improving hydrological function and supporting local livelihoods.

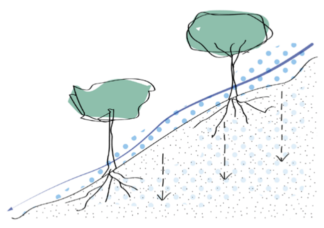
Within the midstream zone, where urban and agricultural uses meet, degraded slopes and gullies are restored as vegetated corridors that link fragmented green spaces. These corridors reduce erosion, improve infiltration, and connect ecological networks between the city and rural surroundings. Vegetation belts along roads and drainage lines serve as buffers that limit encroachment and pollution while reinforcing ecological continuity across the urban-rural gradient.

Further downstream, low-lying areas and depressions are activated as multifunctional ecological zones that combine habitat creation with water storage. Productive vegetation, such as multipurpose trees and perennial crops, is integrated into communal and peri-urban areas, offering both ecological value and social benefit. A natural buffer between Lake Nakuru and adjacent neighborhoods relieves urban pressure on the remaining natural landscape and protects its ecological integrity.

Across all flow zones, the ecology layer connects fragmented patches into continuous green structures that adapt to seasonal dynamics. By embedding natural processes within the urban fabric, it restores the balance between city and nature, transforming degraded land into an active, biodiverse, and resilient watershed system.

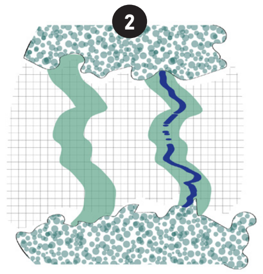
[Figure 105.] Design principles for the guiding lense "ecology"

1



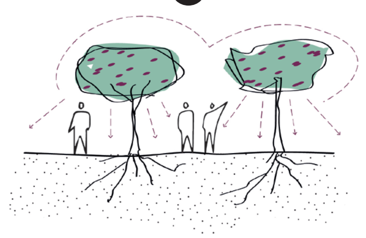
Create infiltration capacity on volcanic grounds | Natural zone for delaying runoff and soil stabilization

2



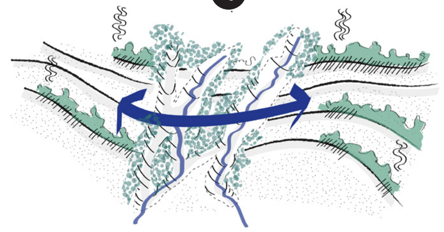
Connect and expand green areas by replanting seasonal watercourses

3



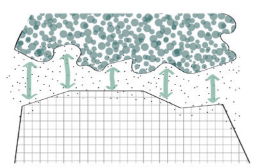
Productive vegetation in the urban context for community benefit

4



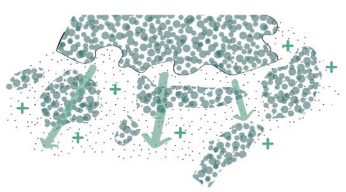
Create space, resilience, and adaptability to seasonal variations through (native) vegetation.

5



Buffer between protected nature reserves and urban areas

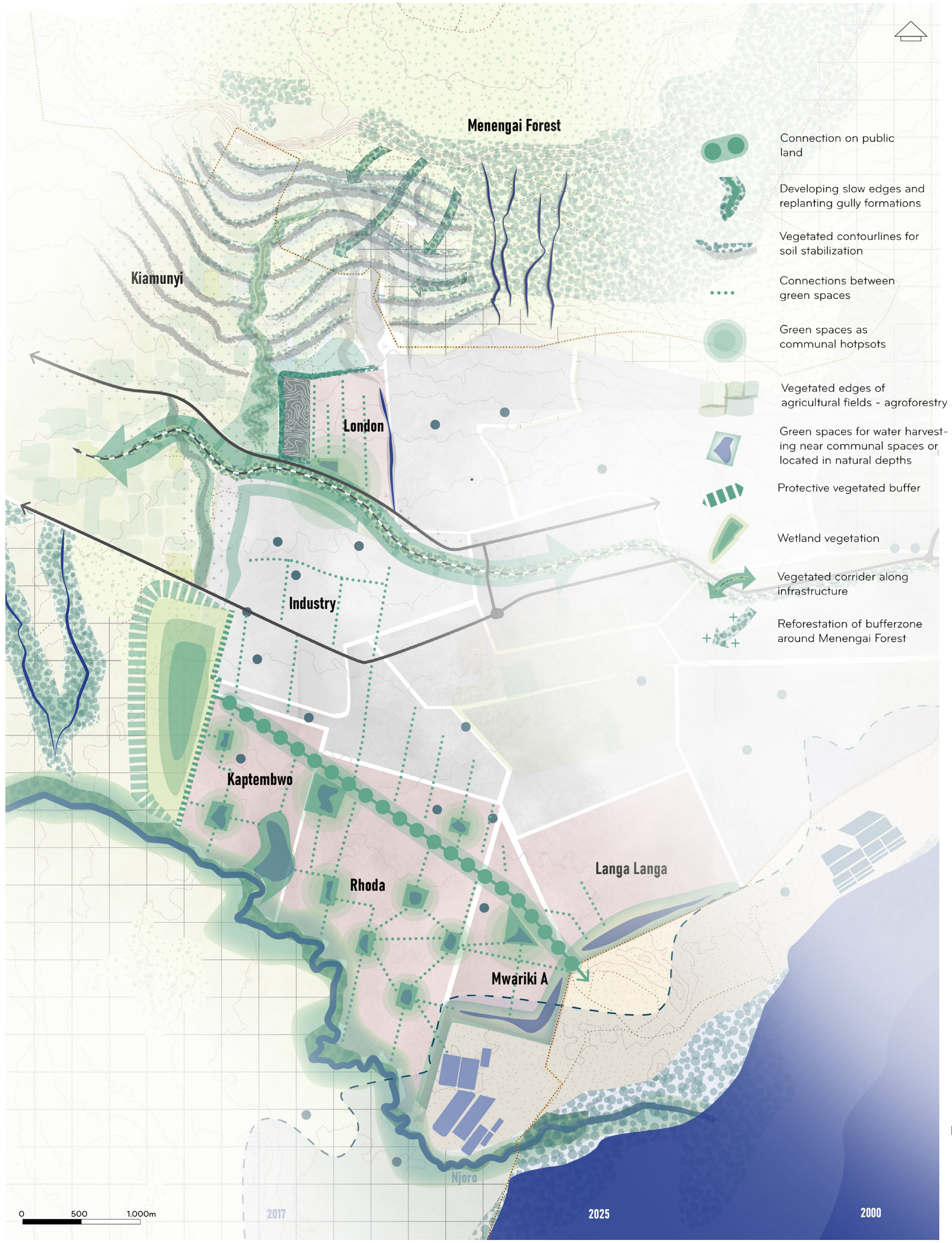
6



Reforestation of slopes >30%

7

Creating zones for ecological succesion in urban context



[Figure 106.] Overview of the ecology layer of the design strategy

Culture

The socio-cultural layer emphasizes the active role of communities in shaping and maintaining water-sensitive landscapes. It strengthens the relationship between people and seasonal water flows by creating awareness, promoting shared responsibility, and ensuring equitable access to green-blue infrastructure. Addressing the vulnerability of downstream settlements, this layer integrates social structures and cultural spaces into the broader ecological and hydrological systems to foster long-term stewardship and engagement.

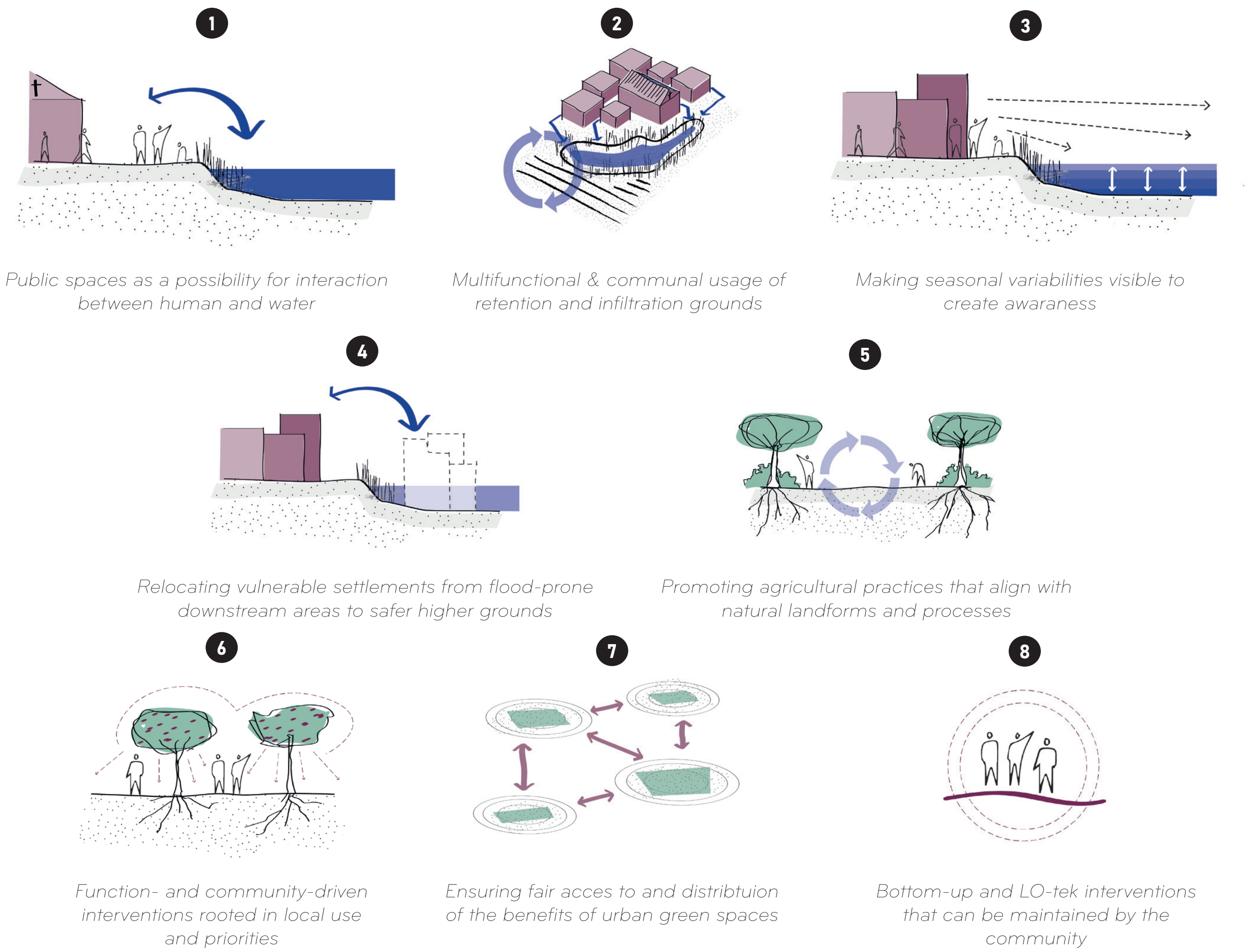
Across the watershed, the importance of public spaces is recognized and reinforced, particularly downstream, where local communities play a leading role in managing daily life. Schools, churches, and communal grounds are reactivated as places for interaction between people and water. These sites serve dual purposes: functioning as seasonal retention areas that temporarily store water while providing shade, recreation, and education. By making seasonal variability visible and tangible within these spaces, the design raises awareness of local water dynamics and builds community resilience.

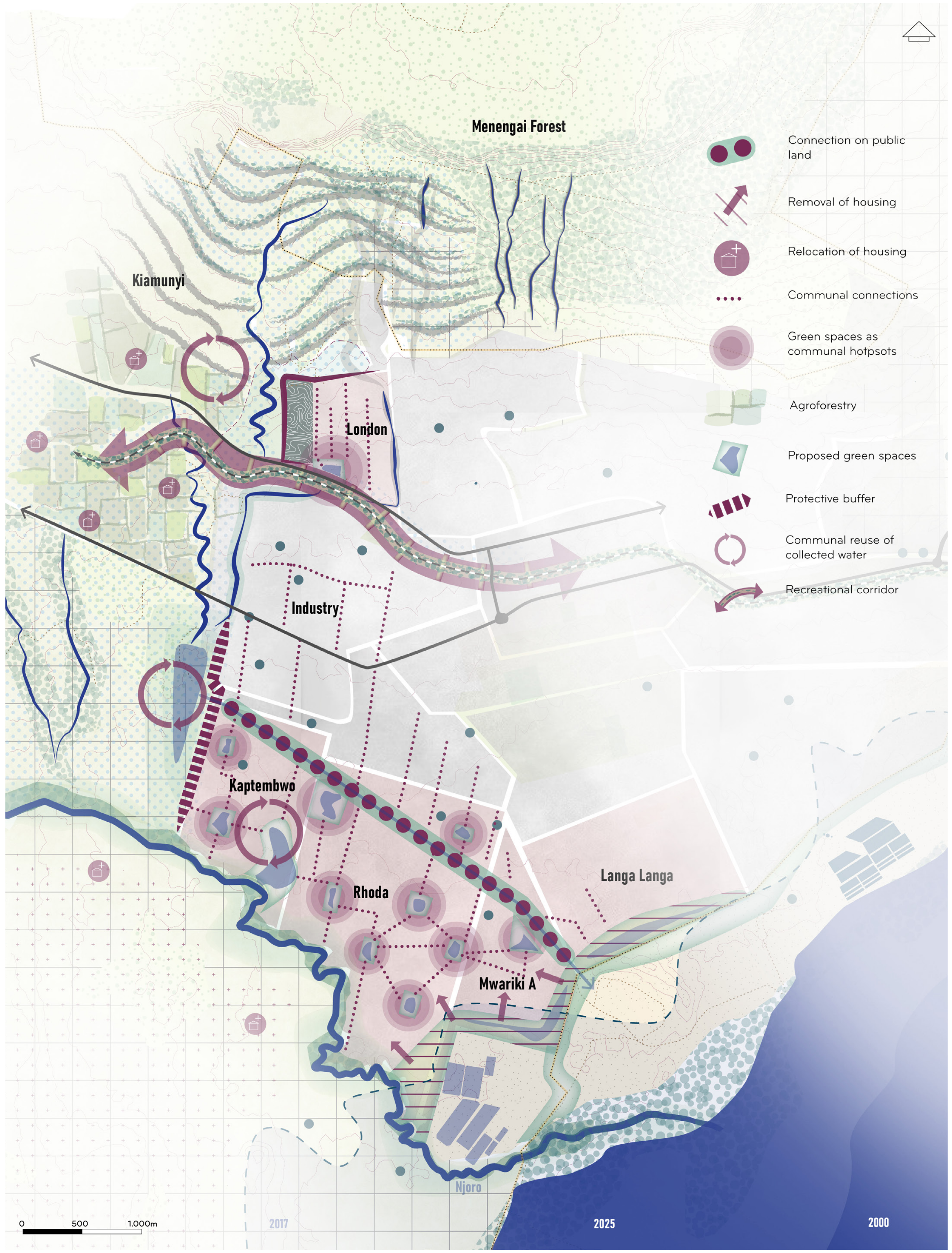
In the most vulnerable downstream zones, the strategy proposes a gradual relocation of settlements from flood-prone areas to safer, higher ground. New relocation sites are planned near green-blue networks, ensuring access to water, fertile soil, and shared public space. Meanwhile, vacated areas are repurposed as multifunctional retention zones, combining ecological restoration with social benefit.

Throughout the watershed, agricultural practices are aligned with natural processes. Farmers are encouraged to adopt methods that follow the landscape, such as contouring, agroforestry, or adapting to seasonal flooding, to improve soil health, regulate runoff, and secure livelihoods. Grounding interventions in local knowledge and priorities ensures long-term adoption, while equitable access to green and blue spaces strengthens social cohesion.

Finally, the strategy promotes bottom-up and Lo-TEK initiatives, empowering communities to manage and maintain interventions through locally tested and familiar methods. By embedding social structures within the spatial design, the socio-cultural layer not only supports water management but also reinforces belonging, cooperation, and shared responsibility, key qualities of a resilient and inclusive urban landscape.

[Figure 107.] Design principles for the guiding lense "culture"





[Figure 108.] Overview of the socio-cultural layer of the design strategy

Retention area downstream, giving shelter to a great variety of plant species (photo by author)

Chapter 6. Design implementation

6.1. Introduction

This chapter translates the design vision and concept into concrete a concrete design outcome for the upstream zone of the seasonal sub-watershed. Building on the defined functional principles (delay & infiltrate, transport & purify, and collect & reuse) the focus here is on how these design principles can be implemented through site-specific interventions. The approach connects natural landscape structures, such as gullies and depressions, with social and productive functions, ensuring that water management measures also strengthen ecological resilience and community well-being.

The implementation is structured into three parts: agricultural changes, gully rehabilitation, and the retention corridor. Each part contains interventions that operate across different scales, from household practices to regional planning, reflecting the multi-layered strategy discussed earlier. Together, they form a coherent design outcome that addresses runoff management, groundwater recharge, and the integration of ecological and social functions in Nakuru's urban landscape.

6.2. Design concept

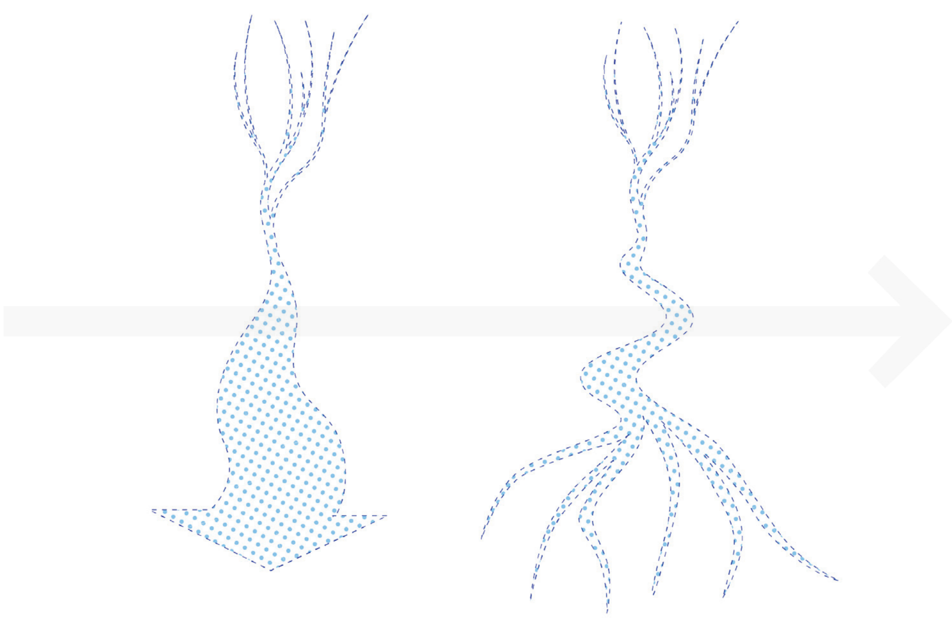
Overall Goal
The design concept aims to transform the movement of surface water, from a condition of saturation, where water accumulates in specific locations, to one of distribution, where flows are gradually dispersed across the watershed. This shift reduces concentrated flooding, slows runoff toward Lake Nakuru, and increases infiltration opportunities to support groundwater recharge and restore the overall water balance.

Desired Effect
By redistributing and slowing surface water, the concept seeks to reduce flood risks, enhance water availability during dry periods, and restore hydrological stability across the watershed. The goal is for water to reach Lake Nakuru in a delayed, controlled manner while maximizing infiltration and minimizing pollution throughout the system.

Integration of Functions
Central to this concept is the integration of water management with ecological and social functions. Retention, purification, and reuse of water are not treated as isolated technical measures but as opportunities to strengthen biodiversity, create community spaces, and build social-ecological resilience. By linking hydrological processes with ecological restoration and community use, the strategy promotes multifunctional systems that work across spatial and temporal scales.

from **saturation** to **distribution**

Focus on the capacity of the landscape



[Figure 109.] Schematic drawing of the overall goal of the design concept.

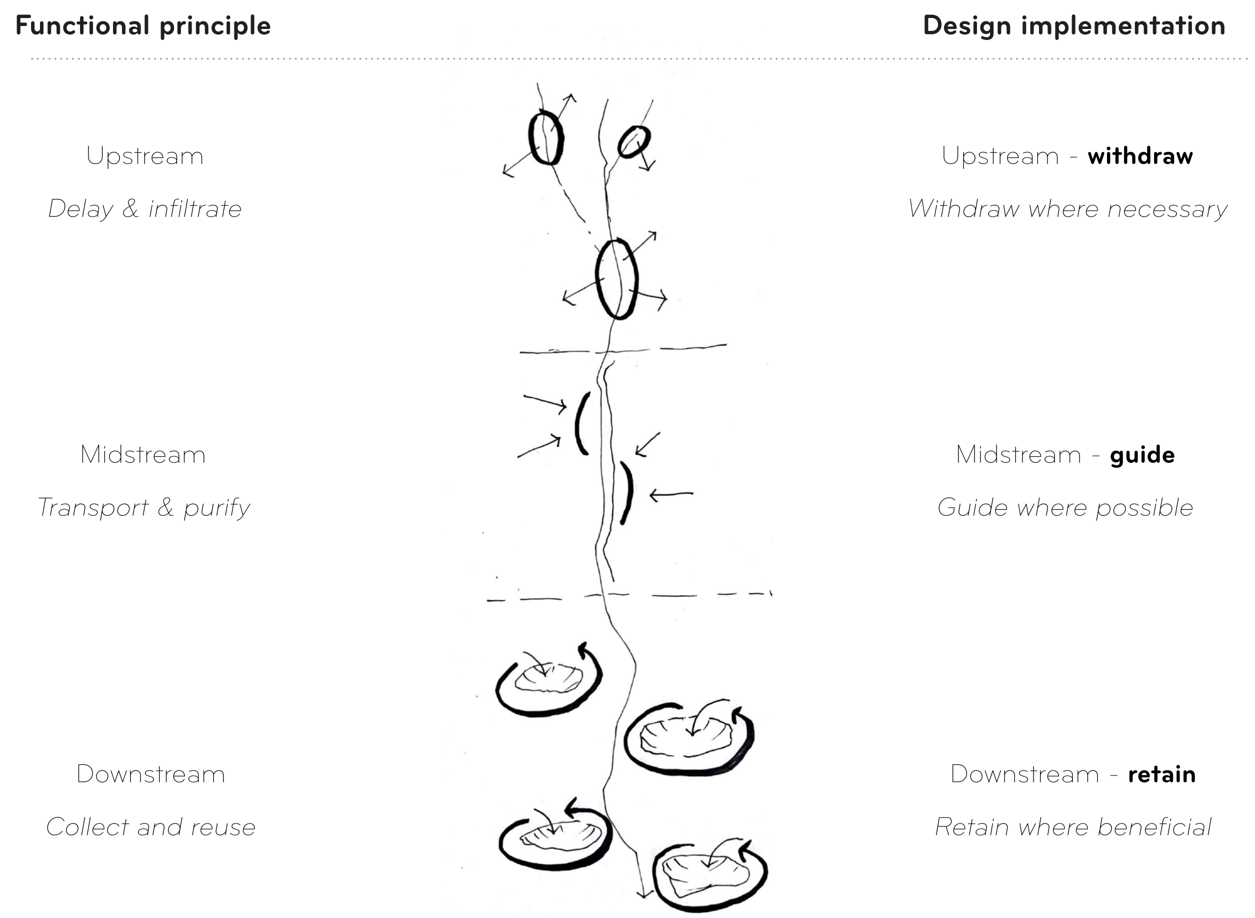
Core Design Concept
The core idea is to reinvent natural depressions and runoff routes as gravity-based retention and purification systems. These landscape features slow, filter, and reuse runoff for both ecological restoration and social benefit. They form the structural backbone of the design, turning gullies, wetlands, and seasonal drainage lines into functional components of a self-regulating water network.

Connection to the Design Vision
This concept directly aligns with the overarching design vision, which works with defined upstream, midstream, and downstream zones of the seasonal sub-watershed. Each flowzone performs a specific function and is paired with a corresponding design motive to guide the implementation, as shown in figure 110.

Upstream – withdraw, retaining water to enhance infiltration and prevent erosion;
Midstream – guide, directing flows along natural or restored pathways;
Downstream – retain, storing and reusing water for ecological and social benefit.

Together, these actions translate the broader watershed vision into tangible, place-based interventions that balance ecological processes, reduce flood risks, and strengthen community resilience.

Reinventing natural depressions and runoff routes to enable gravity-based retention and purification of runoff for ecological and social use



Different strategy for each zone due to variations in the natural landscape, its spatial functions and social dynamics

[Figure 110.] Schematic overview of the functions and design directions that will be established in each flowzone and along the runoff lines in the area.

Spatial assessment

For the design phase, Spatial Link 1, located in the upstream zone, has been chosen as the focus for the designing phase, testing interventions and detail development.

Reasons for selection:

- *Balanced stakeholder presence*

Civil, public, and private interests are all represented in this area (see Chapter 4, Stakeholder Analysis).

- *Multi-scalar relevance*

Stakeholder groups in this zone operate on different scales, allowing the design strategy and principles to be tested across multiple levels of implementation.

- *Groundwater recharge potential*

The upstream zone offers the highest potential for groundwater recharge due to soil properties and already existing infiltration areas. Additional opportunities exist to extend ecological corridors into the urban fabric through nearby gully formations. Reducing the runoff volume and cutting off waste sources at this stage also creates immediate downstream benefits.

- *Critical pollution hotspot*

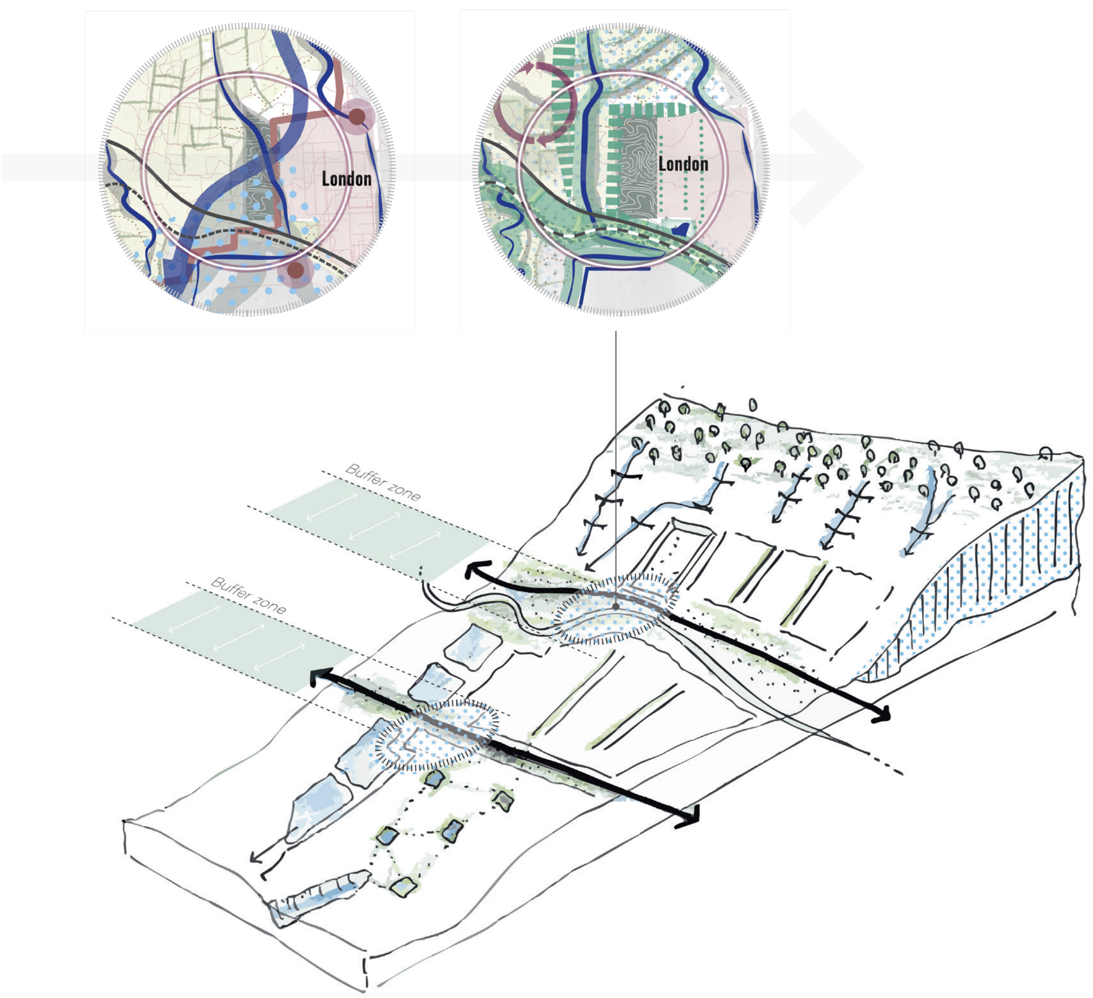
The Gioto dump, Nakuru City's largest landfill, is located in this area. Runoff flows through the site, spreading waste downstream, while wind spreads out waste across the area. Addressing this hotspot can significantly reduce pollution further along the sub-watershed.

- *Opportunity for systemic impact*

To start the restoration of the water balance and prevent further ecological degradation, a large-scale, visible intervention is needed that engages communities while operating across different scales. It can stimulate local communities to implement interventions on smaller scales and contribute to the a healthy system.

- *Institutional and financial feasibility*

Public land and the presence of government institutions responsible for water resources in Nakuru increase the potential for implementation in this area. With proper returns for stakeholders, such as the collection of rainwater or strategic logging, financial feasibility becomes achievable, as does the opportunity of employing local youth.



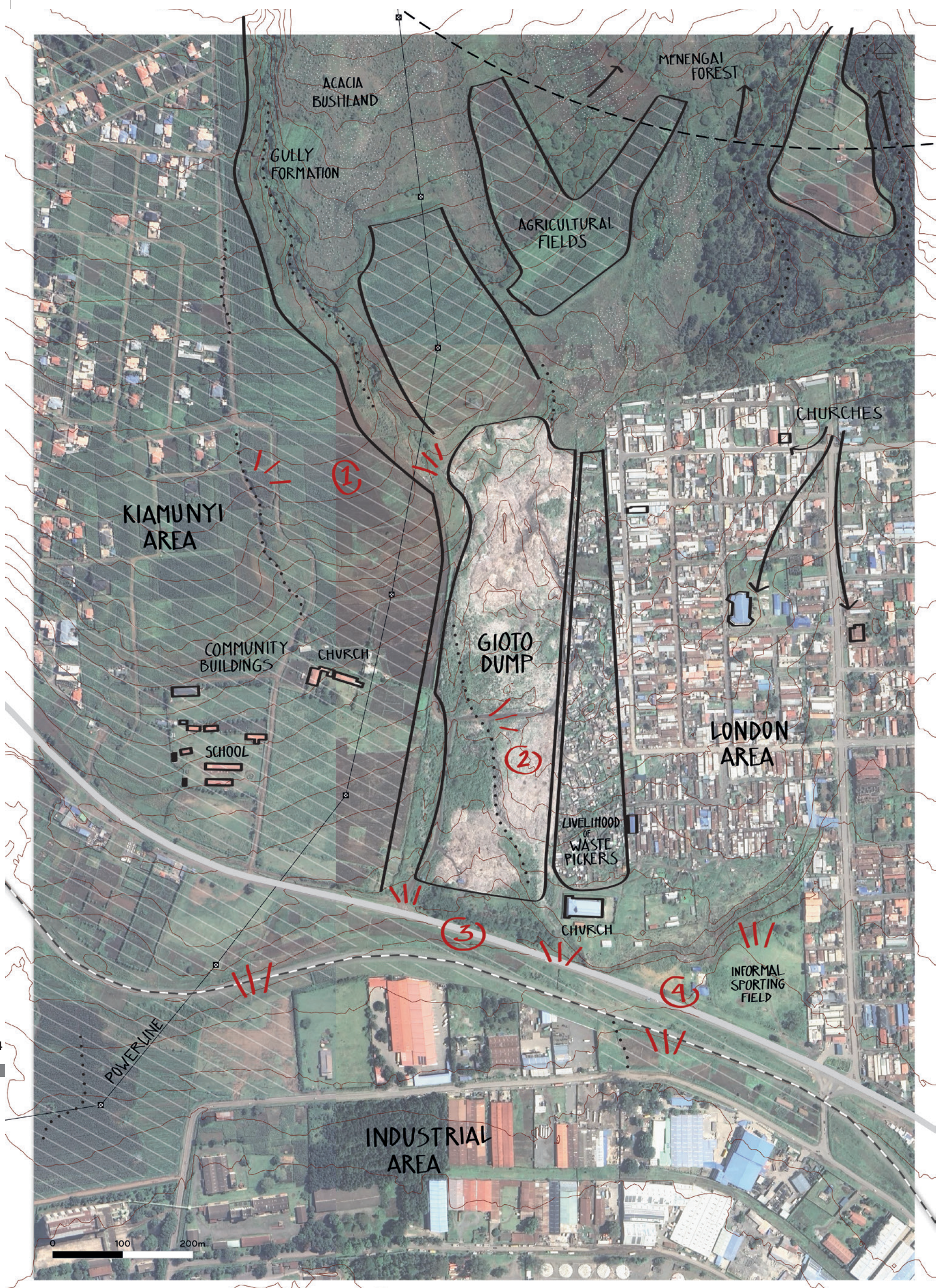
[Figure 111.] Challenges and potentials that have been found in the upper spatial link, that have let to the spatial assesment for a detailed design.

[Figure 112.] Arieal view of the upstream zone in the seasonal sub-watershed.

The upstream zone combines critical ecological, social, and infrastructural functions, while also highlighting several pressing challenges revealed in the analysis. The map presents key landscape elements such as the Gioto dump, gully formations, and surrounding settlements, alongside bottlenecks caused by erosion, pollution, and flood risks. Together, these conditions underline why this area is highly relevant for targeted interventions and what landscape elements can be strategically addressed in the design process

Relevant landscape elements and functions

• ***Menengai Forest & gully formations*** – potential ecological corridors and infiltration zones.
• ***Agricultural fields (Kiamunyi area)*** – productive land use but vulnerable to erosion and runoff.
• ***Agricultural fields (Menengai Forest)*** – productive land use (partly on public land), interrupting the Acacia bushlands and forest areas at this part of the hillside.
• ***Gioto dump*** – largest waste site of Nakuru, intersected by seasonal water flows.
• ***London area (informal settlement)*** – densely populated, highly exposed to polluted runoff.
• ***Powerline*** – located on public grounds
• ***Informal sporting field*** – a large amount of runoff from the London area enters this region as it can be classified as a natural depression. In addition, the area has a multifunctional purpose as an informal meeting and sporting place.
• ***Industrial area & infrastructure (railway and Nakuru–Sigor road) –*** critical infrastructure crossing runoff lines.
• ***Community facilities (churches, schools, sports field)*** – central social functions positioned along runoff routes.



Key bottlenecks identified:

1. Severe erosion on steep upstream slopes, feeding into gullies, causing damage to productive agricultural fields; Deforestation for agricultural land use, enhancing runoff patterns and reducing the ecological value of Menengai Forest.
2. Pollution from Gioto dump; spreading waste downstream through seasonal flows and wind.
3. Flood risks around London area and infrastructure due to uncontrolled runoff and blocked drainage; Caused by poor waste management and intensifies downstream impacts.
4. Conflicting land uses (agriculture, settlement, waste picking, industry) increase vulnerability and complicate management.

[Figure 113.] Relevant landscape elemants in the upstream zone to the final design outcome

This map shows a rough estimation of natural depressions in the upstream area, based on the DEM and overlapped with estimated water flow directions. These low-lying areas indicate where runoff naturally converges, making them key locations for retention, infiltration, and purification. By linking them to the design concept, they guide the placement of interventions such as wetlands and buffer zones. In this way, the existing topography directly informs the final design outcome.

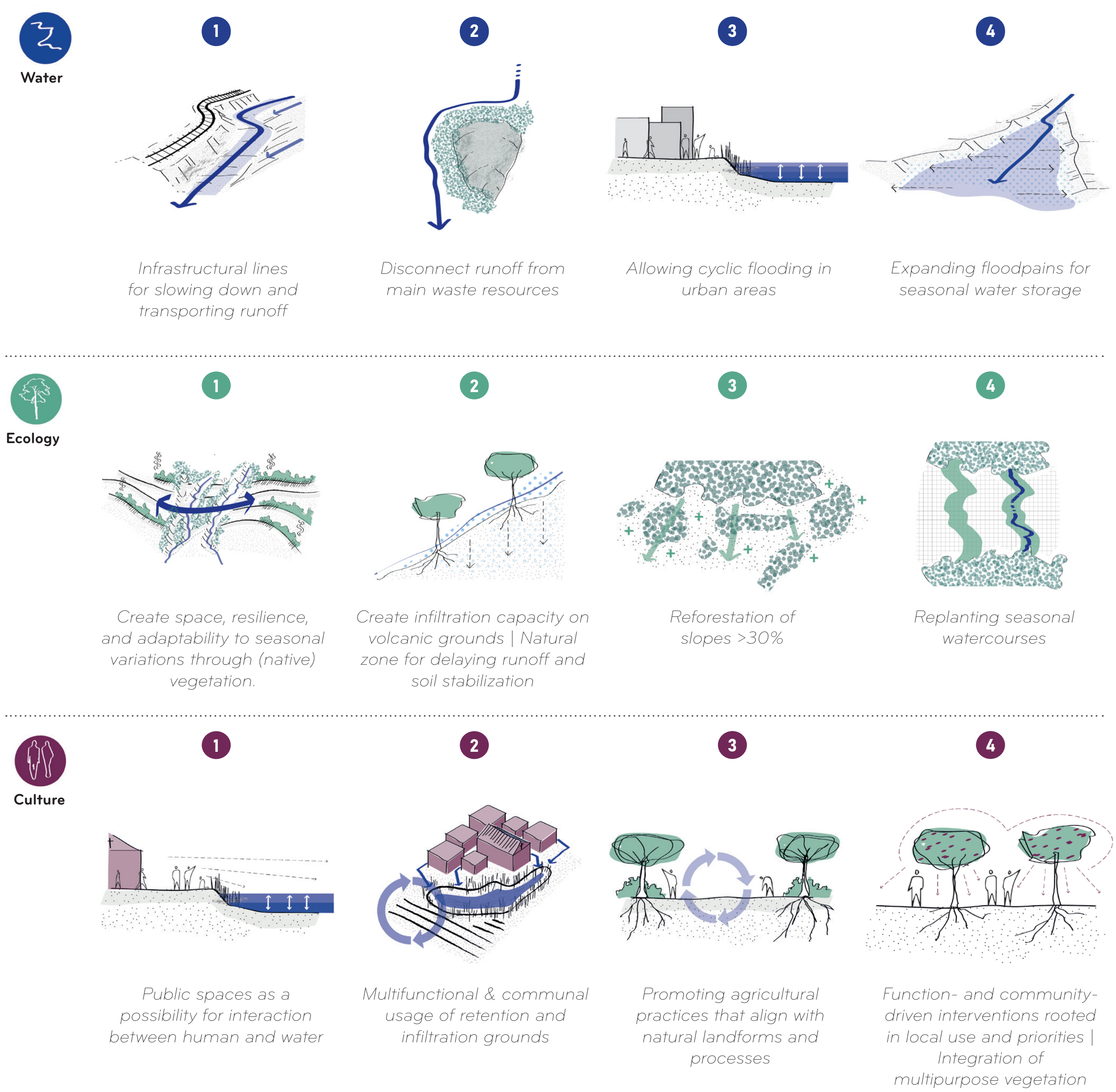
[Figure 114.] Schematic overview of the natural depressions in the upstram area, that will guide the final design outcome

The overview on the right illustrates how the developed design principles are spatially implemented within the masterplan for the spatial link in between the up- and midstream area. The site-specific interventions are developed by combining and applying the design principles most relevant to the function of this zone (Delay & Infiltrate and Transport & Purify), selected from the broader spatial strategy for the whole sub-watershed introduced in Chapter 5.

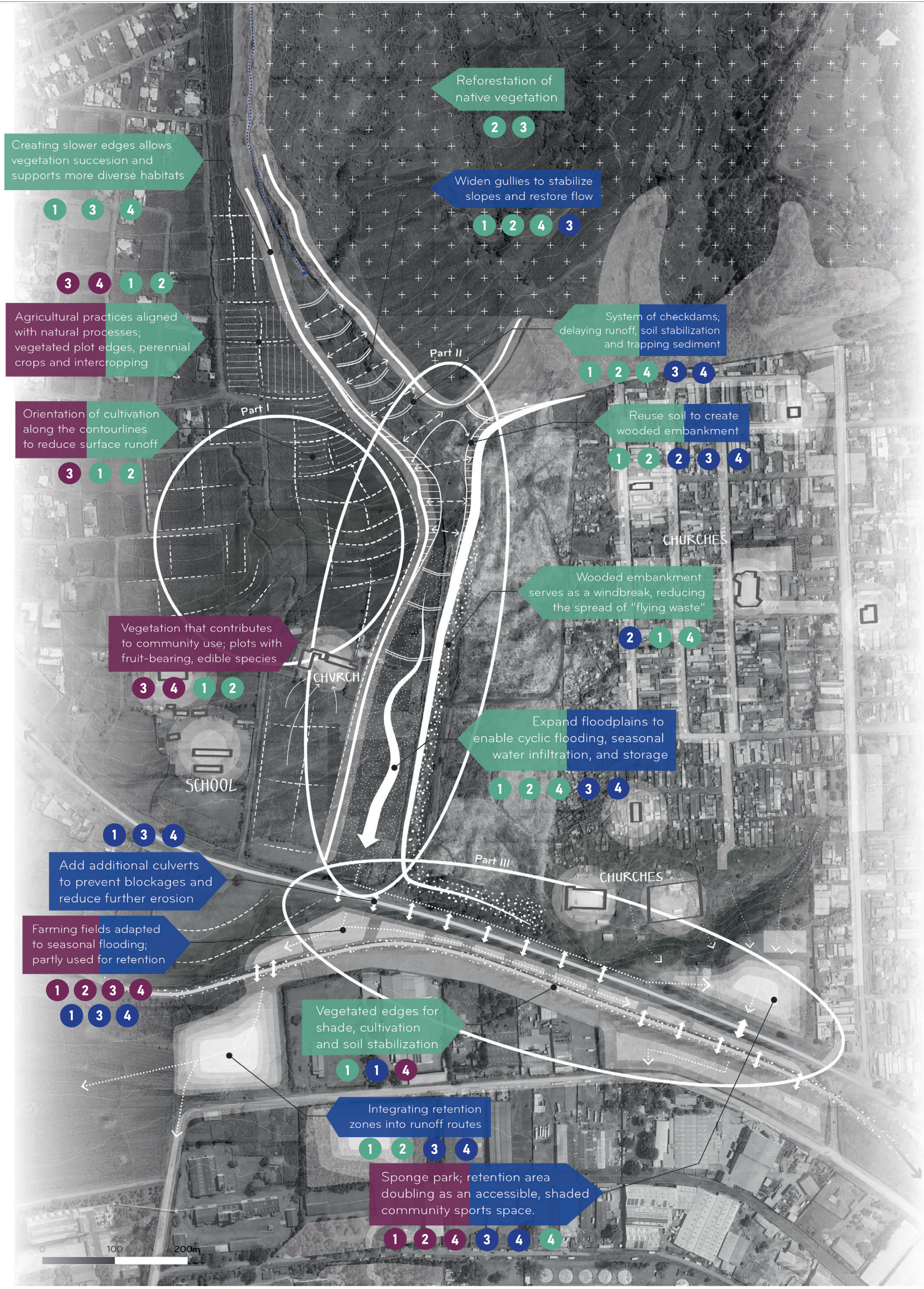
The proposed design outcome for this area integrates hydrological, ecological, and socio-cultural principles to create multifunctional design outcomes that strengthen both hydrological, ecological, and social resilience. For example, by introducing sustainable agricultural practices such as agroforestry in hilly areas prone to erosion by runoff, contour lines become vegetated and thereby contribute to the delay and infiltration of runoff, while improving soil stability and supporting local livelihoods. An important aspect of the proposed design explorations is the generation of co-benefits that extend beyond the primary function of each intervention. This approach enhances effectiveness, fosters local involvement, reduces the risk of encroachment, and addresses broader societal challenges once the design outcomes are implemented. This has been explained in greater depth in Chapter 3.6, Nature-based Solutions (NBS).

Figure 116 highlights these overlaps between design principles, showing how technical, ecological, and social objectives reinforce one another, while answering to the guiding lenses of this research. Three key areas are emphasized for their strategic potential and are further elaborated in the following chapters presenting the design explorations.

Delay & infiltrate | Transport & purify



[Figure 115.] Relevant design principles to the designated function of this spatial link



[Figure 116.] Overview of implementation of the design principles in the upper spatial link, combined with the assesment of their value to the guiding themes of this research (water, ecology and culture).

Proposed Masterplan for the Upstream Zone of the Seasonal Sub-Watershed

The overall design outcome is presented in this masterplan for the upstream zone of the seasonal sub-watershed. Since Nakuru City faces long dry periods alternated with short but intense rainy seasons, the masterplan is developed for both dry and wet conditions. This dual approach illustrates the crucial role of seasonal water: where it accumulates, how it flows downstream, and through which spatial structures it is retained or guided. The key interventions at four strategic locations are outlined below:

1. Rehabilitation of the gully

- The existing gully, which previously ran through the waste dump, is closed off from this area by means of a wooded embankment.
- Seasonal runoff is redirected downstream through lower areas and slowed by a system of check dams.
- This creates a seasonal riverbed where vegetation succession is stimulated, stabilizing the soil, enhancing water retention, and strengthening ecological resilience and continuity.

2. Introduction of agroforestry along the seasonal riverbed

- In the current situation, monocultural farming depletes the soil and disrupts the water system. The masterplan introduces an agroforestry system combining annual crops with perennial planting and natural vegetation along field edges.
- This diversified system increases vegetation cover on slopes, improves long-term soil fertility, and reduces surface runoff.
- Proximity to community buildings such as schools and churches offers opportunities for awareness-raising and agricultural education, enhancing the adoption of sustainable practices.
- On steeper slopes (≥15%), terracing is proposed to improve crop yield, stabilize water management, and reduce erosion, thereby preserving valuable topsoil.

3. Hydrological management around the main road and railway corridor

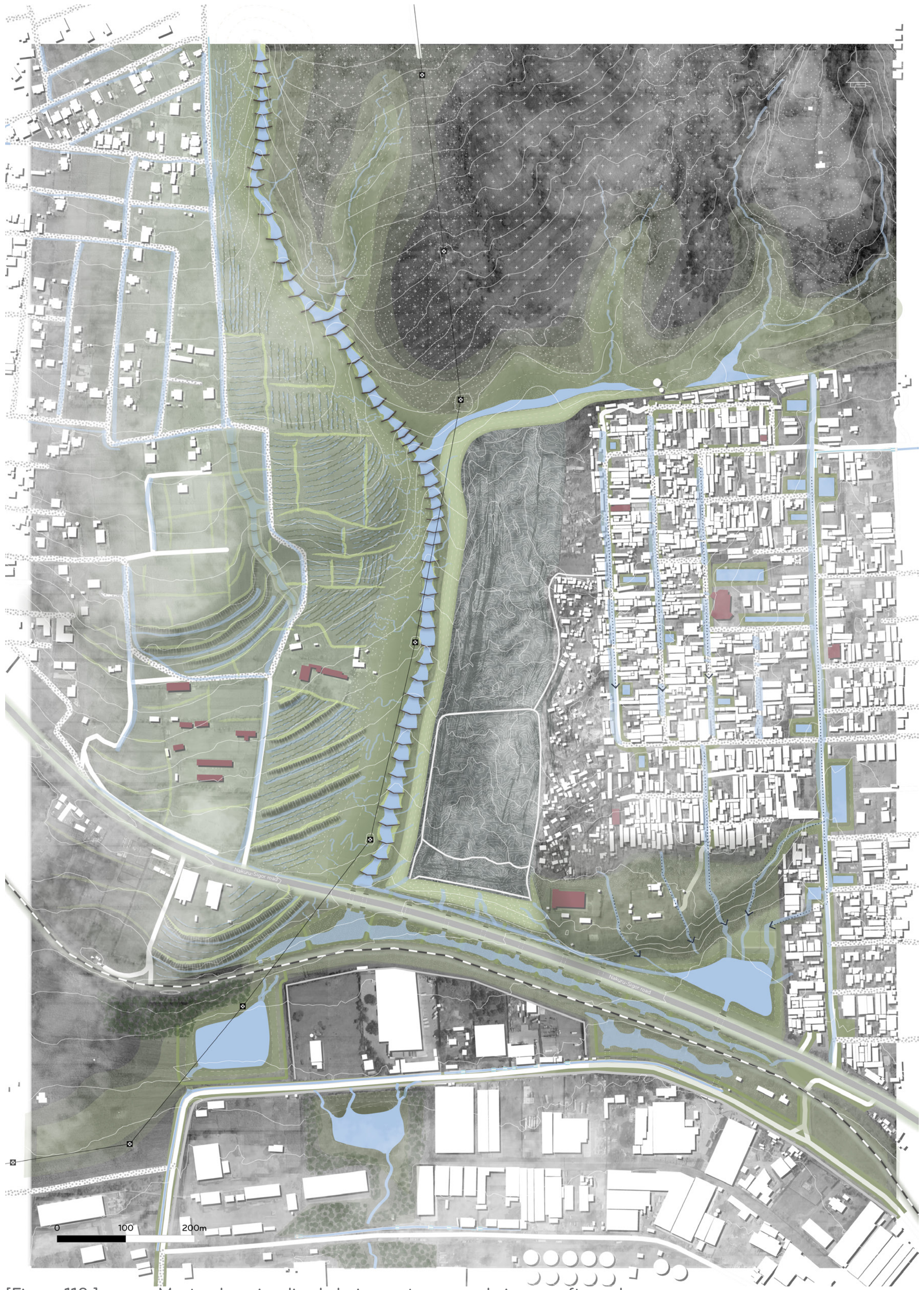
- At the lower end of the seasonal riverbed, the main road and railway cut across the landscape on elevated structures. To ensure water passage, additional culverts are required beneath these lines, placed deeper into the ground to prevent erosion of the existing limited outlets.
- Between these infrastructures, water tends to accumulate after heavy rainfall and subsequently spreads uncontrolled into the urban fabric. This area is therefore designated for small-scale agricultural fields that may temporarily flood, functioning as retention and infiltration zones.
- The railway corridor, already a strong spatial feature, is enhanced as a recreational route connecting the inner city with the surrounding landscape. Greening with fruit- and seed-bearing trees is proposed to provide shade, stabilize the soil, enhance biodiversity, and enrich the user experience.

4. Surface runoff management below the London Area

- This multifunctional area is assigned an additional role: collecting and slowing surface runoff from the London Area to prevent further uncontrolled spread into the downstream urban environment.
- Tree planting and preservation are proposed both to provide shade for existing sports facilities and to reduce evaporation from retained water, thereby improving soil moisture.
- Selected vegetation will serve productive purposes as well, prioritizing fruit- and seed-bearing tree species that combine ecological, social, and economic benefits.

[Figure 117.] Masterplan of detailed design for the upstream zone of the seasonal sub-watershed

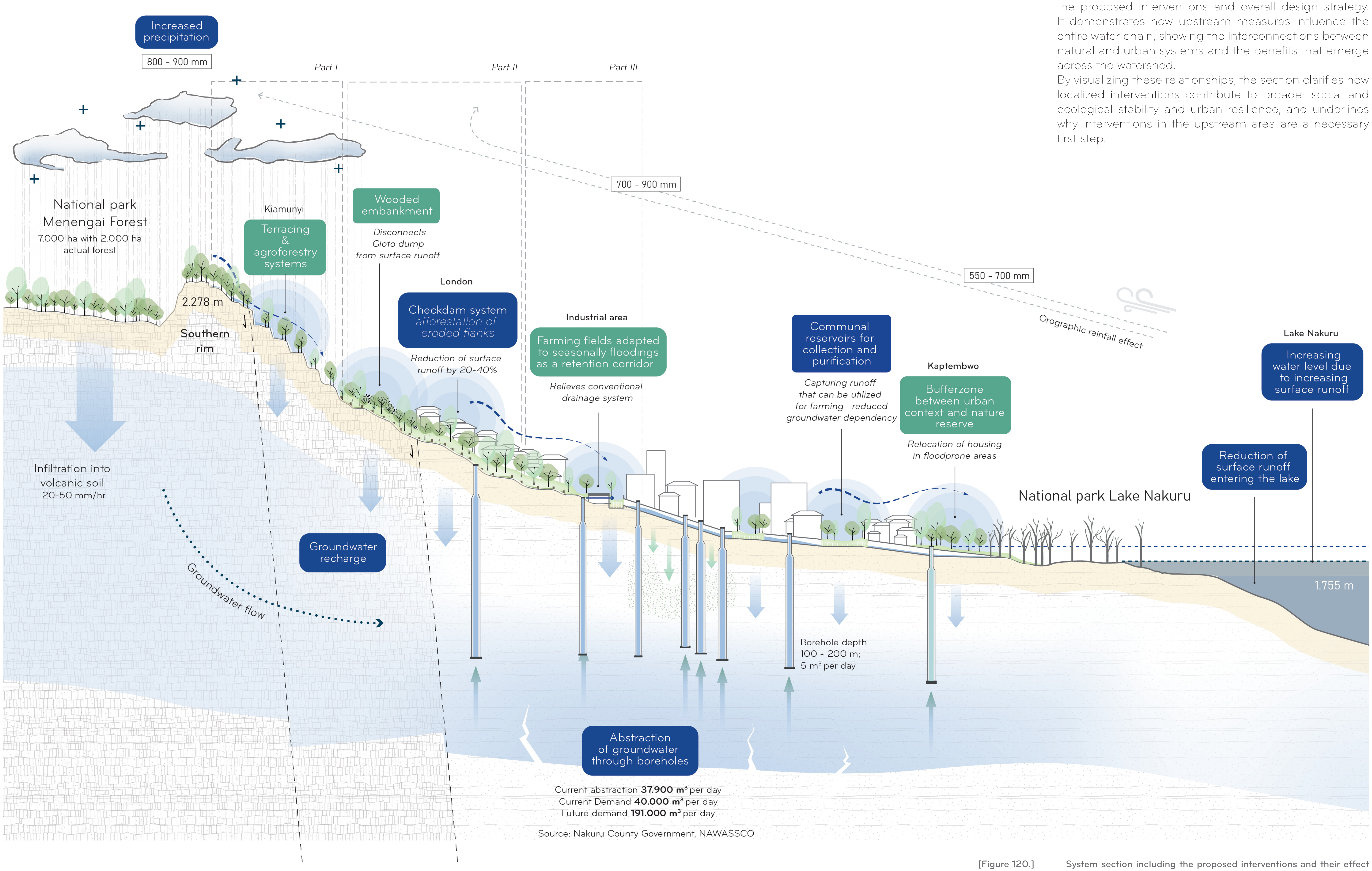
As mentioned earlier chapters, the region experiences two rainy seasons each year, while the masterplan was presented during the dry season. Given that a large part of the challenges addressed are water-related, it is essential to also depict the proposed design under wet-season conditions, as is done with this map. In this way, the role of the water-retaining structures, as well as those designed to capture runoff, becomes clearly visible. The indicated volumes of water represent an approximate estimation of the conditions during or immediately after a heavy rainfall event, which is expected to occur more frequently in the future (see Chapter 4). Presenting both seasonal scenarios strengthens the masterplan by demonstrating its capacity to adapt to climatic variability and future hydrological extremes.



[Figure 118.] Masterplan visualized during wet-season dyring or after a heavy rainfall event. Implicates where the water flows in this situation.

[Figure 119.] Schematic overview of water-related interventions within the detailed design for the upstream zone and how they are linked to each other.

This section illustrates the system changes resulting from the proposed interventions and overall design strategy. It demonstrates how upstream measures influence the entire water chain, showing the interconnections between natural and urban systems and the benefits that emerge across the watershed.
By visualizing these relationships, the section clarifies how localized interventions contribute to broader social and ecological stability and urban resilience, and underlines why interventions in the upstream area are a necessary first step.



[Figure 120.] System section including the proposed interventions and their effect on the urban ecosystem of the seasonal sub-watershed on the Western side Nakuru City.

6.5. Interventions on different scales

As discussed in the masterplan, four key interventions are proposed for the upstream zone. These are organized into three parts: agricultural changes (Part I), gully rehabilitation (Part II), and the retention corridor (Part III). Each part contains interventions that operate at different scales, inspired by Tjallingii's Ecopolis theory (1995, see Chapter 3.5). This means that interventions involve a specific range of stakeholders, from the bottom layer (local residents) to the top layer (governmental organizations). Collaboration across these groups is essential to achieve both effectiveness and long-term implementation of the proposed interventions.

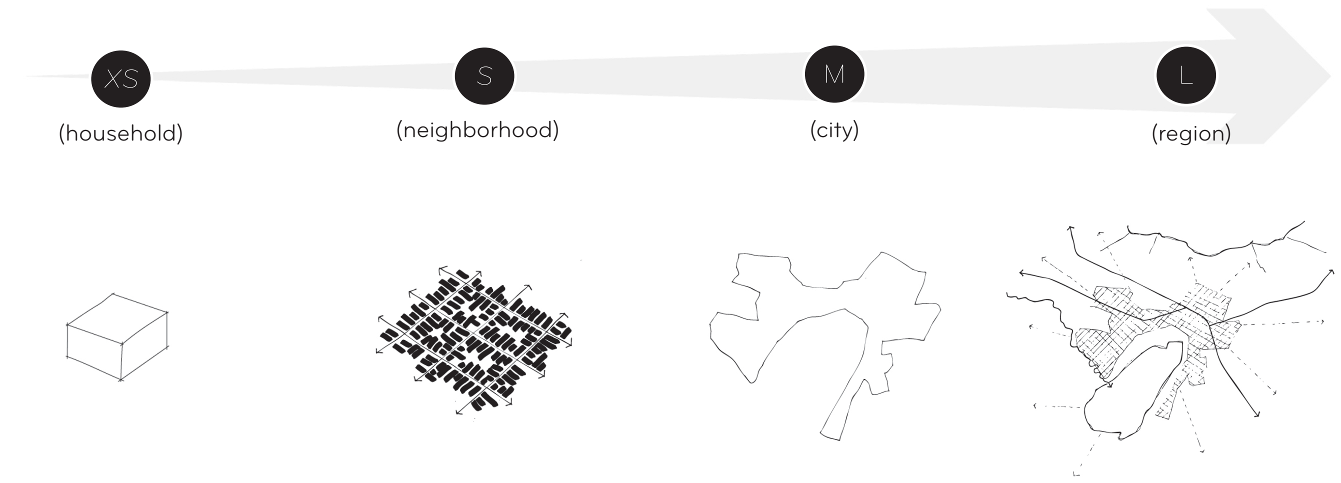
In this research, scales are treated conceptually rather than as fixed sizes (figure 121). The main aim is to demonstrate how actions at one level should align with and support those at others. For example, measures at the household scale, such as stone lines (figure 122), can slow runoff locally. These measures in turn reinforce interventions at the neighbourhood scale, such as culverts that guide water into retention areas. Together, they connect to the city and regional scale, where guided and delayed flows can be collected in natural or man-made depressions to enhance the overall retention capacity of the watershed.
Effectiveness and conditions.

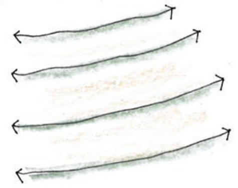
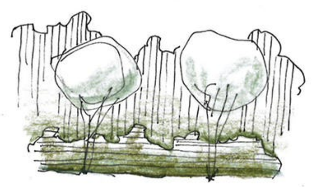
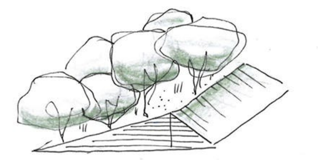
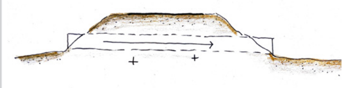
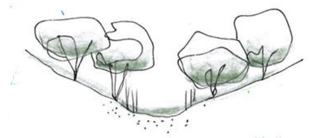
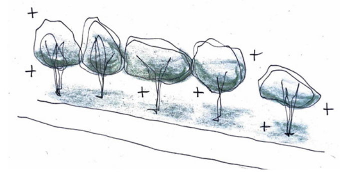
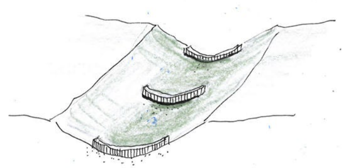
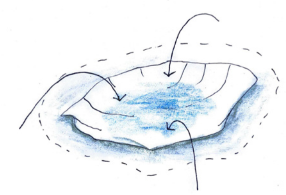
Not all interventions, however, are equally effective at every scale. Some, such as water retention and green corridors, are most impactful at the neighbourhood level, while ecological and transport structures operate best at the city scale

Scale selection depends on three main conditions:

1. *Stakeholder level* – who can implement it?
2. *Maintenance* – who can sustain it over time?
3. *Financial feasibility* – when investments are required, interventions are automatically shifted to higher levels where coordination and resources are available.

[Figure 121.] Scaling of interventions, as presented by Tjallingii (1995)



intervention / scales	Part I Agricultural changes	Part II Gully rehabilitation	Part III Retention corridor
XS (household)	 *Orientation of cultivation*		 *Stonelines to reduce runoff/enhance infiltration*
S (neighborhood)	 *Agroforestry system*	 *Wooded embankment to disconnect waste source from surface runoff*	 *Additional culverts to prevent bottlenecks*
M (city)		 *Slow edges | afforestation of eroded flanks*	 *Expand (productive) vegetation next to infrastructural lines*
L (region)	 *Terracing the landscape*	 *Checkdam system in gully formations*	 *Activation of natural depressions to enhance water retention capacity*

[Figure 122.] Overview of interventions on different scales (see chapter 3.5)

Part I

Agricultural changes

[Figure 124.] Current landscape of Part I; aerial view.

[Figure 123.] Current landscape of Part I; unsustainable farming on steep slopes, near gully formations shaped by runoff and the Gioto dump.

[Figure 125.] Part I positioned on masterplan

Culture — *Main return*

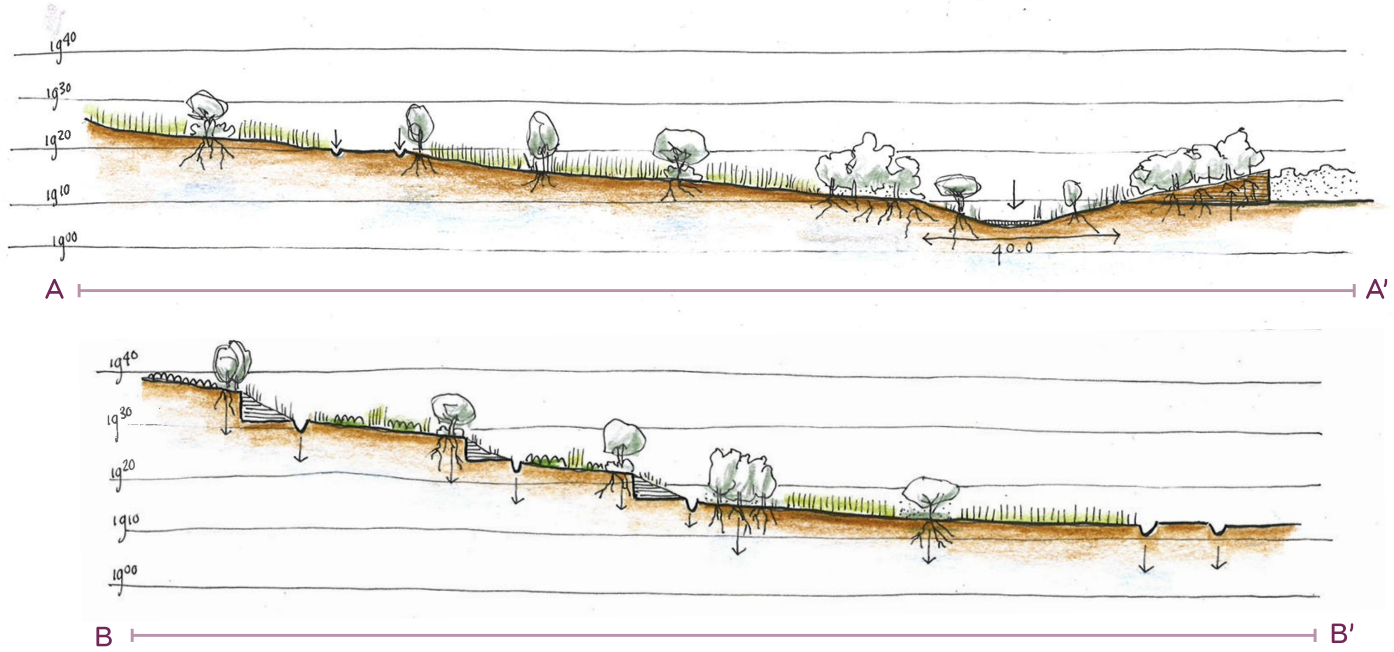
Water — *Co-benefit*

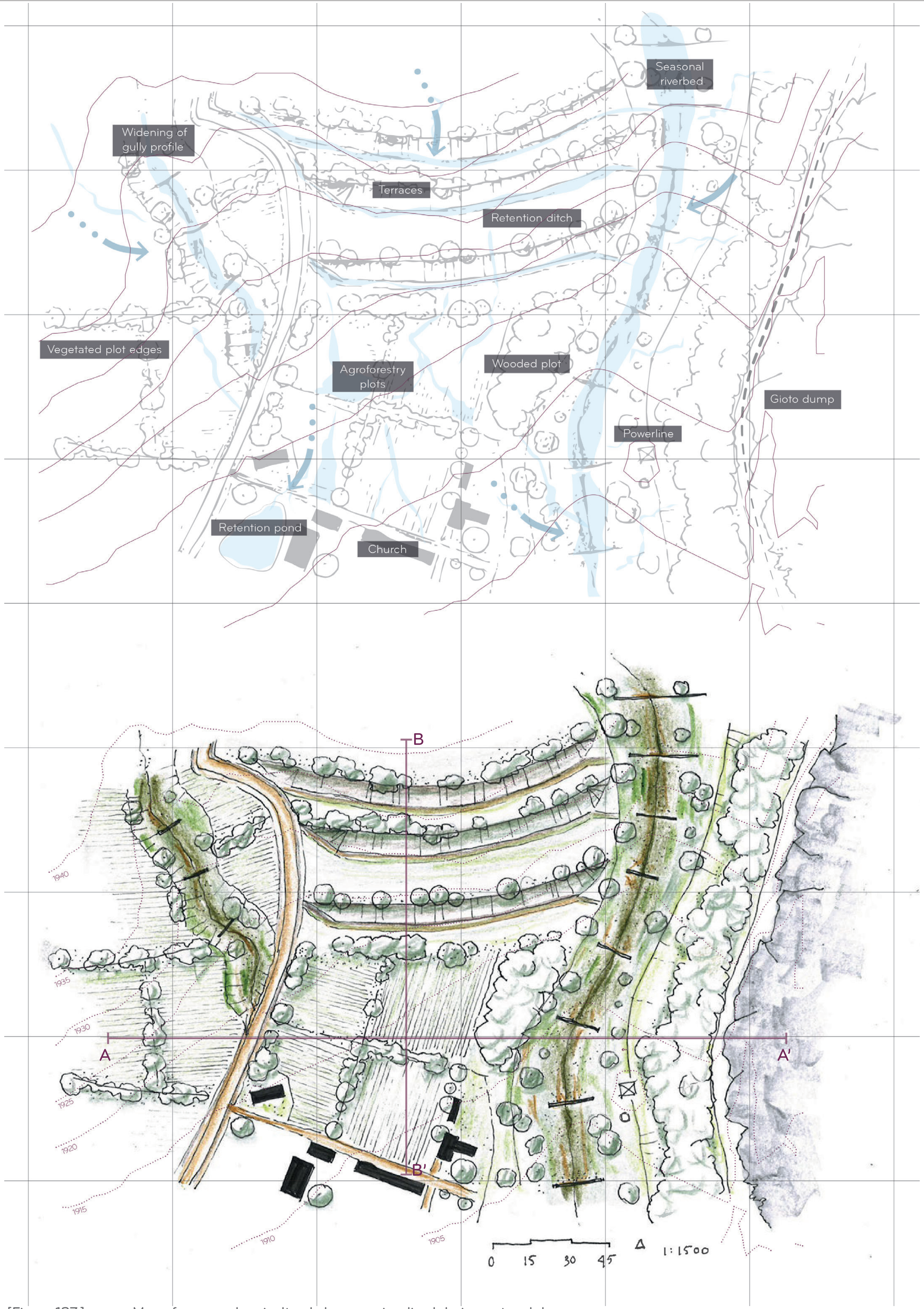
The first part of the proposed design focuses on agricultural changes in the Kiamunyi area, particularly along the edges of gully formations. The aim is to introduce sustainable farming practices that align with the existing landscape processes while safeguarding the area's agricultural function. At the same time, these interventions seek to increase the social-ecological resilience of the area. By stabilizing soils, reducing erosion, diversifying crops, and allowing natural vegetation to regenerate, the design improves ecological value and slows surface runoff, thereby enhancing infiltration opportunities.

As demonstrated in the analysis of local practices (Section 4.6), agroforestry holds significant potential in this area. Combined with terracing along the steeper contourlines, it can strengthen the diversification and ecological quality of farmland, support livelihoods, and contribute to restoring the water balance. Some measures can already be implemented at a small scale, such as orienting cultivation along contour lines. This simple adjustment slows runoff, helps retain topsoil, reduces damage to farmland and prevents the vegetation an crops of being washed away.

The detailed plan and sections (Figure 127) illustrate how these interventions can be applied in practice. They take advantage of local elevation differences to make cultivation easier, safer, and more sustainable. Terracing and agroforestry together form a productive and resilient system, while natural vegetation at field edges provides a buffer between gully formations and farmland and creates a windbreak for the vulnerable crops. This not

[Figure 126.] Sections of agroforestry system in the detail design, linked to the detailed map



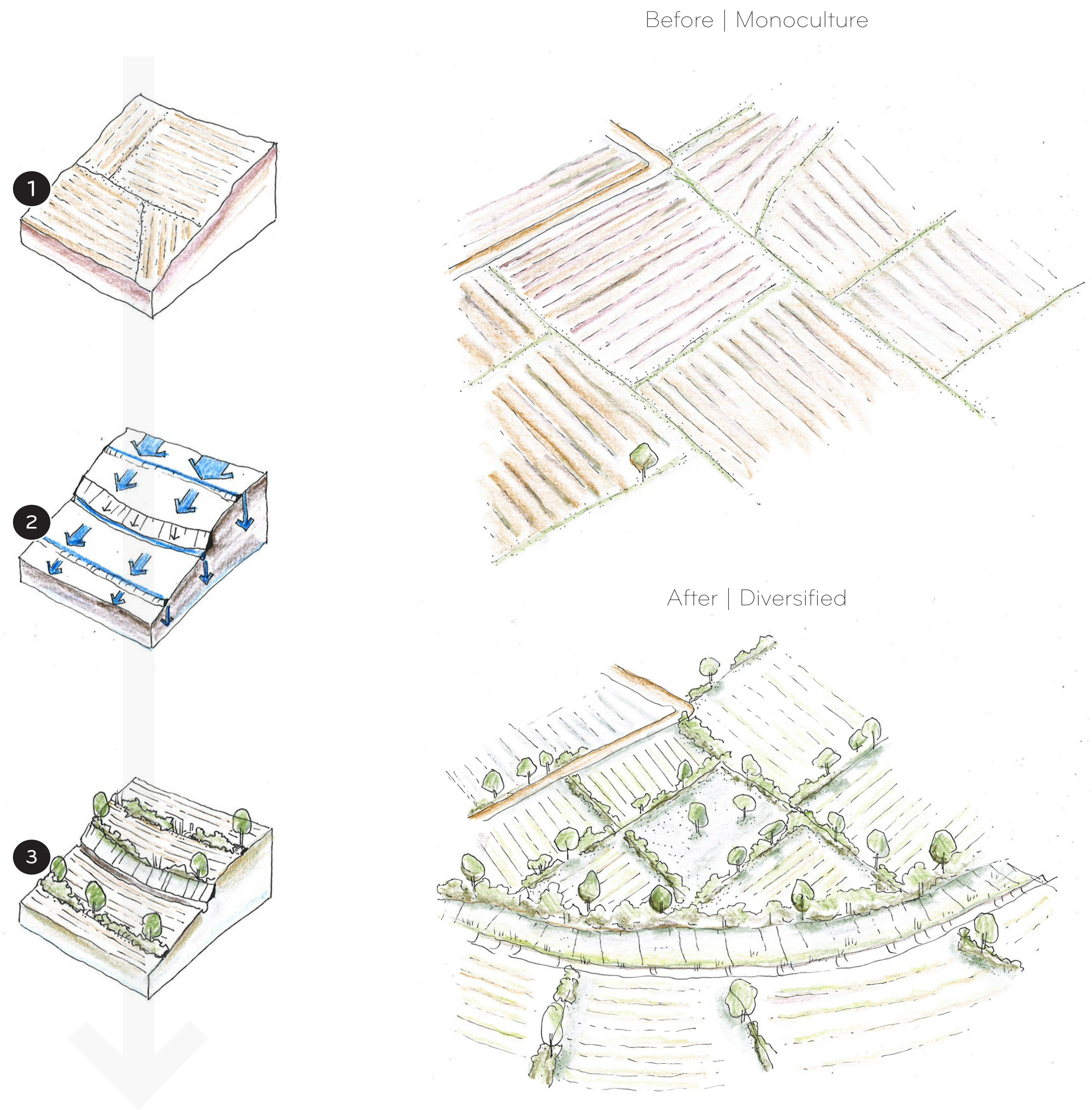


[Figure 127.] Map of proposed agricultural changes, visualized during wet and dry season.

only reduces runoff flows overland from entering the gullies, but also stabilizes the soil and improves moisture retention in the ground, which supports the crops during dry season.
To establish a resilient and vegetated agricultural system, contouring the landscape is a crucial first step (Figure 128). Without this, runoff would wash away crops before they can stabilize in the soil. Contouring can be achieved through several methods: orienting cultivation along contour lines to create ridges, allowing natural vegetation to remain at plot edges, or constructing terraces. Once runoff is slowed and infiltration improved, new crops can be introduced on the slopes of the Menengai Caldera.

The proposed agroforestry system builds on these measures by diversifying the conventional agricultural system. Rather than monoculture, perennial and annual crops are combined to promote intercropping and establish a more sustainable balance in soil health and water management. An example of such a system was identified on site and further developed through an interview with a local botanist from Egerton University (Figure 69, see appendix). The system is structured into three layers of vegetation, each contributing to the protection, maintenance, and improvement of agricultural plots.

Ultimately, this diversified yield increases resilience to seasonal extremes, strengthens farmers' livelihood security in the Kiamunyi area, and supports the natural system as a whole, including hydrology, ecology, and soil as an important co-benefit.



[Figure 128.] Changes over time of the productive, agriculture landscape of Kiamunyi.

Planting specifications

1. Tall and perennial species for shade, windbreak, biodiversity and erosion control.

- Grevillea robusta;
  Fast-growing, timber for construction poles, enhances the fertility of the soil.
- Azadirachta indica
  Drought tolerant and medicinal
- Faidherbia Albida
  nitrogen-fixing, drought tolerant, retaines moisture in the soil
- Croton Megalocarpus
  Indigenous, fruits for bio-fuel, deep rooted, used as firewood
- Moringa Oleifera
  Indigenous, edible leaves, seeds for oil, harvest after 6 months, drought tolerant

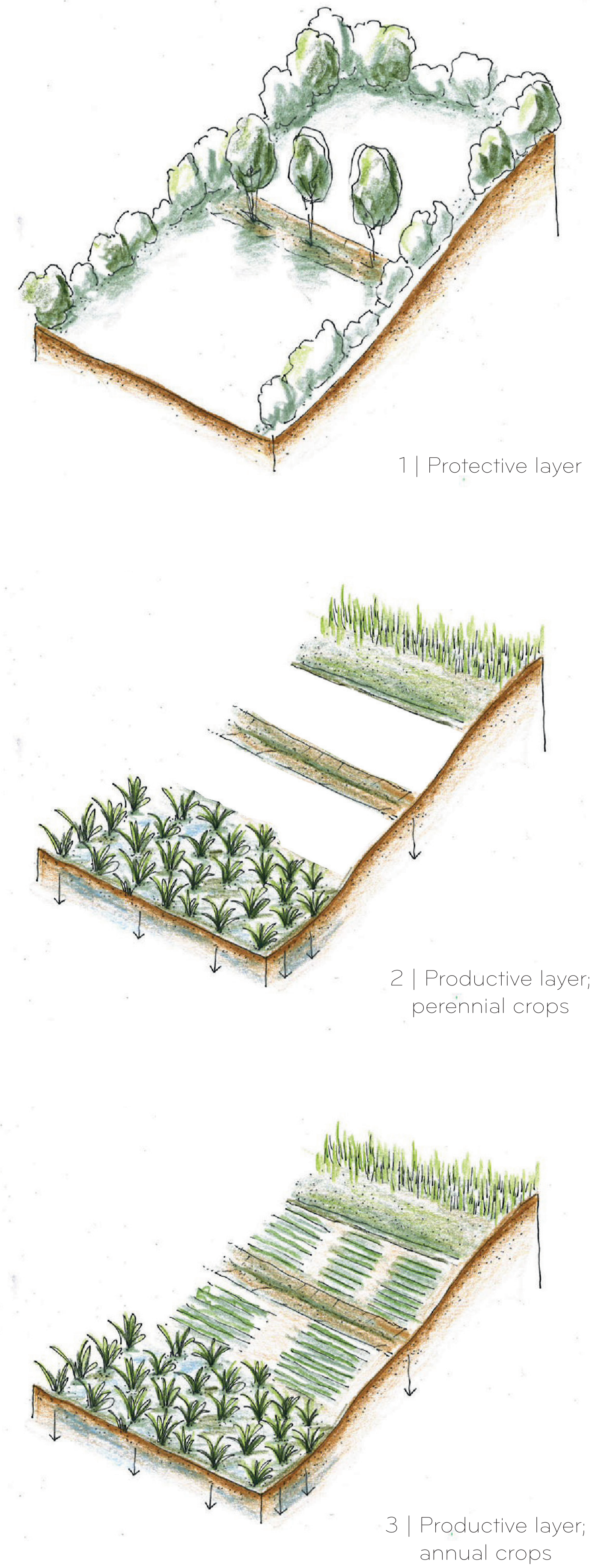
2. Fruits trees, perrenial crops, fodder grasses and shrubs - main productive layer

- Mangifera indica (mango);
  Drought tolerant once established
- Carica papaya (papaya);
  Fast-yielding fruit, moderately drought tolerant
- Psidium guajava (guava);
  Drought hardy
- Cajanus cajan (pigeon pea);
  Semi-perennial legume, nitrogen-fixing, edible pulses
- Pennisetum purpureum (napier grass);
  Fodder, planted along contours, erosion control
- Chrysopogon zizanioides (vetiver grass);
  Erosion control, deep rooted, enhances infiltration
- Solanum betaceum (tree tomato);
  Fruit-bearing, short-lived perennial, suited to mid-zones

3. Vegetables, ground covers and livestock - nutrition, food security and soil improvement

- Amaranth spp. Amaranthus (pig weed);
  Leafy greens, drought hardy
- Daucus carota L. subsp. sativus (carrot);
  Root crop, suited to well-drained volcanic soils
- Vigna unguiculata (cowpea);
  Edible leafs an beans, nitrogen fixing, drought tolerant
- Vigna radiata (mung bean);
  Short cultivation-cycle, nitrogen-fixing, drought tolerant
- Desmodium uncinatum (silverleaf);
  Perennial crop, nitrogen-fixing, erosion control

(Source: local initiative (see chapter 4.) and an interview with local expert and botanist Dr. Patrick Kisangau, Egerton University (see appendix))



[Figure 129.] Vegetation layers of the agroforestry system

Part II

Gully rehabilitation

[Figure 130.] Current landscape of Part II; a gully formation In the Kiamunyi area next to Gioto dump

[Figure 131.] Current landscape of Part II; entry of the gioto dump is the main outlet of seasonal runoff in this area at the same time.

[Figure 132.] Current landscape of Part II; aerial view.

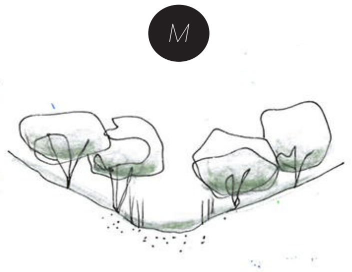
Water — *Main return*

Ecology — *Co-benefit*

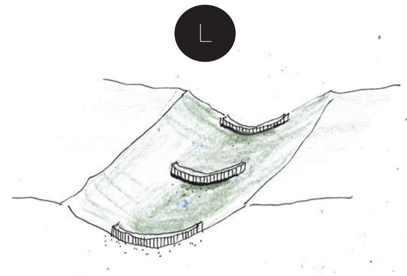
The second part of the proposed design focuses on the gully formations near the Gioto dump, which currently cause erosion, pollution, and flood risks in the surrounding area. In the current situation runoff flows from uphill areas through the Gioto dump and consequently causing contamination of the surrounding areas. To reduce these impacts, the design proposes rehabilitation of this gully system and the disconnection of seasonal water flows from the dump through the establishment of a wooded embankment. This intervention operates at a large scale and therefore depends on collective cooperation for implementation. The scale is essential to ensure the effectiveness of the check-dam system, which gradually slows down runoff.

[Figure 133.] **Part II positioned on masterplan**

Wooded embankment to disconnect waste source from surface runoff

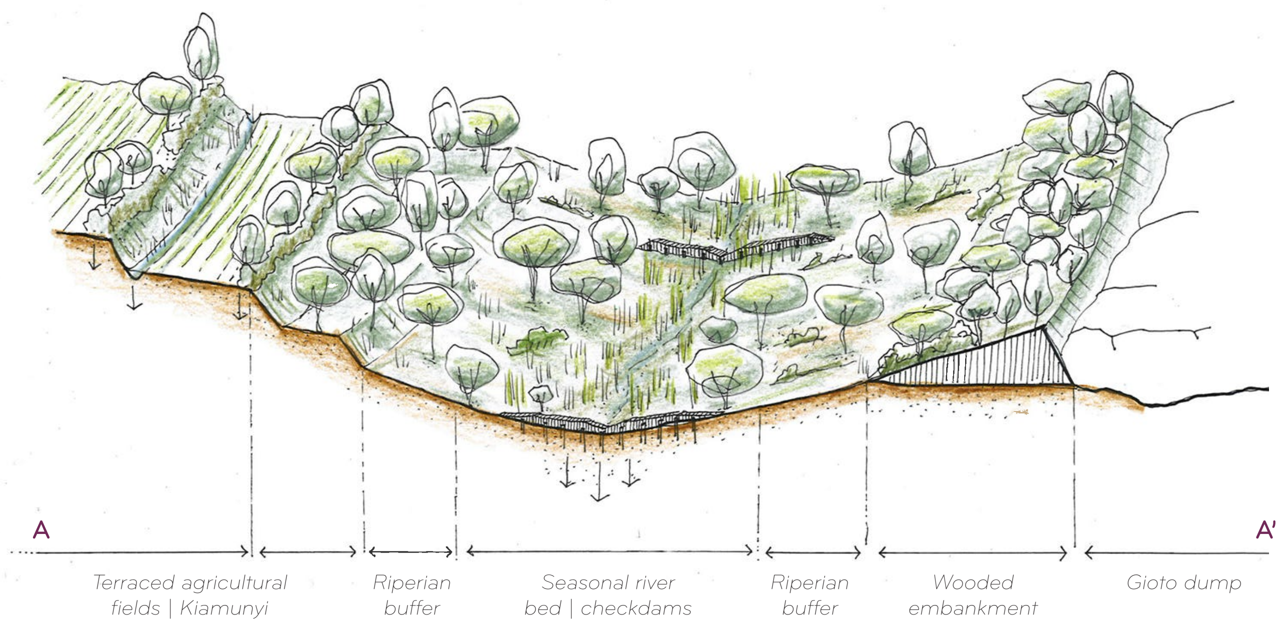


Slow edges | afforestation of eroded flanks

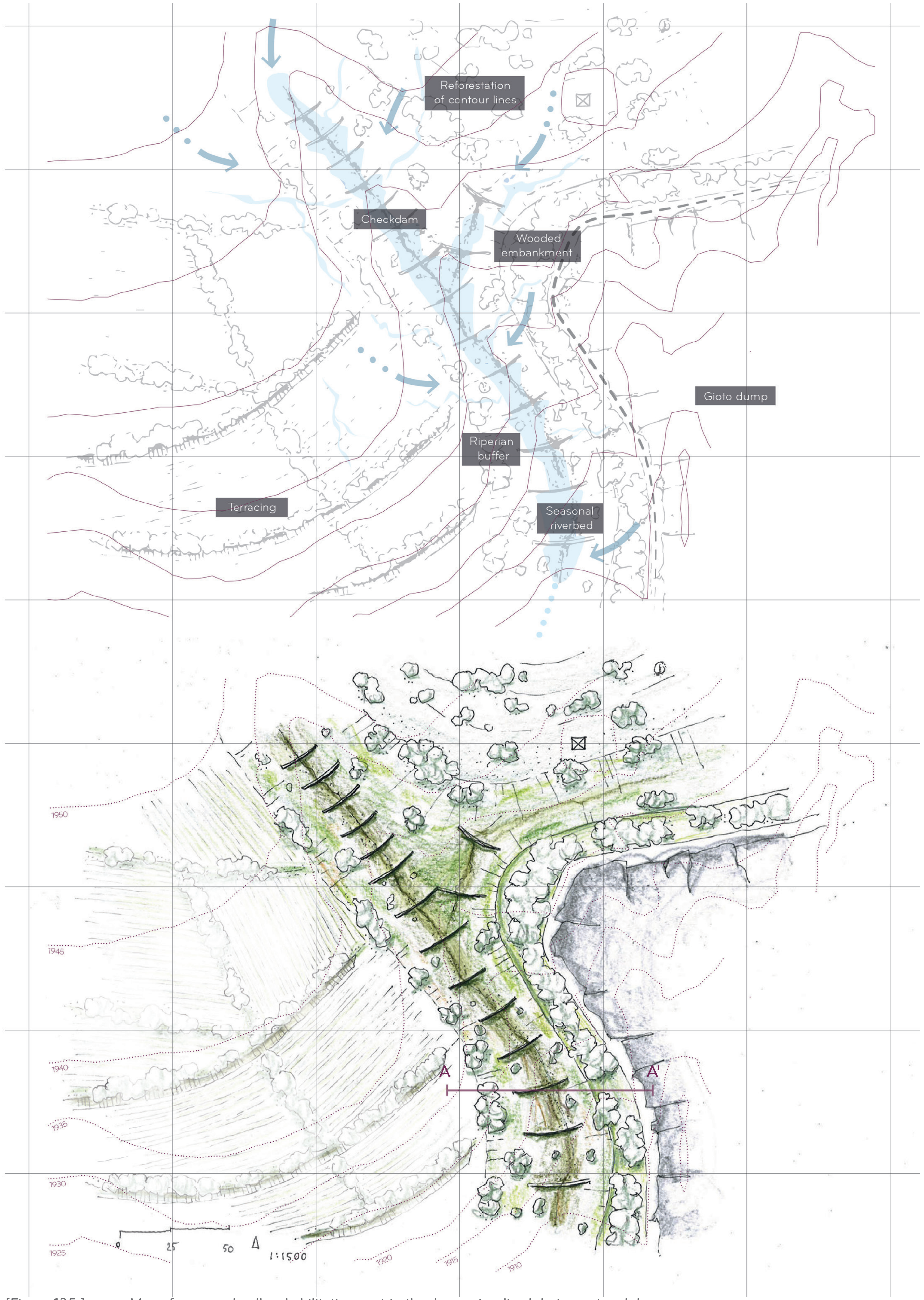


Checkdam system in gully formations

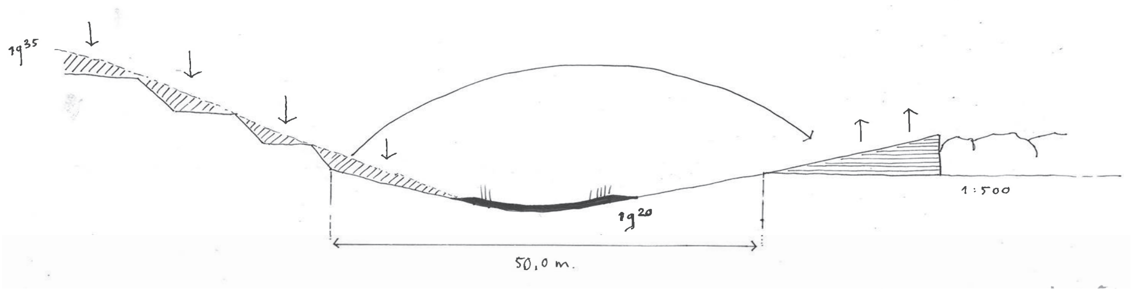
Therefore, a seasonal riverbed is proposed in the current gully formation next to the dump, including a system of check-dams in combination with a wooded embankment that disconnects the waste dump from seasonal runoff (Figures 134 and 135). Taking the feasability of a large scale intervention into account, a closed soil balance on site is introduced; by widening the gully profiles and contouring the surrounding landscape, soil becomes available for the construction of the embankment. However, such interventions require significant manpower and financial investments, which need to be coordinated and supported by actors at higher levels.



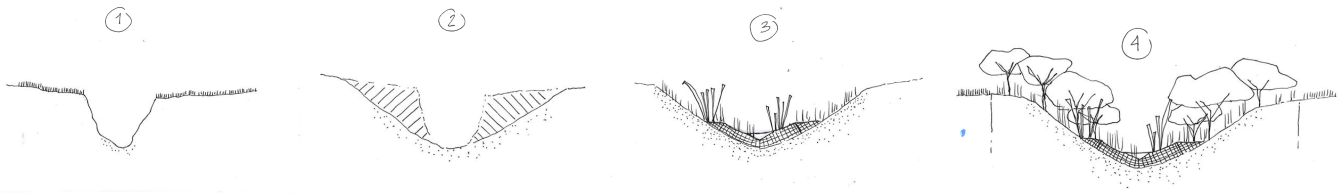
[Figure 134.] **Section of seasonal riverbed, with checkdams implemented**



[Figure 135.] **Map of proposed gully rehabilitation next to the dump, visualized during wet and dry season.**



[Figure 137.] Section of soil replacement in the seasonal riverbed

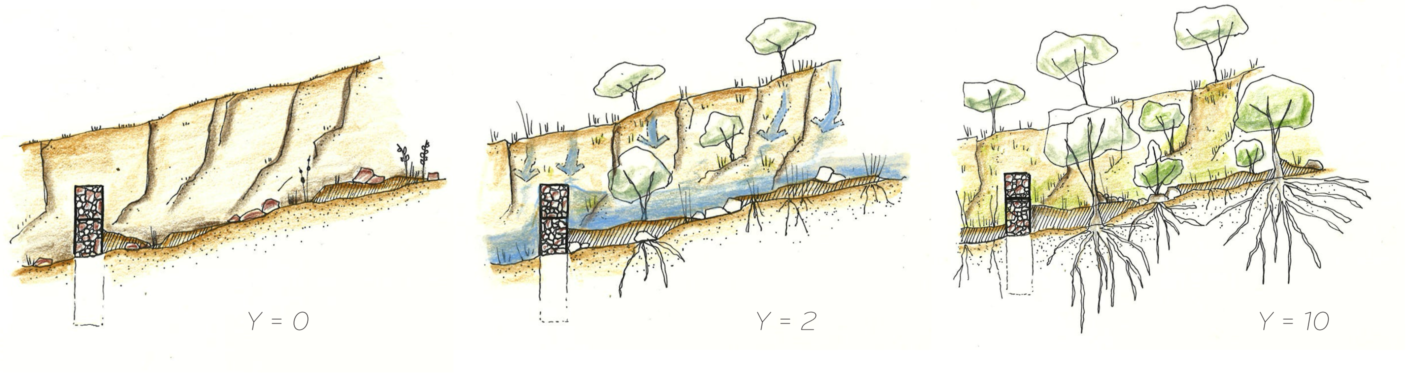


[Figure 138.] Steps in widing the gully profile

Intervention though time
By creating gentler gully slopes and trapping sediment with a system of check-dams, the gullies can be stabilized and gradually rehabilitated. This creates space for natural vegetation to pioneer and establish in the seasonal riverbed, as demonstrated in successful rehabilitation projects on the Loess Plateau in China (Chapter 3.7). Over time, it is not only the check-dams that strengthen the system, but also the diversity of vegetation and the rooting structures that reinforce the soil. Whereas gullies in their current condition accelerate runoff during rainy seasons and remain eroded and dry in dry seasons, the new system will slow down and retain water, provide infiltration opportunities, and increase resilience against climatic extremes. In addition, moisture and shade provided by vegetation will benefit surrounding agricultural fields (figure 136).

Planting specifications
The design of a widened, seasonal riverbed with gentle slopes creates space for ecological succession. Based on expert input from the botanical department of Egerton University (see appendix), species are proposed that stabilize soil, improve water retention, and are native to region. The wooded embankment forms part of this scheme (Figure 139). At the southern end of the Gioto dump, an initial attempt at such a vegetated embankment is already visible from Nakuru-Sigor Road (figure 131). As proposed in the masterplan, this could be extended along the full length of the dump, thereby cutting off a major source of pollution from runoff. This would significantly reduce contamination and downstream impacts. The stability of the embankment will be reinforced with vegetation and wooden poles, creating both a buffer against runoff and a windbreak that reduces the spread of waste by wind.

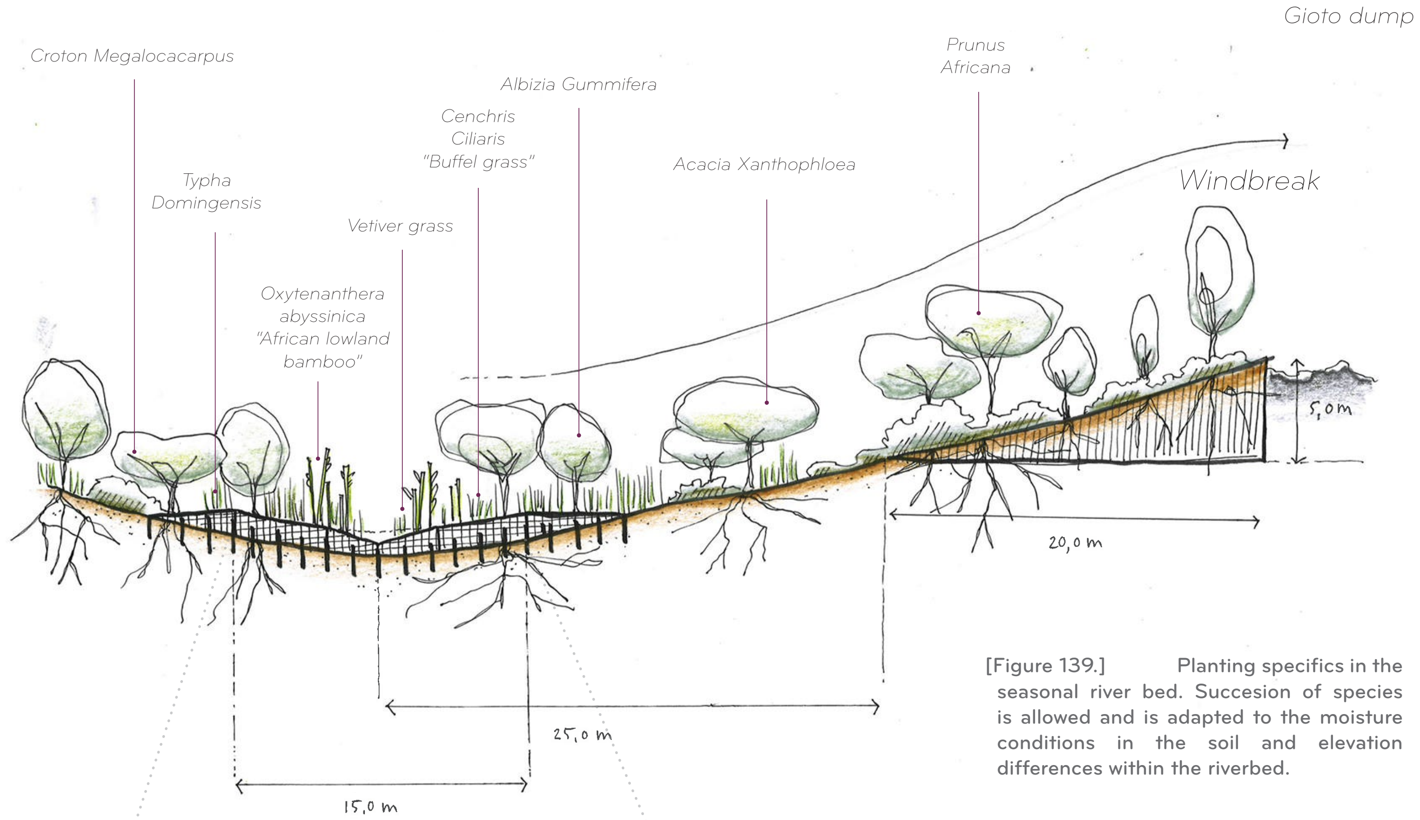
[Figure 136.] Process of sedimentation and soil stabilization by checkdams over the years. Timeline shows how a checkdam can create space for succesion when widining up the profile of gully formations.



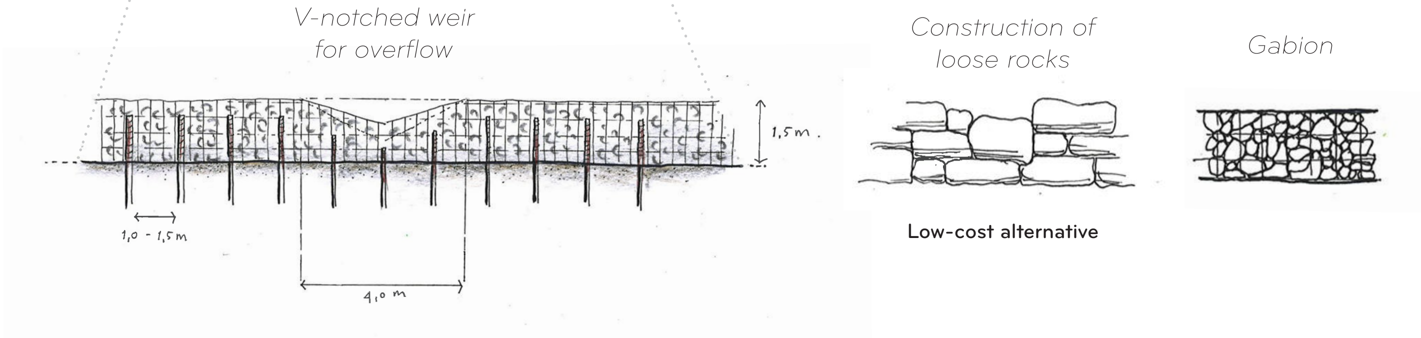
Materialisation
Gabion structures are proposed as the primary material for constructing check-dams. The metal cages filled with stones ensure long-term stability and safety. As visualized in the technical drawing, a V-notched weir is included in the center of each check-dam to manage the gradual overflow of water and reduce the risk of erosion. The recommended depth of this triangular notch is not well established in existing literature and has therefore been estimated at 0.5 meters for this design.

Proper spacing between the check-dams is also essential. To secure performance and safety, the "head-to-toe" rule has been applied, where the base of one dam aligns with the crest of the next. For financial feasibility, fewer check-dams could be constructed with wider spacing; however, literature reviewed in Chapter 4.6 indicates that the effectiveness of such positioning remains uncertain.

[Figure 141.] Example of gully rehabilitation by gabion checkdams (Doten, 2020)



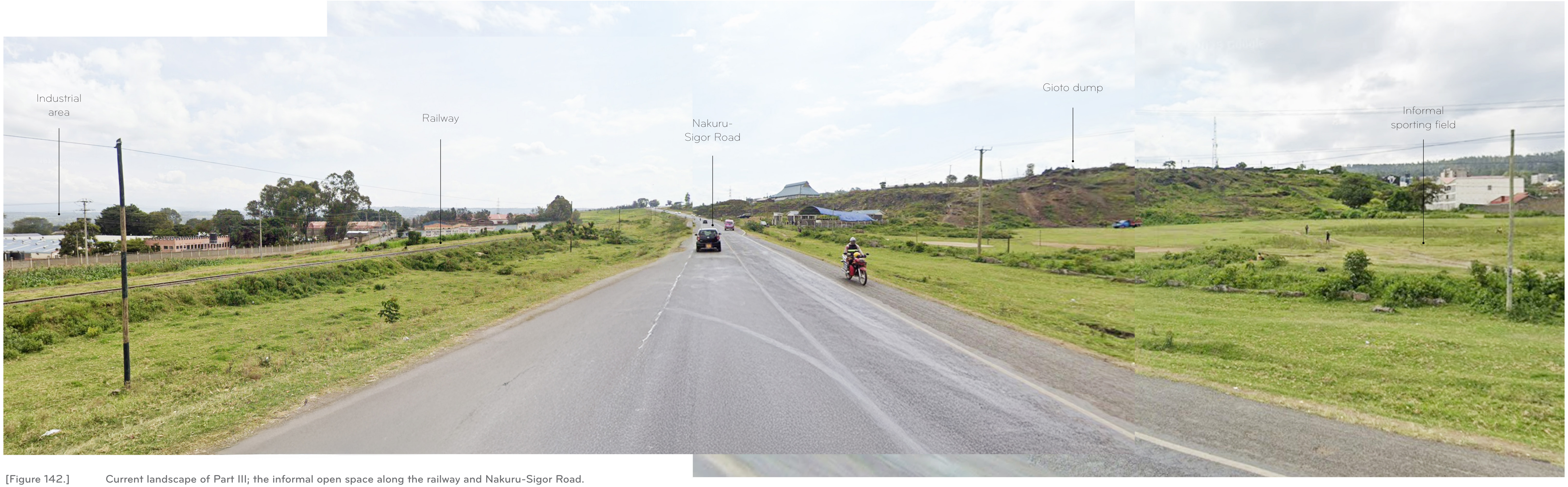
[Figure 139.] Planting specifics in the seasonal river bed. Succesion of species is allowed and is adapted to the moisture conditions in the soil and elevation differences within the riverbed.



[Figure 140.] Technical details and materialisation options of a checkdam.

Part III

Retention corridor



[Figure 142.] Current landscape of Part III; the informal open space along the railway and Nakuru-Sigor Road.

Part III

[Figure 143.] Current landscape of Part III; aerial view.

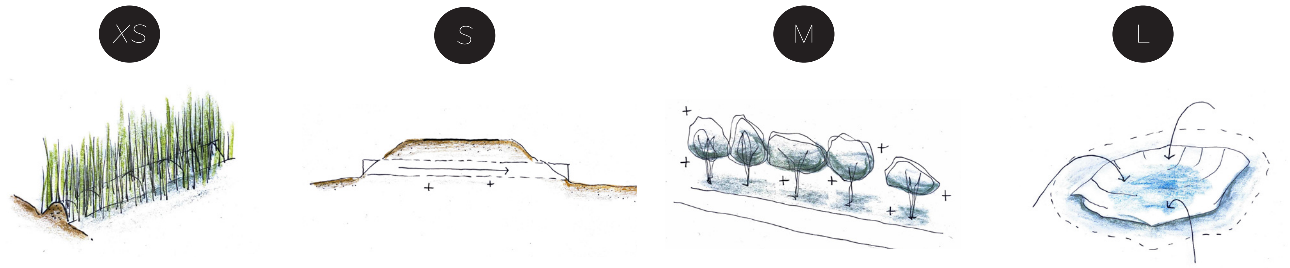
[Figure 144.] Part III positioned on masterplan

Water *Main return*

Culture *Co-benefit*

The third part of the proposed design focuses on establishing a retention corridor around the infrastructural lines below the Gioto dump, including the Nakuru–Sigor road and the railway (figure 141). This area is currently used for informal agriculture on public land but faces severe erosion and pollution due to the accumulation of runoff and an insufficient number of culverts beneath the infrastructure. These bottlenecks exacerbate erosion and intensify downstream flood risks.

The potential of this area lies in its available space, the presence of natural depressions, and the elevated position of the infrastructure, which together provide opportunities for interventions at multiple scales. The first step in reducing erosion and seasonal water accumulation, in line with the design concept, is the addition of culverts to guide runoff more effectively beneath the raised infrastructure to lower areas. This enables a more equal distribution of seasonal water between the proposed retention area near London and the agricultural fields between the infrastructure lines.



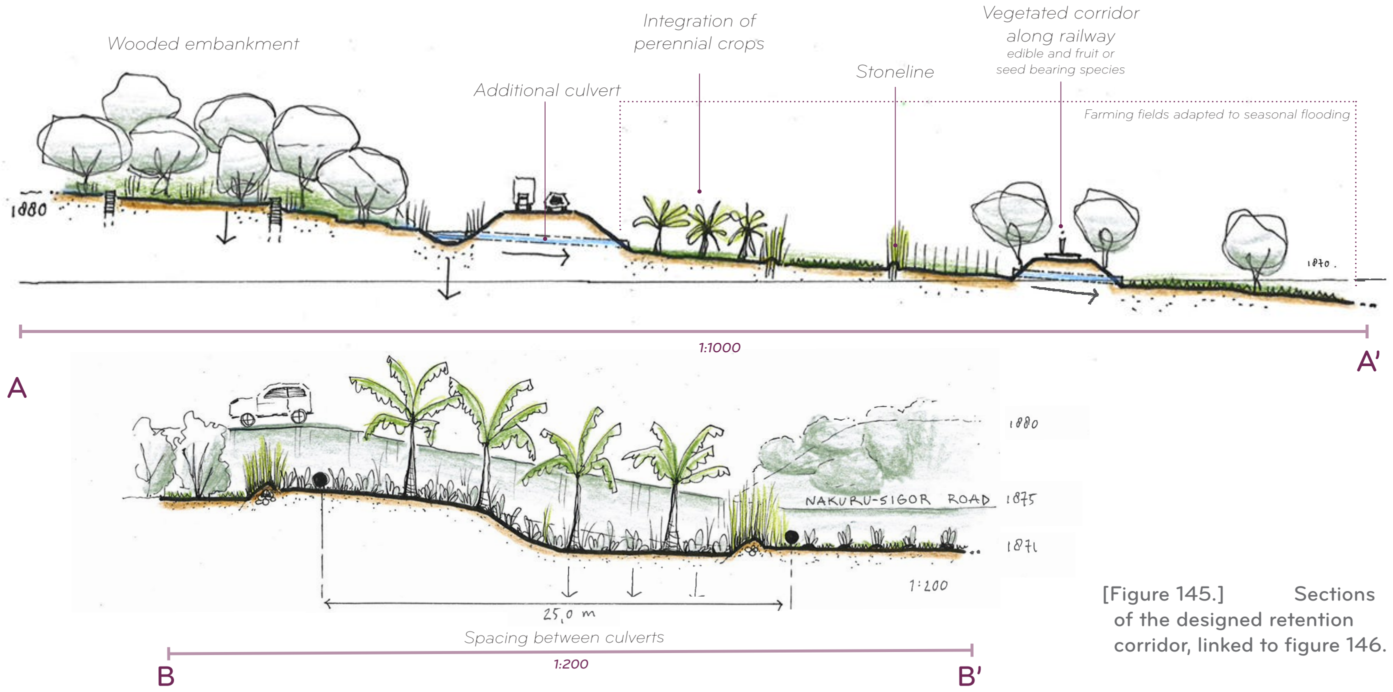
Stone lines to reduce runoff/enhance infiltration

Additional culverts to prevent bottlenecks

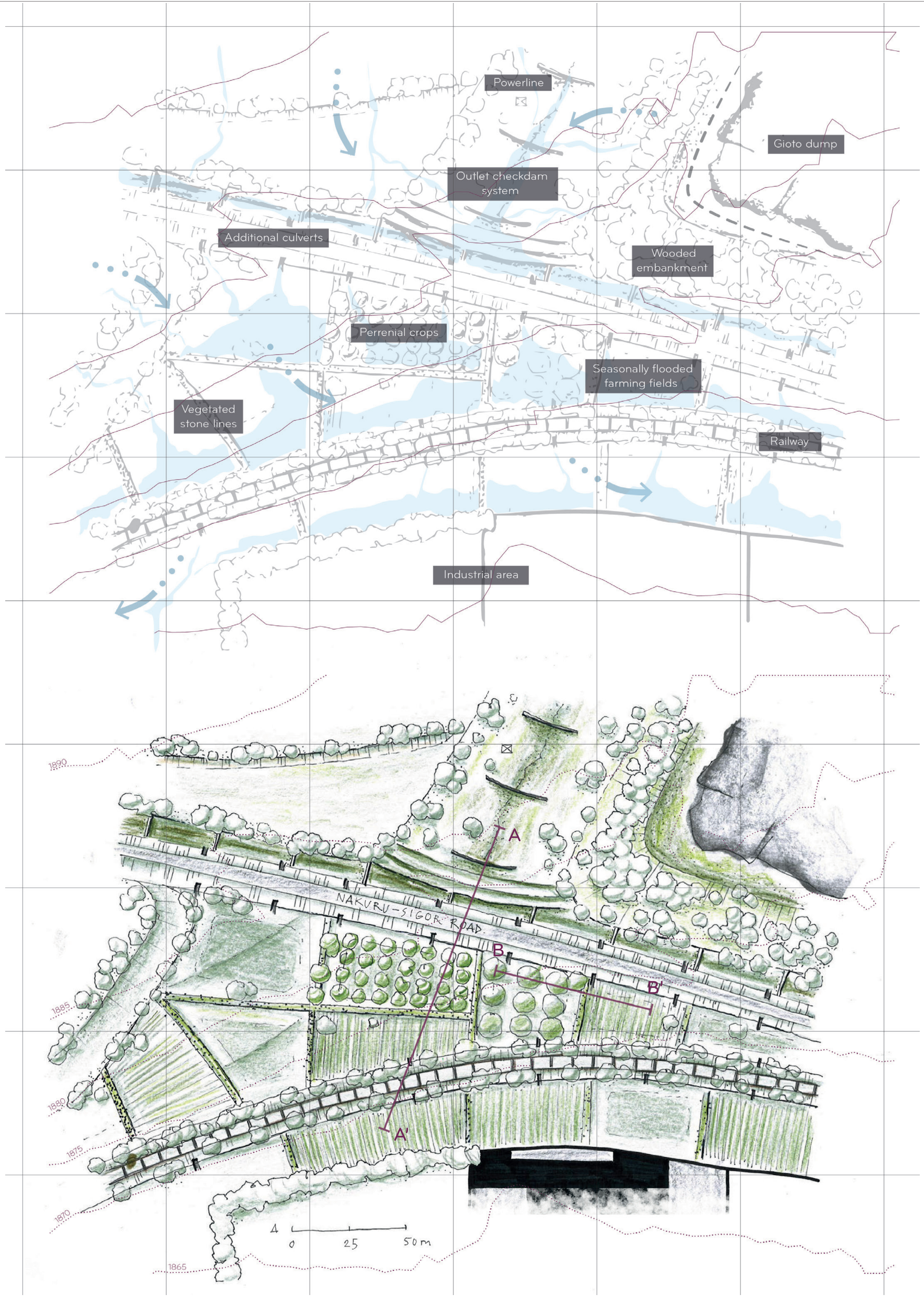
Expand (productive) vegetation next to infrastructural lines

Activation of natural depressions to enhance water retention capacity

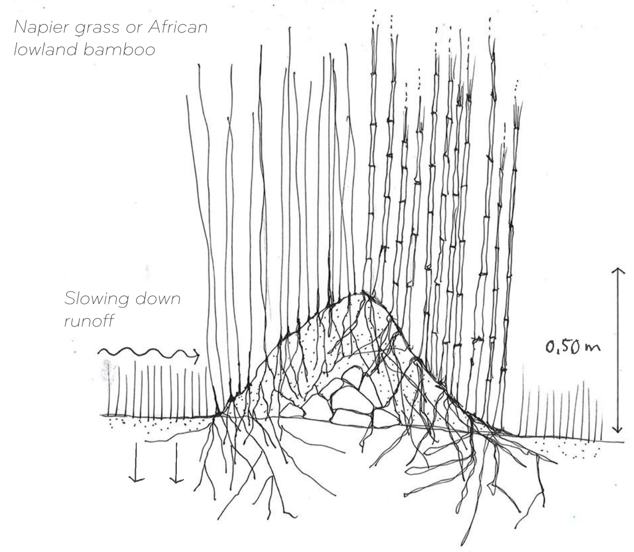
Within these fields, crops need to be adapted to seasonally flooded conditions (figures 145 and 146), allowing the area to gradually slow, collect, and partially infiltrate surface water. This process not only recharges soil moisture and groundwater reservoirs but also preserves long-term agricultural productivity. To further delay runoff, stone lines reinforced with deep-rooted species such as



[Figure 145.] Sections of the designed retention corridor, linked to figure 146.



[Figure 146.] Detailed map of proposed retention corridor, in between infrastructural lines and visualized during wet and dry season.



[Figure 147.] Constructive section of stone lines in the retention corridor, stabilized with Napier grass or African lowland bamboo. The root systems of these species reinforce the structure, further slow surface runoff, and prevent soil erosion.

Flow of water through the retention corridor

The proposed retention corridor slopes gently southward, collecting surface runoff from higher catchment areas such as the Kiamunyi hills. In the current situation, an insufficient number of culverts beneath the Nakuru–Sigor Road and the railway causes water to accumulate along these infrastructural lines, leading to local flooding and erosion of drainage structures.

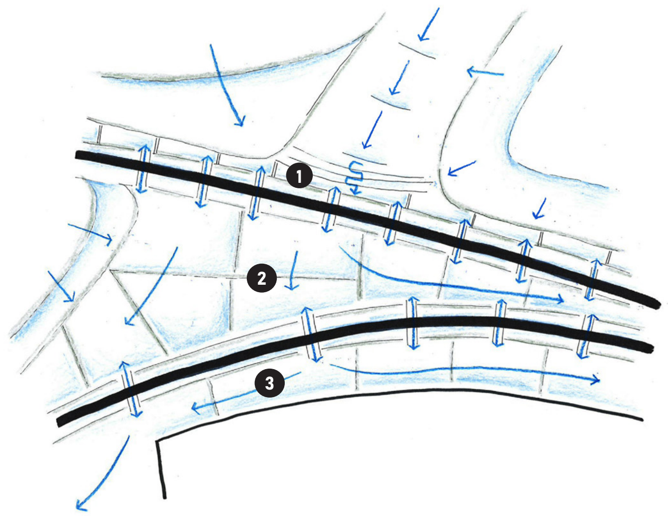
By introducing additional culverts at key locations that follow natural drainage lines, runoff can be evenly distributed across three functional zones (figure 148). In Zone 1, runoff enters the area through drainage channels along the Nakuru–Sigor Road and from the adjacent check-dam system. Excess water is guided through culverts toward Zone 2, located between the infrastructural lines. Here, small-scale agricultural plots are adapted to seasonal flooding, allowing water to be retained and gradually infiltrated. Crops tolerant to periodic inundation strengthen soil stability and contribute to water storage capacity.

Once Zone 2 reaches saturation, water is directed through additional culverts beneath the railway into Zone 3, where it is stored in lower-lying agricultural and industrial areas. These areas act as temporary retention spaces, reducing downstream flood peaks while supporting productive land use.

The overall system is designed as a multifunctional landscape that combines hydrological, ecological, and social objectives. Existing land-use functions are maintained and strengthened by involving local communities in the implementation and maintenance of the interventions within the corridor. In doing so, the design enhances both ecological continuity and social value, contributing to a more livable and resilient environment. Infrastructure, which once defined Nakuru's growth, is reimagined as a structuring element that supports the water chain, restores ecological connectivity, and offers an attractive recreational route linking the city center to its rural hinterland.

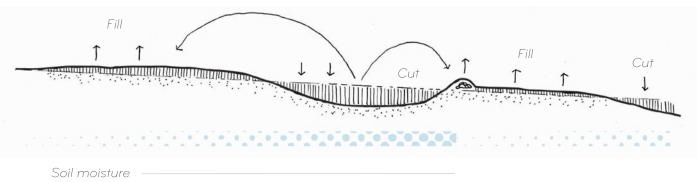
Napier grass or African lowland bamboo are proposed along field edges (figure 147). These species stabilize soils while also providing additional benefits, such as fodder or construction material, for local communities. Given their simplicity and low maintenance requirements, these measures can be implemented effectively at the small (XS) scale.

At a larger scale, replanting along infrastructure lines and field edges is essential to strengthen the retention function of this corridor. Vegetation provides shade that reduces soil evaporation, stabilizes the embankments of infrastructure, and lowers their suscepti-bility to erosion. In addition, replanting creates a continuous green corridor along the rail-way, which currently functions as an important pedestrian route connecting Nakuru's urban core with its rural hinterlands. To secure the long-term presence of vegetation in this heavily used public space, fruit- and seed-bearing tree species are proposed. These species will not only stabilize the soil but also generate tangible benefits for local residents, ensuring community ownership and care for the vegetation over time.

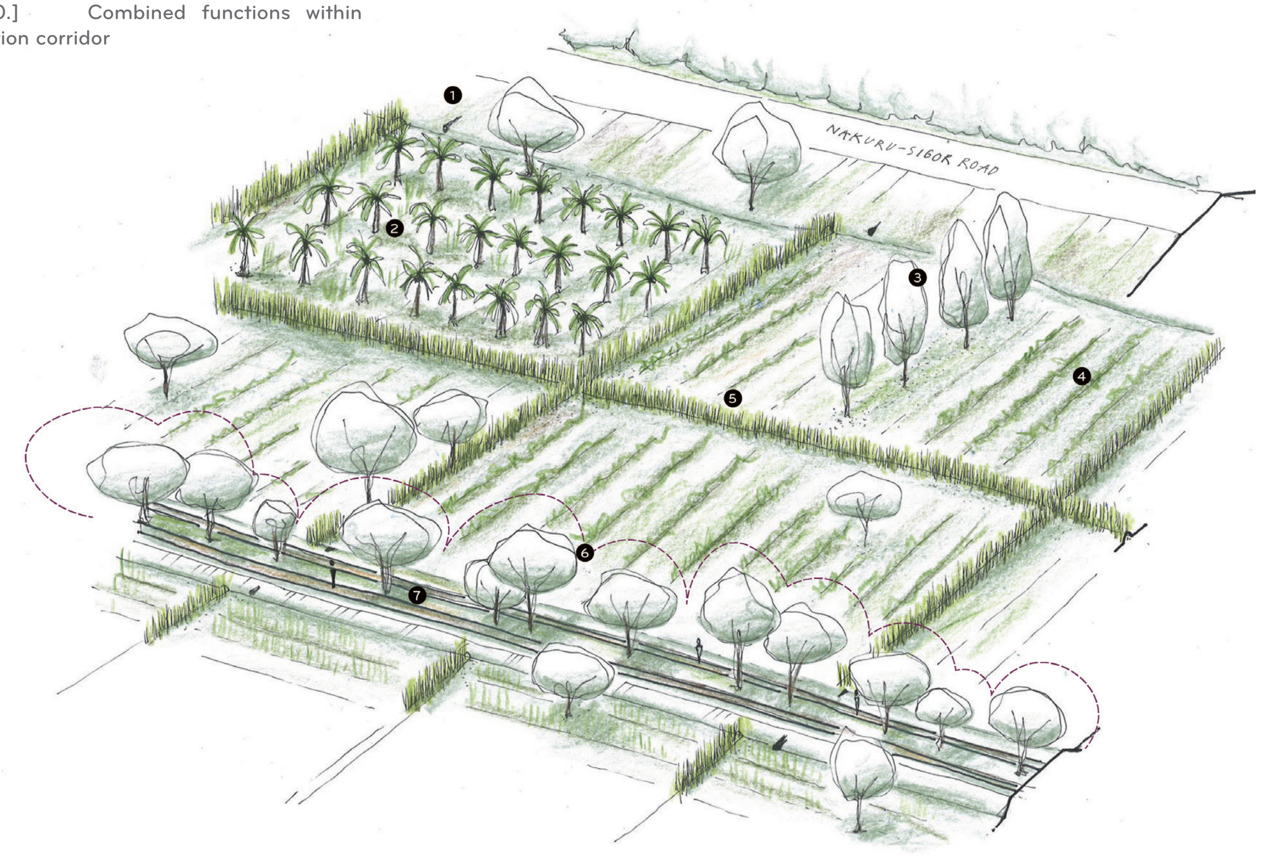


[Figure 148.] Waterflow direction through farming fields in the retention corridor

[Figure 149.] Elevation differences in the farming fields to create extra water storage

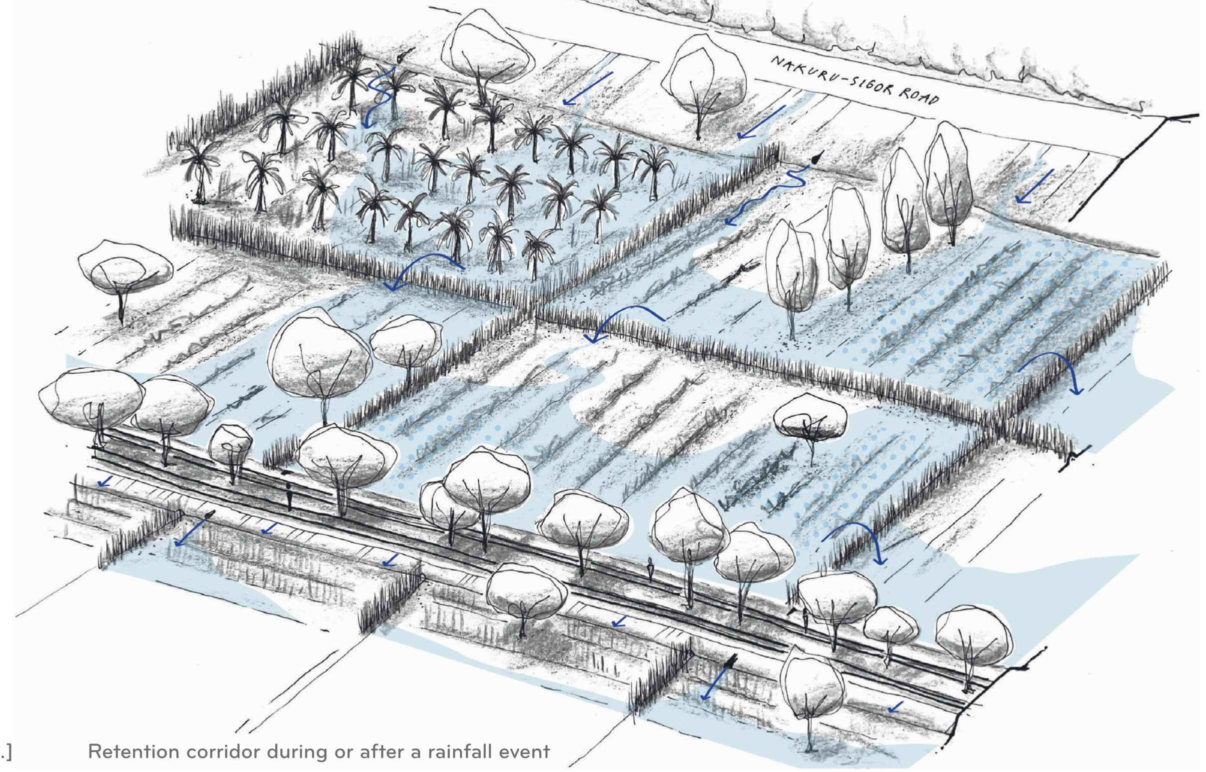


[Figure 150.] Combined functions within the retention corridor



1. Additional culverts to overcome blockages
2. Cultivation of perennial crops
3. Adding trees to cultivation plots for shading
4. Lower areas in agricultural plots for seasonal waterstorage
5. Stoneline vegetated with napier grass reduce runoff, combined with production of fodder
6. Vegetated corridor with fruit and seed-bearing species along the railway for shading and production
7. Railway as a recreational connector

During wet conditions

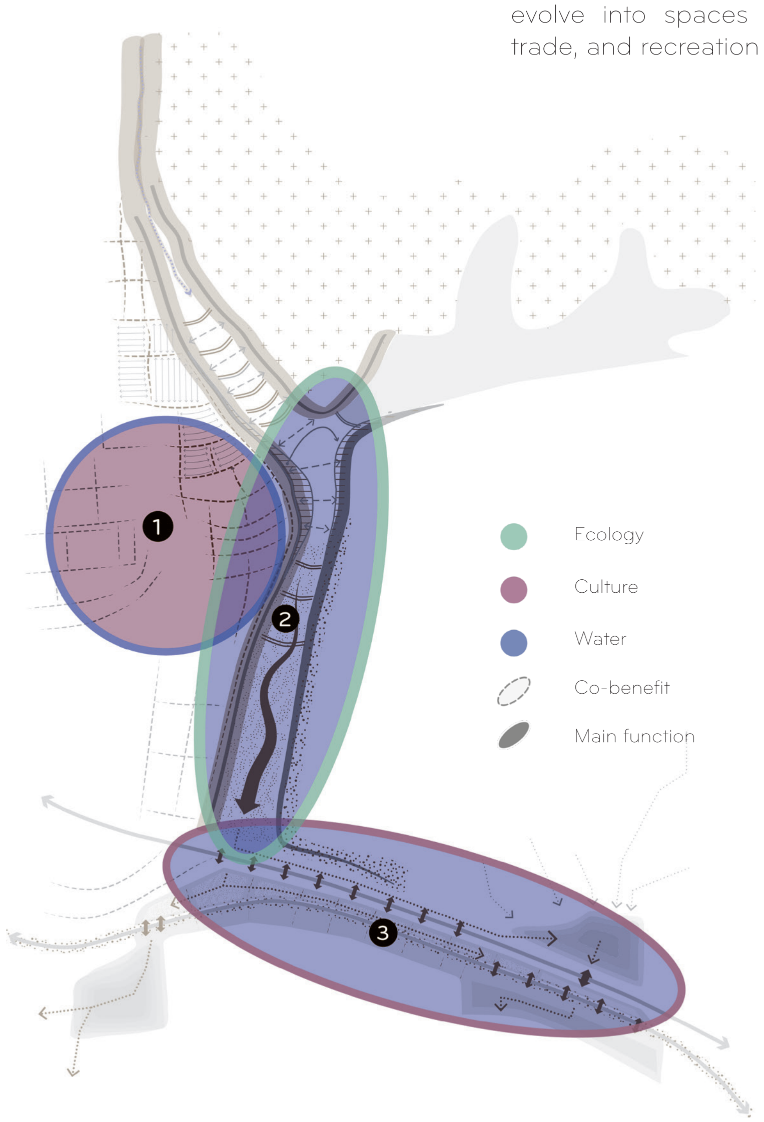


[Figure 151.] Retention corridor during or after a rainfall event

Returns to the overall system

As previously discussed, the detailed design explores how interventions at different scales can collectively support the hydrological, ecological, and social objectives of this research. Each design part (I-III) introduces a multifunctional landscape with a primary function responding to one of these objectives, while also generating co-benefits that strengthen the overall system. This demonstrates how the integration of nature-based and Lo-Tek solutions can restore ecological processes, support livelihoods, and enhance resilience across the watershed at the same time.

1. **PART I** - At first, changes in the agricultural system are proposed, by growing more diverse crops with agroforestry systems and contouring the landscape. These changes can stabilize and regenerate the soil, while producing a more diverse yield that can preserve the livelihoods of farmers in the Kiamunyi area. Additionally, an important co-benefit arouses from these agricultural changes as they promote the delay and infiltration of runoff in this area and support thereby the restoration of the water balance in this area.
2. **PART II -** The primary function of this part is to slow down and retain seasonal runoff within existing gully formations and reduce erosion by creating a seasonal riverbed with check dams and slow edges. This increases the storage capacity of the area. As co-benefits, these measures create space for the succession of natural vegetation, allowing the gully to function as an ecological corridor connecting to the Menengai Forest and enhancing biodiversity.
3. **PART III -** The primary function of this part, the retention corridor, is to collect and transport water while enabling infiltration in lower areas during or after rainfall events. The co-benefits are largely social and arise from adapting the agricultural system and replanting field edges and infrastructural corridors with productive and multipurpose vegetation. These measures restore soil and water systems while also improving the usability and livability of the area. Over time, this creates tangible benefits for local communities: increased agricultural productivity, more reliable harvests through enhanced soil moisture, and new income opportunities through the maintenance of retention areas and vegetation management. In addition, replanting along pathways and infrastructure provides shaded and greener environments that can evolve into spaces for social interaction, informal trade, and recreation

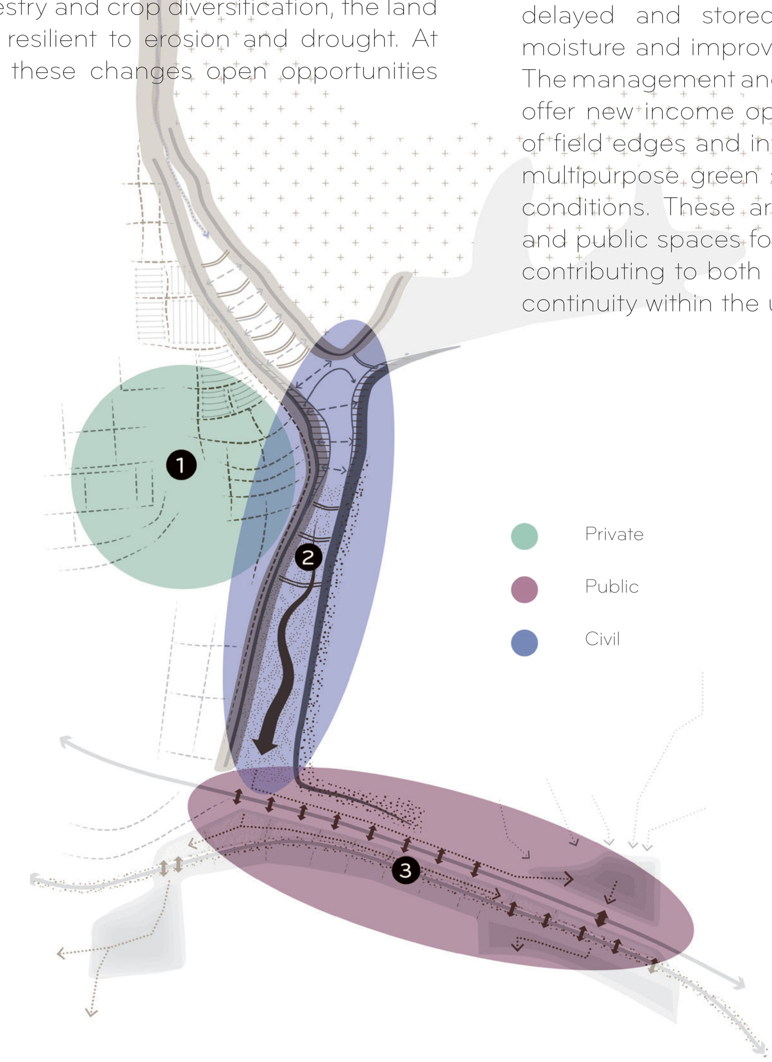


[Figure 152.] Main functions and co-benefits of the three design areas within the proposed restoration network

Returns to the stakeholder groups

This map illustrates how the proposed interventions generate specific benefits for different stakeholder groups present in the design area. Each part (I-III) of the design outcome delivers returns to a particular stakeholder group, depending on existing land ownership, use, and management responsibilities.
By linking ecological restoration with productive and social functions, the design ensures that each intervention strengthens both the local water system and the livelihoods connected to it. Runoff is delayed, infiltrated, and purified, while soil quality and agricultural productivity improve. These environmental gains translate into concrete social and economic benefits, such as greater agricultural security for farmers, reduced maintenance costs for public infrastructure, and new income opportunities for local communities.
In this way, the design demonstrates how systemic landscape interventions can create targeted amd complementary returns across private, public, and civil actors, fostering collaboration and long-term stewardship of the area.

1. **PART I - Private stakeholders**; In the upper zone, the proposed agricultural interventions secure the long-term productivity of farmland by regenerating soils and stabilizing production. Through measures such as agroforestry and crop diversification, the land becomes more resilient to erosion and drought. At the same time, these changes open opportunities for new economic activities, including processing alternative crops into livestock feed or bio-based building materials, which strengthen the financial stability of local farmers.
2. **PART II - Public stakeholders**; The second zone primarily benefits institutional actors and NGOs. Here, interventions such as check dams and infiltration zones increase groundwater availability and secure the water supply from boreholes. This improvement reduces dependence on expensive remediation projects by limiting pollution from the nearby dumpsite and controlling runoff quality. The realization and maintenance of these measures also generate large-scale employment opportunities for local residents, fostering social inclusion while strengthening regional water security. In addition, the improved management of seasonal runoff and the clear demonstration of co-benefits may attract investments from international organizations, enhancing the long-term sustainability of the project.
3. **PART III - Civil stakeholders**; In the lower retention corridor, the main function of water retention and transport also creates important returns for local communties. and informal users. The "commons" (chapter 3.5), who have established small-scale productive landscapes in this area, benefit from delayed and stored runoff, which enhances soil moisture and improves the productivity of their land. The management and maintenance of retention areas offer new income opportunities, while the replanting of field edges and infrastructure corridors introduces multipurpose green spaces that improve local living conditions. These areas provide shade, biodiversity, and public spaces for meeting, trade, and recreation, contributing to both social well-being and ecological continuity within the urban fabric.

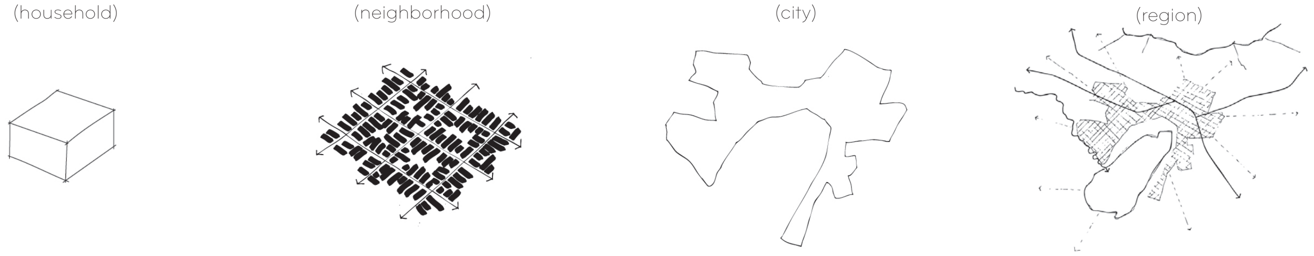


[Figure 153.] Stakeholder returns of the proposed interventions across private, public, and civil domains

Development | Sandwich-strategy

The sandwich strategy by Tjallingii (1995) is used to create an development strategy wherein the bottom layer and the top layer are connected through collaboration in the middle layer, which focuses on the actual implementation of the design. This prevents the approach from being purely decentralized or purely centralized, and instead ensures that spatial plans created at higher levels leave room for local initiatives. In this way, responsibility and support are shared across different scales. For this design, the proposed steps follow this logic and align with the principles of the sandwich strategy (Tjallingii, 1995). In this diagram the Sandwich-strategy has been applied on the design outcome of this research, to ensure inclusion of both the bottom and top layer in the development phase.

XS (household) | S (neighborhood) | M (city) | L (region)



Very local; | Mid-scale; | Large scale; | Very large;

Bottom layer

Connecting with local residents' and religous' associations

Workshops on site - testing with locals & introducing small-scale systems changes

Top layer

Formalizing design vision into spatial plan, focusing on key sites, and provide policies/resources for local action.

Finding investments from institutional organisations (NGO's, County Government, etcetera)

Middle layer

Local employment (of the youth) for realisation of proposed interventions

Maintenance by institutional organisations and local communites

Promoting long-term social-ecological resiliency of functions through a healthy urban ecosystem & recharging the groundwater reservoirs, while mitigating the effects of seasonal surface runoff

Upscaling; implementing design principles in the mid- and downstream area

[Figure 154.] Sandwich-strategy applied on the detail design study

01

The construction of contour-based measures forms the foundation for slowing surface runoff, stimulating the growth of natural vegetation, and shaping the basis of the design outcome. Considering the time vegetation needs to establish and become effective within the system, its impact will grow exponentially over the years. It is therefore essential to start early with the planting of key green corridors, such as along the railway line, since it will take time before the vegetation reaches sufficient size to contribute meaningfully to the landscape.

02

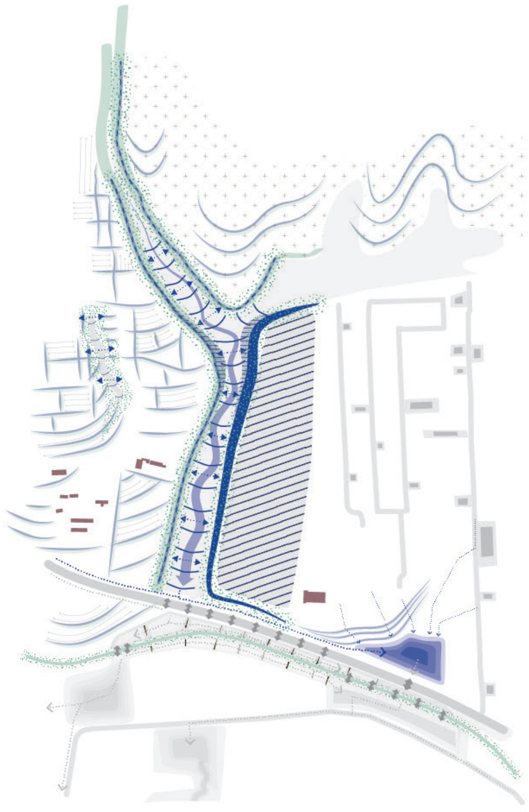
The second phase introduces larger-scale interventions, including a check dam system and a wooded embankment, to further slow seasonal runoff and disconnect it from major pollution sources. In addition, the first retention zone above Nakuru-Sigor Road should be implemented to store excess runoff at the earliest point. These measures not only improve local water quality but also create employment opportunities for surrounding communities. By this stage, the earlier contour-based measures will have allowed natural vegetation to establish and pioneer along the slopes. These first layers of planting already contribute to delaying and retaining runoff, while increasing infiltration capacity across the site.

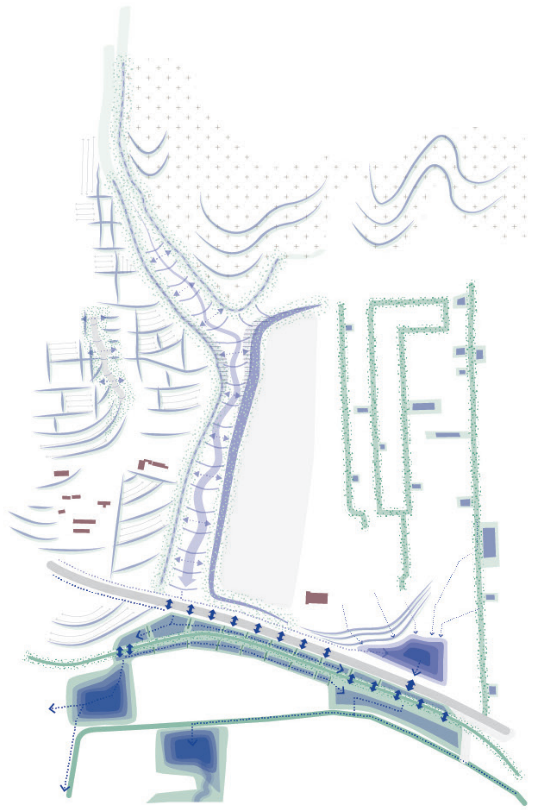
03

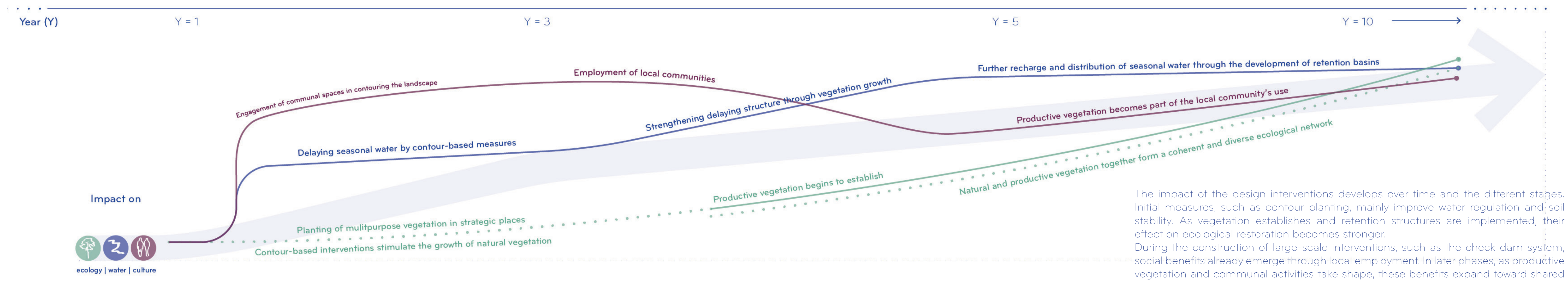
This phase focuses on strengthening the existing delay network by expanding retention capacity throughout the area. Strategically designed low-lying zones capture and store a significant amount of seasonal water, enhance infiltration, and encourage local use of collected water. The creation of the retention corridor plays a key role in distributing seasonal flows more efficiently while simultaneously greening the landscape with multipurpose vegetation. Together, these areas contribute to improved ecological continuity and local resilience.

04

By the final phase, the previously planted multipurpose vegetation has matured and can now be utilized for community benefit. It is strategically positioned along frequently used routes and communal spaces, enriching both ecological value and daily livability. Small-scale interventions can continue to evolve through local initiative, such as aligning cultivation parallel to contour lines or maintaining stone lines within the retention corridor. By integrating green-blue interventions that align with natural landscape processes, the system becomes adaptive and resilient to changing climatic conditions. Over time, it will continue to strengthen and expand as a self-sustaining landscape network.







The impact of the design interventions develops over time and the different stages. Initial measures, such as contour planting, mainly improve water regulation and soil stability. As vegetation establishes and retention structures are implemented, their effect on ecological restoration becomes stronger.

During the construction of large-scale interventions, such as the check dam system, social benefits already emerge through local employment. In later phases, as productive vegetation and communal activities take shape, these benefits expand toward shared maintenance, local food production, and improved living conditions.

6.9. Vision; What is next?

In this research, a first step has been made towards a landscape-based strategy for the western part of Nakuru City. A design vision and strategy was developed for all three flow zones (up-, mid-, and downstream) of the defined seasonal sub-watershed, accompanied with suitable design principles. Following a spatial assessment, the upstream zone was selected for a detailed design study, where several design principles were applied and tested.

The detailed design phase not only tested spatial and hydrological strategies but also revealed how ecological and social functions can be integrated within dense urban areas. It demonstrated that technical measures for flood mitigation gain long-term value when combined with community participation, creating shared responsibility for maintenance and adaptation.

Insights from the upstream design informed a broader systemic understanding of the watershed, emphasizing interdependencies between retention capacity, urban morphology, and community practices across zones. This systems-based perspective provides a foundation for future decision-making and prioritization within Nakuru's western catchment.

As shown in the section of Chapter 6.4, which illustrates the systemic changes generated by these interventions, the next step beyond this research would be to expand the study by a detailed design study for the downstream zone. Even after the proposed interventions upstream, critical situations will likely continue to appear over time in the lower areas, making further action downstream essential.

Several principles that were implemented upstream—such as using public land for large-scale water retention, reactivating communal spaces for water harvesting, and strengthening the interaction between people and water—could also be applied downstream, provided they are carefully adapted to the local social and spatial context.

Moreover, the design process highlighted several challenges that should inform the next steps: limited data availability, fragmented institutional collaboration, and the need for long-term monitoring. Addressing these aspects through cross-agency partnerships, participatory mapping, and iterative design processes will be key to scaling the proposed LO-tek and nature-based solutions effectively across Nakuru's Western (seasonal) watershed.

These insights form the basis for the following discussion and conclusion, where the broader implications for urban water resilience and the integration of nature-based approaches in rapidly urbanizing contexts are explored.

[Figure 155.] Overview of seasonal-subwatershed with the detail design for the upstream integrated.


Flooded settlements on the Western city edge, bording the RVIST terrain (photo by author)

Lessons taken

PART IV

Small settlements positioned at the border of Menengai Forest (photo by author)

Chapter 7. Design evaluation and reflection

Seasonal water flows can be reframed from a source of risk into a spatial tool to strengthen resilience, connectivity and freshwater recharge

This research explored how a landscape-based spatial strategy can strengthen social-ecological resilience in Nakuru, Kenya, by improving freshwater availability and reducing the impacts of seasonal runoff. The study addressed this main question through four sub-research questions, which together guided the process from understanding the local water system to developing and testing design principles and reflecting on their wider relevance.

RQ1: How did the water and socio-cultural system in Nakuru change over time in relation to the natural and urban landscape?

The evolution of Nakuru's landscape shows a shift from a naturally balanced ecosystem to a highly altered and fragmented urban environment. Before colonial settlement, water and vegetation patterns followed seasonal rhythms, and local communities lived in close connection with these natural systems. During the colonial period, large-scale agriculture, deforestation, and the introduction of infrastructure such as the railway disrupted this balance. These interventions initiated intense land-use change and reduced the capacity of the landscape to absorb and store water.

After independence, population growth and rapid urbanization further increased pressure on land and water resources. Expanding agricultural areas and paved surfaces led to excessive surface runoff, soil erosion, and declining groundwater recharge. Today, Nakuru faces recurring problems of too much, too little, or too polluted water, varying through the seasons and affecting the most vulnerable communities. This transition has changed how people relate to their environment: water has shifted from being a guiding element for settlement and productivity to a growing source of risk.

RQ2: What design principles and strategies are suitable for recharging freshwater availability in the social-ecological context of Nakuru City?

Building on the theoretical framework and the site analysis, this research identified three interrelated design layers: water, ecology, and culture. Together they form the basis of the landscape-based design strategy. Each layer corresponds with one of the guiding lenses of this thesis and collectively addresses the imbalance between hydrology, environment, and society in Nakuru's seasonal sub-watershed.

The water layer forms the structural backbone of the strategy. It redistributes and retains seasonal flows by linking the functions of the three flow zones: delay and infiltrate in the upstream, transport and purify in the midstream, and collect and reuse downstream, into a conherent spatial system. Interventions such as terracing, vegetated buffers, check dams, constructed wetlands, and retention zones slow down, filter, and store runoff, turning it from a hazard into a resource. It works with existing structures like infrastructure, by reintventing these lines as delaying measures.

The ecology layer reconnects fragmented natural patches and strengthens the relationship between soil, vegetation, and water. It proposes reforestation of steep slopes, rehabilitation of gullies as ecological corridors, and the introduction of productive green spaces such as agroforestry and multipurpose vegetation in important commual public spaces. These measures improve infiltration, reduce erosion, and enhance biodiversity while supporting local livelihoods.

The socio-cultural layer integrates human and ecological systems by aligning spatial interventions with local use, awareness, and participation. Public spaces such as schoolyards, church grounds, and community plots are reimagined as multifunctional water landscapes that store runoff while offering social and educational value. The layer also promotes bottom-up and low-tech (Lo-TEK) approaches that build on local knowledge and empower communities to maintain these interventions over time.

Together, these design layers turn analytical insights into an actionable framework that is ecologically sound, spatially coherent, and socially grounded. By combining water management with ecological and cultural perspectives, they guide the creation of restoration networks that can recharge freshwater availability and strengthen resilience throughout Nakuru's watershed.

RQ3: How can these design principles be implemented into a landscape-based design and long-term strategy that recharges freshwater availability in Nakuru City?

The analysis of the seasonal sub-watershed revealed three distinct flow zones, each requiring a specific approach to water management: delay and infiltrate in the upstream, transport and purify in the midstream, and collect and reuse downstream. Together, these zones form the design vision of this research, which connects hydrological, ecological, and social processes throughout the watershed.

From this vision, an overarching design concept was developed: Reinventing natural depressions and runoff routes to enable gravity-based retention and purification of runoff for ecological and social use. This concept translates the analytical findings into a practical spatial approach that guides how water can move naturally through lower areas of the landscape while also creating opportunities for ecological restoration, productive land use, and community interaction.

The implementation of this concept was explored through a detailed plan for the spatial link between the upstream and midstream areas. Here, design principles were combined and applied according to the functions of this zone, focusing on delaying, infiltrating, transporting, and purifying seasonal runoff. The proposed design integrates hydrological, ecological, and social objectives to create multifunctional outcomes that strengthen both water regulation and community resilience. For example, introducing sustainable agricultural practices such as agroforestry on erosion-prone slopes transforms contour lines into vegetated buffers that slow runoff, improve infiltration, and stabilize soil while supporting local livelihoods.

A key aspect of the design explorations is the creation of co-benefits that extend beyond each intervention's primary purpose. By linking ecological restoration with social and productive uses, the interventions become more effective, inclusive, and sustainable over time. This approach supports the implementation of social-ecological restoration networks on site, strengthens local ownership, and reduces the risk of encroachment by aligning interventions with daily needs and shared community values.

The design explorations are structured in three interconnected parts: sustainable agricultural changes, gully rehabilitation, and a retention corridor. Each part includes interventions that operate at different spatial scales and involve multiple stakeholder groups. This multi-scalar approach encourages collaboration between local residents, community associations, and institutional actors to ensure long-term management, adaptability, and local relevance of the proposed design.

In this research, scales are treated conceptually rather than as fixed sizes. The goal is to show how actions at one level reinforce those at another. Small-scale measures such as stone lines or vegetated contour strips help slow runoff locally, supporting medium-scale interventions such as culverts and retention basins that guide and store water. At the largest scale, these flows reconnect with natural depressions or constructed wetlands that retain and reuse water across the watershed.

The effectiveness of each measure depends on three main conditions: the stakeholder level, the ability to maintain the intervention over time, and financial feasibility. Larger-scale interventions often require institutional coordination and investment, while smaller actions can be initiated and maintained by local communities.

Altogether, these design explorations demonstrate how the developed principles can be spatially implemented to form a social-ecological restoration network that operates across scales. The upstream zone was developed in greater detail to test and visualize how such a network can function as a prototype for the wider watershed. It illustrates how interventions can simultaneously recharge freshwater, control erosion, and strengthen ecological continuity while creating shared, productive spaces for the community.

RQ4: How can the design outcome for Nakuru City inform and inspire future sustainable urban development in regions with similar challenges?

This research builds on the broader understanding presented in the introduction of this research (Chapter 1), which outlines the global trend of rapid urbanization and its growing conflict with ecological systems. Against this backdrop, Nakuru was selected as a critical case study due to its visible water-related challenges, where seasonal runoff, flooding, and water scarcity converge as a result of uncontrolled expansion and fragmented land-use practices.

The study has shown that addressing water challenges in rapidly urbanizing areas like Nakuru requires systemic strategies that connect natural processes with spatial and social structures. The proposed framework redefines seasonal runoff from a source of risk into a driver of resilience, connectivity, and freshwater recharge. Even though the detailed design outcome represents a first step, the systemic approach developed within this research provides a basis for up scaling the interventions across watersheds with similar conditions. It demonstrates the potential of landscape architecture in Global South contexts when guided by systemic thinking, local knowledge, and cultural sensitivity.

Landscape-based spatial design proves valuable not only for understanding complex relationships but also for translating them into clear, actionable strategies that can foster long-term, community-based climate resilience and work with the natural systems within the landscape. Although rooted in Nakuru's context, the guiding design principles, such as working with seasonal variability, restoring water pathways, connecting existing natural patches and communal places for interaction between people and water, offer insights for other regions facing comparable environmental and hydrological pressures. Their success elsewhere, however, depends on careful adaptation to local conditions and strong community involvement to ensure long-term effectiveness.

[Figure 156.] Value of the developed spatial strategy assessed through the three Ecopolis pilars - Flow, Area and Participants (Tjallingii, 1995).

FLOW

Seasonal runoff is delayed, collected, infiltrated, and partly reused through landscape-based interventions. These actions help to reduce flooding and erosion, recharge groundwater, and improve water quality, turning excess runoff from a hazard into a valuable resource. By restoring natural drainage routes and aligning them with local land use and infrastructure, the strategy re-establishes a balanced and self-regulating water system on Nakuru's western side.

AREA

Floodplains, stream buffers, and retention zones are reimagined as multifunctional landscapes that regulate seasonal water while supporting biodiversity, agriculture, and everyday community life. Integrating ecological restoration with spatial development creates a continuous green-blue network that links urban and rural areas, contributing to a more adaptive and resilient regional system.

PARTICIPANTS

Communities, institutions, and government bodies share responsibility for developing, managing, and maintaining the landscape. Grounded in local knowledge and collective action, interventions operate at different scales and locations. Through low-tech and participatory approaches, stewardship becomes a daily practice that fosters local ownership, awareness, and long-term adaptability.

7.2. Discussion

The chosen topic, a landscape-based spatial strategy for recharging freshwater availability in Nakuru, Kenya, directly relates to designing resilient landscapes that integrate ecological, social, and hydrological systems. By addressing runoff management and groundwater recharge through spatial design, and by examining how this can strengthen social and ecological resilience, the project contributes to the broader (professional) field by developing sustainable strategies for complex and interconnected urban and peri-urban challenges.

Interaction between research and design

Research and design have continuously informed one another in this project. The analytical phase, including a spatial analysis on different scales and interviews with stakeholders on site, revealed the main challenges of seasonal runoff, erosion, and pollution, which could all be connected to an imbalanced water system. These findings directly shaped the design vision by assigning functional roles to upstream, midstream, and downstream zones, acknowledging there interconnectivity. In turn, the design process clarified research priorities: for example, testing the feasibility of terracing and agroforestry, or exploring how communal spaces could be integrated as retention sites, required further consultation with local experts and case studies. This iterative relationship ensured that the design outcome is both evidence-based and spatially grounded in the context of Nakuru

Approach and Methodology

The research combined systemic landscape analysis with a design-led approach, using both research on and through design. This combination made it possible to study complex relationships between water, ecology, and human activity while developing concrete spatial solutions for Nakuru. Local knowledge played a key role throughout the process. By studying existing initiatives and interviewing experts, the research learned from on-site practices and reintroduced these insights within an explorative spatial strategy for the city.
Working in a data-scarce environment demanded a flexible and iterative methodology. The absence of detailed data limited quantitative precision but encouraged a more spatial and systemic way of reasoning. Maps, drawings, and site observations became essential tools to test hypotheses and visualize potential effects of interventions. This design-driven method helped to generate applicable strategies even under uncertain conditions. The approach worked well to address the complex, multi-scalar nature of the problem, even though it required continuous balancing between conceptual frameworks and estimating context-specific details.
The Ecopolis framework by Tjallingii (1995) was particularly valuable in bridging theory, analysis, and design. It offered a structure for developing an integrated and coherent spatial strategy for Nakuru, linking different stakeholder levels and emphasizing the management of interconnected urban and ecological systems. The framework also informed implementation of the two-network strategy on site, combining water flows (blue) and (black) infrastructure to strengthen chain management across the watershed.

Academic and Societal Value

This research demonstrates how landscape architecture can address water-related challenges in a Global South context by linking systemic analysis to spatial strategies. The study contributes to the discourse on social-ecological resilience and runoff management, providing an applied interpretation of the Ecopolis framework (Tjallingii, 1995) within a developing country. It shows how the discipline can bridge the gap between theory, analysis, and design, offering a coherent framework that connects different stakeholder levels and emphasizes the management of interlinked urban and ecological systems.
The project illustrates that landscape architecture can move beyond site-specific design toward structuring entire ecological and hydrological systems. The spatial strategy developed for Nakuru frames the landscape as an interconnected network that can collect, delay, and purify runoff while supporting ecological restoration and human use. This systemic perspective highlights the role of the landscape architect not only as a designer of places but also as a mediator between natural processes and social systems. It positions the profession as one capable of translating complex environmental dynamics into spatial frameworks that guide long-term change.
Within the broader professional field, this study reinforces the importance of design as both an investigative and projective tool. In situations where quantitative data and technical resources are limited, design enables the discovery of patterns, the testing of spatial ideas, and the communication of relationships that would otherwise remain invisible. The project demonstrates the value of design as a research method that bridges disciplines, translating analytical findings into tangible strategies for action.
The findings further underline the relevance of nature-based and low-tech approaches in hydrological design. By emphasizing multifunctionality, where interventions simultaneously serve ecological, social, and productive

roles, the research contributes to the ongoing discussion on how sustainable impact can be achieved under conditions where resources are limited. The Nakuru case shows that effectiveness depends not only on spatial form but also on alignment with cultural practices, governance structures, and community engagement. In this sense, landscape architecture functions as a language of negotiation between science and policy, between communities and infrastructure, and between short-term needs and long-term resilience.

Societally, the research proposes realistic and adaptable interventions that respond to urgent issues of flooding, water scarcity, and pollution in Nakuru. With their low-threshold character and use of local materials, these strategies offer feasible steps toward restoring the water system and recharging groundwater. Ethical considerations have been central throughout the process. The recognition of commons and the dominance of informal practices in public space were explicitly integrated into the design to ensure that interventions do not displace but rather support vulnerable groups who depend on these landscapes.

Throughout the research process, ethical considerations played a central role. The recognition of commons and the dominance of informal practices in public space were explicitly integrated in the design, ensuring that interventions do not displace but rather support vulnerable groups who depend on these landscapes. At the same time, I must add a degree of caution; because of my own background, I remain an outsider and lack a certain familiarity with the Kenyan context and culture. While active engagement with stakeholders at multiple levels helped to bridge this gap in relevant ways to this research, it is likely that some distance to the Kenyan context still remains in the outcomes of this research.

Transferability of results

This research developed a systemic design strategy that approaches the watershed as an interconnected system of flows, capable of managing water dynamically across spatial and social scales. The strategy connects the upstream, midstream, and downstream zones through three guiding functions: delay and infiltrate, transport and purify, and collect and reuse. In this framework, water is not treated as a threat but as a continuous resource that can be stored, filtered, and reused throughout the landscape. The strength of this approach lies in its scalability. It provides a structure that can be adapted to other watersheds, offering guidance for designing resilient landscapes that integrate hydrological, ecological, and social processes.

To test and refine this systemic framework, the upstream zone of Nakuru's seasonal watershed was developed in detail. Here, the overarching principles were translated into tangible design interventions suited to the semi-arid environment and the socio-cultural context. Through terracing, agroforestry, check dams, and retention areas, the design demonstrates how runoff can be delayed, infiltrated, and purified while improving soil stability, restoring biodiversity, and maintaining productive land use. These explorations illustrate how a social-ecological restoration network can function in practice, addressing both environmental challenges and community needs.

The insights gained from these explorations show how the framework can be adapted to other contexts. Its transferability depends on flexibility rather than replication. The guiding principles remain the same, but their spatial form, scale, and implementation must respond to local conditions such as topography, governance, and land-use practices. Successful application elsewhere will depend on collaboration between communities, institutions, and local authorities to ensure long-term management and ownership. Without this foundation, interventions risk losing their intended function or being replaced by informal uses that respond more directly to livelihood needs.

The Nakuru case therefore offers both a conceptual model and a practical example of how landscape architecture can strengthen water resilience in rapidly urbanizing regions. By combining systemic thinking with place-based design, it demonstrates how runoff can become a source of freshwater, ecological regeneration, and social value, contributing to a more adaptive and resilient urban landscape.

Learning Process

This project has been a continuous learning experience in working with uncertainty and translating complex systems into spatial strategies. I learned to critically assess the role of data gaps and to develop methods that allow the design to progress despite these uncertainties. Working with incomplete or fragmented data emphasized the importance of design as a research tool that allows testing ideas spatially, reasoning through drawings and maps, and identifying opportunities that quantitative models alone cannot reveal.

The process deepened my understanding of how spatial strategies can connect ecological processes with social needs, particularly in vulnerable and fast-changing urban contexts. It also taught me how systemic and design-based approaches complement one another. Analysis helps to reveal the structure of problems, while design explores how solutions might work spatially and socially. This balance between analytical reasoning and creative exploration proved essential in studying Nakuru's seasonal watershed, where environmental, social, and hydrological systems are closely connected.

I also gained new insight into the potential of Lo-Tek and nature-based solutions. These approaches generate multiple co-benefits such as improved soil health, biodiversity restoration, and livelihood support, beyond their primary hydrological function. By working with natural processes instead of controlling them, they provide more adaptive and long-term solutions that fit the realities of the Global South, where maintenance capacity and resources are often limited.

On a personal and professional level, this research taught me that long-term feasibility depends not only on technical design quality but also on embedding interventions within local practices, communities, institutions, and governance systems. Recognizing commons and informal practices as integral parts of the city was essential for creating feasible and accepted outcomes. This understanding reinforced my view that cities like Nakuru must be seen as living ecosystems, closely linked to their surrounding environments and dependent on them for their resilience, livability, and long-term sustainability.

Future directions

The outcomes of this research open several directions for further exploration.

First, there is a need to test the proposed spatial principles through on-site pilot projects that monitor both hydrological and social performance over time. Long-term observation could provide crucial evidence on how restoration networks affect groundwater recharge, soil stability, and community benefits.

Second, future studies could examine how governance, finance, and land tenure systems can support the implementation of such landscape-based strategies. Developing tools and policies that connect design proposals with planning and management frameworks would help move from vision to practice.

Third, the principles developed here could be explored in comparative studies across different urban contexts. Understanding how systemic design methods perform in other semi-arid cities, or in places facing contrasting climatic and social pressures, would help refine their adaptability and broaden their relevance.

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Appendix

As part of the fieldwork conducted in Nakuru County, I visited the Botanical Department at Egerton University, where I met with Dr. Patrick Kisangau, a botanist specialized in native vegetation and ecological restoration. The meeting aimed to gain a deeper understanding of local vegetation types and their potential role in developing Nature-Based Solutions (NBS) for the Nakuru region.

During the discussion, valuable insights were provided into the ecological functions of both native and introduced plant species, focusing on their relevance for water management, soil stabilization, and climate resilience. It was explained that prolonged droughts, in combination with shallow root systems, cause many plant species to be washed away during rainy seasons. This cyclical pattern of prolonged droughts and intense rainfall has intensified in recent years and is directly linked to broader climatic changes in the region. According to Dr. Kisangau, the overall trend points toward a semi-arid climate, with heavy rainfall events becoming more sporadic and unpredictable. As a result, several tree species that were considered indigenous fifteen years ago may no longer be found in the same areas today, due to both climate shifts and ongoing land-use changes leading to vegetation relocation.
Beyond the ecological perspective, Dr. Kisangau emphasized that the multifunctionality of plant species is deeply rooted in Kenyan culture. Many plants are traditionally used for multiple purposes—ranging from food and medicine to biofuel and building materials—reflecting an integrated understanding of natural resources and livelihoods. Recognizing these cultural dimensions is crucial when proposing new planting or restoration strategies, as they determine not only ecological suitability but also community acceptance and sustainability.

Overall, the meeting highlighted how botanical expertise can inform the design of resilient landscapes in Nakuru. It clarified the interconnection between vegetation structure, hydrological processes, and socio-cultural practices, providing essential knowledge for the development of a planting matrix that supports both ecological restoration and community resilience in the context of Nakuru. within the chosen research-area of this research.

[Figure 157.] (Left) Physical herbarium made by the department over the years; (right) Constructed wetland on campus for research purposes (photo left by B. de Jong; photo right by author)

Planting matrix

Tree species

Name	Charateristics	Habitat	Usage	Recommended planting zone
Albizia gummifera	Deep-rooted, nitrogen-fixing, improves soil structure	Highlands and mid-elevation slopes	Provides shade, enhances soil fertility, supports biodiversity	Upstream / Midstream (forest transition areas)
Acacia xanthophloea	Native species, stabilizes riverbanks, tolerates seasonal flooding	Riparian and wetland edges	Erosion control, shade, supports riparian ecosystems	Midstream / Downstream (riparian buffers)
Prunus africana	Deep-rooted, fast-growing, stabilizes soil	Highlands and riparian areas	Bark used for medicinal purposes, supports biodiversity	Upstream (agroforestry and biodiversity restoration)
Croton megalocarpus	Deep-rooted, drought-tolerant	Upland and dryland habitats	Source of biofuel, shade, soil stability	Upstream (productive slopes)
Grevillea robusta	Deep-rooted, improves soil fertility, softwood	Highland and mid-elevation areas	Timber, construction poles, shade; multipurpose species	Upstream (agroforestry and slope stabilization)
Acacia albida (Faidherbia albida)	Nitrogen-fixing, moisture-retaining, drought-resistant	Semi-arid slopes and drylands	Shade, improves soil fertility, stabilizes slopes	Upstream (erosion control and soil restoration)
Acacia nilotica	Nitrogen-fixing, supports infiltration	Dryland and riparian zones	Firewood, shade, improves soil	Midstream / Downstream (riparian corridors)
Moringa oleifera	Fast-growing, drought-tolerant, antibacterial properties	Semi-arid to sub-humid zones	Water purification (seed use), edible leaves, medicinal tree	Midstream (retention and purification zones)

Grasses and groundcovers

Name	Charateristics	Habitat	Usage	Recommended planting zone
Oxytenanthera abyssinica (African lowland bamboo)	Fast-growing, deep-rooted, forms dense clumps	Riverbanks and lower slopes	Gully rehabilitation, building material, renewable biomass	Up-, mid- and downstream (gully and riparian restoration)
Cenchrus ciliaris (Buffel grass)	Drought-tolerant, fast-growing, strong root structure.	Grasslands and semi-arid zones	Fodder, soil stabilization, erosion control	Upstream / Midstream (slope stabilization)
Vetiver grass (Chrysopogon zizanioides)	Deep root system, prevents erosion, controls runoff	Slopes, gullies, along contour lines	Slope stabilization, reduces runoff velocity	Upstream (contour-based interventions)
Chloris gayana (Rhodes grass	Deep-rooted, stabilizes soil, retains moisture	Grasslands, areas prone to runoff	Fodder grass, improves infiltration	Upstream / Midstream (runoff control)
Panicum maximum (Guinea grass)	Dense ground cover, high water retention	Grasslands and buffer zones	Fodder, erosion control	Upstream / Midstream (buffer strips)

Aquatic and wetland vegetation

Name	Charateristics	Habitat	Usage	Recommended planting zone
Typha domingensis (Cattail)	Emergent aquatic plant, traps sediments	Shallow wetlands and swamp margins	Water purification, flood buffering	Downstream (wetlands and retention zones)
Cyperus papyrus (Papyrus)	Dense root mat, purifies water	Wetlands, lakeshores, riverbanks	Natural filter, provides wildlife habitat	Downstream (wetlands and purification zones)
Phragmites mauritianus (Reed)	Deep rhizomes, prevents erosion	Wetlands, drainage corridors	Water purification, soil stabilization	Downstream (wetlands and drainage corridors)

[Figure 158.] Climate-resilient planting matrix adapted to the local conditions of Nakuru, based on information from the Botanical Department of Egerton University (2025).

During the site-visit in Nakuru, on the 12th and 13th of February, the TU Delft was invited to join a two-day introducing design-workshop for the Water as Leverage (WaL) project in Nakuru, as being part of the design-team for the WaL project. The event aimed to connect the involved foreign consortiums working on the project, such as RVO, Felixx Landscape Architects & Planners, Witteveen+Bos, and Bantu design with the local partners in the project, like VEI and NAWASSCO. Also the knowledge partner UN-Habitat was introduced in the process. The goal was to held a two-day design workshop to discuss and visualize how Nakuru can become a Sponge city by introducing Nature-Based Solutions (NBS). Even though, the TU Delft team was presented during the workshop as part of the design-team in the WaL project, this graduation project can be seen as an independent research. The design outcome is developed as an method and strategy for possible, local and bankable interventions in Nakuru within the chosen research-area of this research.

[Figure 159.] (Photo by J. Chege, NAWASSCO)

Day 1 – Co-creating a resilient vision

The day started with an introduction of the Water as Leverage project, what challenges and opportunities can be found in Nakuru to create a sponge city. Mainly the water challenges were discussed and how a research of the systems in Nakuru can lead to suitable and area-specific solutions. The scalability, positioning, phasing and prioritizing within the WaL project was discussed to create a more proactive rather than reactive approach. Additionally, the importance of a feasibility study was discussed to develop bankable proposals and interventions that add to a long-term solution. As mentioned, motivation from stakeholders comes from realistic plans and beneficial economical outcomes. These presentations helped to gain a realistic and bankable perspective for this graduation research and how the outcome of this research can be carried forward on site after completion.

It emerged from the discussions that most existing NBS arise primarily from the bottom up, and thus involving local communities is of great importance in the policy and design process. It also became clear that many local initiatives that improve the resiliency of the natural and social systems already exist and can be classified as NBS and that local residents are not always aware of this. This underlines the importance of sharing the positive effects of NBS among local communities.

Day 2 – Co-designing solutions for the identified hotspots

The second day began with an introduction by the Nakuru County Government, in which they presented their vision for Nakuru in 2050. This helped to better understand the institutional-level of Nakuru, what future plans have been developed and how this can serve as a future development framework. Then, as a TU Delft student, I was given the opportunity to present my research to the partners present in the WaL project to give inspiration of what design can do for future development in a city like Nakuru. I was asked to share a tentative vision and, in the process, gather feedback for this thesis research. This was very helpful in arriving at new insights and especially a focus on the implementation, fundability and feasibility of my design outcomes. With that, the response was also positive to the storylines I picked up from various locations in my research area.

In addition, it was made clear that the problem statement of this research is urgent, affects several neighborhoods in Nakuru and needs to be viewed at the system level, where the classification of upstream, middle stream and downstream as part of the watershed approach is applicable.

The final component of the day consisted of a design exercise where key stakeholders, a future vision for 2050 and a pilot project were hatched for the seven identified hotspots in Nakuru. To make this exercise relevant to this research, I was assigned the role as moderator for the zone at the Menengai Calerda. With the participants, several formal as well as informal stakeholders were identified for the area, where local knowledge came in handy.
While creating a future vision and an appropriate, financially feasible pilot project, mainly Lo-Tek interventions proved to be applicable and desirable in the area. Here, in particular, the "minimum effort, maximum benefit" is the convincing factor of the choice of LO-tek, NB interventions for the area around the Menengai Caldera.

When it comes to the financial feasibility of the pilot project, it can be concluded that the project should be profitable in the long run for the local community and independent of money injections from above. It is important that the profits remain within the local community and that maintenance can be done without too much financial resources. However, this depends very much on the scale of the interventions. For example, a community borehole or a farm pound can in many cases be set up and financed from within the local community, see case study projects, but for interventions on a larger scale, a larger investor is required. It emerged from the discussions that here the bankability of the project is important, in order to convince investors. To realize an intervention that generates profit for investors, such as water storage, but is also of social importance and not profitable in itself, such as reforestation, a cooperation between private investors and NGOs can be a possible solution. However, it is important to make clear agreements about the responsibilities of the parties within these interventions on larger scale.

[Figure 160.] (Photo by J. Chege, NAWASSCO)

After the two-day workshop, it became clear that the urgency of water problems in Nakuru is alive and well among not only the residents of Nakuru, but also the stakeholders of the WaL project.
Nakuru's current system is reactive in design and focuses on solving the problems present in the short term. The county government is committed to preserving the natural landscape, but the lack of a systems-oriented approach is keeping a long-term solution away. This erodes Nakuru's flexibility and resilience, making the current urban landscape insufficiently resilient to future climate change and urban growth. This indicates the urgency of a landscape-based approach, as was done during the WaL event in Nakuru. This approach can lay a resilient foundation for the city where the natural landscape is not inferior to the urban landscape and space is made for restoration and adaptation, for nature and people.

3. Scenario-workshop Egerton University, Njoro

Following the Water as Leverage (WaL) workshop in Nakuru, a complementary student workshop was organized at Egerton University. The aim was to engage with local students, collect their insights on Nakuru's future development, and test the feasibility of the four future scenarios that had been designed by our student group from TU Delft, that all have done their graduation project based on an subject in or around Nakuru town.

Together with another student, I took responsibility for guiding the group working on the bottom-up ecological scenario, which emphasized the potential of Nature-Based Solutions (NBS) informed by local ecological knowledge (LO-TEK) and community-driven initiatives.
The workshop began with an introduction to the scenario and an exploration of the opportunities and challenges of implementing ecological interventions from the bottom up. Students from the environmental studies program participated in the discussion, bringing their academic background and local perspectives into the conversation. The exercise was structured around two central questions: *What do you wish for the future of Nakuru? and What do you see as the biggest challenges for the city?*

The students' wishes for Nakuru's future reflected a strong desire for ecological integration and improved quality of life. They emphasized the importance of green spaces that combine ecological functions with recreational use, sustainable urban drainage systems, and the development of clean rivers and pollution-free water sources. Several participants highlighted the need for reforestation, both around Lake Nakuru and in the Mau Forest, as key strategies for enhancing biodiversity and water regulation. Wastewater treatment and expansion of sewer infrastructure were also central themes, with students stressing that untreated wastewater remains a major driver of lake pollution. Importantly, the discussion also brought forward socio-economic concerns, including the need for public-private partnerships to support slum upgrading and more effective management of housing prices to curb informal encroachment.

When asked about the most pressing challenges facing Nakuru, the students identified four interlinked issues. First, housing was described as a critical pressure point. With increasing numbers of people moving to Nakuru, insufficient land availability and high levels of private ownership were seen as drivers of unplanned expansion and settlement encroachment. Second, traffic and infrastructure emerged as a growing concern: roads are increasingly congested, yet there is little space to expand them, and existing infrastructure is outdated. Third, safety was described as deteriorating, with unemployment and drug use among youth leading to more crime and unsafe conditions in the city's peripheries. Finally, pollution and flooding were both identified as urgent environmental threats, exacerbated by inefficient waste treatment systems and poor drainage.

From a research perspective, the discussions provided valuable insight into how local stakeholders perceive the feasibility and desirability of NBS in Nakuru. The wishes expressed by the students show that ecological interventions are not only viewed as environmental necessities but also as strategies to address wider urban challenges such as housing, safety, and infrastructure. The challenges they outlined underline the structural limitations that bottom-up ecological solutions may face in scaling up, particularly in the context of land scarcity, insufficient infrastructure, and limited governance capacity.

The outcomes of this session strengthen the argument that a bottom-up ecological approach can play a meaningful role in shaping Nakuru's future development. They highlight both the opportunities for localized, community-driven NBS, such as reforestation, sustainable drainage, and water treatment, and the structural barriers that need to be acknowledged in any realistic planning process. For this research, the results serve as an important reference point for evaluating the social acceptance and potential integration of NBS in Nakuru's long-term development strategies.

[Figure 161.] Co-designing workshop with student from Egerton University; dicussing four future scenarios for Nakuru, while including relevant NBS to it (photos by B. de Jong)

During the site visit to informal settlements, the urban planner highlighted the municipality's current and future strategies. It was noted that slums in the city center are expected to undergo more privatization in the future. Governmental housing initiatives are being considered in the city center, and residents may be registered as part of this process.

Settlement profiles

Bondeni
Bodeni is described as highly informal. Although there is sewage infrastructure, residents strongly resist relocation. Land transactions often happen "underhandedly," bypassing formal systems.

Rhoda
Rhonda is a more formalized neighborhood compared to Bondeni. Many residents have no income, but the area has become increasingly structured and formalized. Waste management follows a PPP (public-private partnership) model, as private parties get payed to collect waste at households (figure 144). and identification of households is based on materials used for construction.

Kaptembwo
Kaptembwo developed earlier than Rhonda, with significant privatization occurring around 1990. The area is characterized by illegal markets with little to no regulation. One of the biggest challenges is elevation, many areas function like a "bathtub," making them prone to flooding. Residents have built many self-made flood prevention measures.

Environmental and spatial characteristics
- Rhonda has more open green spaces left compared to other neighborhoods.
- It also contains the lowest-lying areas, which are vulnerable to flooding.
- A relatively new, formalized neighborhood is emerging, with available space that will likely densify in the future.
- Urban agriculture is common.
- Sewage systems across these settlements are gravity-based.

Community and cultural aspects

Kenya has around 42 communities, with most of them represented in Nakuru. The urban planner noted that the internet has contributed to a loss of cultural traditions, though citizen culture and participation remain strong.

The planning approach in Nakuru is largely bottom-up, with high levels of local engagement. Importantly, interventions only succeed if communities support them. If the majority does not want a project, it will not happen, even if it is considered a "good" intervention.

Environmental awareness
As explained by the County government, Kenyans are highly concerned about environmental issues. Ownership of forests, for example, carries strong symbolic and practical value, as it is considered a status symbol.

[Figure 162.] Waste collecting service in Rhoda (PPP).

[Figure 163.] Visit to the office of the City Manager of Nakuru City (Photos by County Government of Nakuru).

[Figure 164.] Guided tour by the County Government of Nakuru through a new park in CBD, Nakuru Town.

During the visit to Nawascoal, I was guided by the production supervisor, Francis, who explained the company's operations, challenges, and contributions to both the environment and the local community.

Nawascoal's production has a significant environmental impact, as it prevents the cutting down of approximately 80 trees every day. At the same time, the company provides employment opportunities, particularly for young people. Production volumes depend heavily on funding, but on average, the company produces between six and ten tons monthly, with an overall capacity of fifty to sixty tons. Much of this production is tailored for institutions, which often enter into contracts for one ton per month over the course of a year. On a daily basis, output corresponds to around three truckloads.

The production process makes use of milled sludge, which can serve as fertilizer. However, this comes with health risks, as it may contain harmful bacteria such as salmonella. For this reason, rough sludge must be burned and dehydrated before it can be processed into briquettes, which are produced at high temperatures of around 200°C. Other raw materials used in the process of making briquettes include waste products from the sugar industry, which act as binding material for the powder, as well as a mix of water, clay, and charcoal. A new intervention introduced by Nawascoal was the addition of seeds of native trees into the briquettes. By spreading the briquettes with seeds, the product not only provides fuel but also helps promote the reforestation of indigenous species. This approach ensures that the briquettes contribute to both energy supply and ecological restoration, as the fertilizer included supports plant growth after use.

The company currently produces about twelve tons per day under favorable conditions. One of the notable improvements has been the drying process, which has been shortened from up to ten days to just four days, greatly increasing efficiency.

Despite these advances, Nawascoal faces seasonal and environmental challenges. Parts of the treatment ponds are often flooded during the rainy season, while production slows during the dry months of December to March and July to August. Additionally, overgrazing in the Lake Nakuru area has pushed wildlife into Nawascoal's facilities, interfering with operations and demolishing machines.

To address these challenges, the company has identified two priority steps: the installation of electric fences to keep wildlife at bay, and an upgrade of the sewage treatment infrastructure. Looking ahead, an important question remains around the economic sustainability of briquette production: the cost of producing one ton needs to be compared with the market price of normal charcoal to assess competitiveness and scalability.

[Figure 165.] Machinal system for treatement of sewage was out of system, which led to severe pollution of the surroundings, especcially of National Park Lake Nakuru in the background.
[Figure 166.] Production of briquettes by binding the dehydrated powder of sludge with sugar water.

(1)

(2)

(3)

[Figure 167.] Sequence of drainage channel entering the sewage treatment area. (1) Drainage channel prior to treatment; (2) Accumulated solid waste filtered at a sluice within the channel; (3) Drainage exit, where partially treated wastewater continues to flow into Lake Nakuru. The sequence illustrates the insufficient filtering capacity of the system and highlights how untreated pollutants remain a direct threat to the ecological health of the lake.

During the field visit to the Rift Valley Institute of Science and Technology (RVIST), located west of Nakuru, I met with lecturers from the departments of Hydrology and Agriculture. Together, we toured the institute's research fields to observe the impact of surface runoff on agricultural land and to discuss the measures currently being taken to manage it.

The tour began along several locations where conventional drainage systems had failed due to severe soil erosion. In many places, the soil had been washed away, undermining drainage channels and exposing infrastructure (figure 149). The lecturers explained that water infiltrates into the ground at various points across the campus, yet little is known about where this water eventually goes. They suggested that tectonic activity in the Rift Valley likely contributes to this phenomenon, as fissures along fault lines create unpredictable subsurface flow paths. Because of this geological complexity, there has been limited research into the complete hydrological system, including groundwater movement.

A considerable amount of surface runoff enters the area from higher catchment zones and flows through the RVIST fields before continuing toward the Njoro River and the downstream neighborhoods of Nakuru, as also examined by Schalkwijk (2025). During the site walk, it became clear that the most prominent runoff lines are deeply incised into the terrain and are partly covered by riparian forest (figure 150). Although this vegetation helps to slow and retain seasonal water, it remains insufficient when compared to the large volumes of runoff that eventually reach the urban area of Nakuru.

[Figure 168.] Erosion of conventional culvert (photo by author)

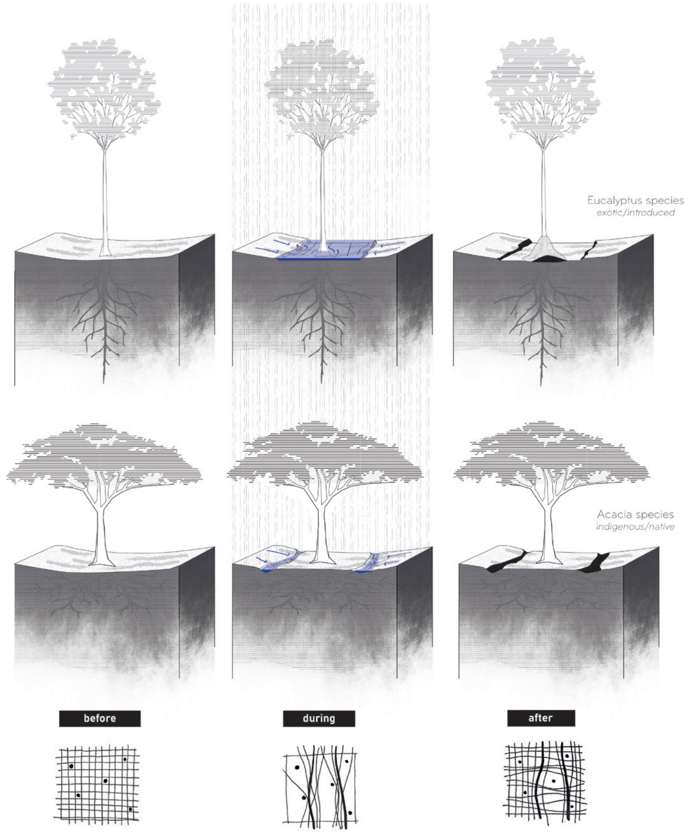
[Figure 169.] Riperian forest along runoff line (photo by author)

[Figure 170.] Overview map terrain of the Rift Valley Institute of Science and Technology, showing the runoff lines.

As illustrated in figure 151, the agricultural fields adjacent to the Kaptembwo neighborhood, located downstream of the institute, are mainly used for intensive monoculture research and have limited vegetative diversity. Combined with the large contributing surface area of the sub-catchments draining into this zone, this results in extensive flooding in the lower-lying informal settlements surrounding Lake Nakuru.

A key observation made on site concerned the apparent influence of tree species on soil stability and surface runoff. As demonstrated by the lecturers, there is a noticeable difference between areas dominated by Eucalyptus species and those with native Acacia trees. Figures 153 and 154, taken along the same runoff line only a few meters apart, illustrate that the soil beneath eucalyptus trees appears more eroded compared to that beneath acacia stands. Although this observation does not establish a direct causal relationship, as factors such as slope, soil composition, and runoff velocity also play important roles, it highlights a significant contrast in vegetation structure and its hydrological implications. The acacia species, with their horizontal and fibrous root systems, tend to maintain a vegetated ground layer that stabilizes the soil and slows surface flow. In contrast, the deep vertical roots of eucalyptus extract groundwater but provide limited lateral support (figure 152). Eucalyptus species are also known to dry out and acidify the soil, which often prevents the growth of understory vegetation. Acacia trees, by comparison, have a more open canopy and are less water-demanding, allowing ground vegetation to thrive beneath their crowns. This layered vegetation structure further contributes to reducing the velocity of surface runoff, as described by Belsky et al. (1989).

Finally, the lecturers emphasized the potential of integrating runoff collection and purification systems to strengthen freshwater availability. They see opportunities to capture and filter surface water through natural and engineered retention areas, promoting active groundwater recharge and improving water quality for both agricultural and domestic use. This perspective aligns with the broader goal of the research, which is to design restoration networks that delay, collect, and purify runoff while enhancing ecological and social resilience.



[Figure 171.] Differences in soil stabilization between tree species
[Figure 172.] Native Acacia trees positioned along runoff line (photo by author)
[Figure 173.] Eucalyptus tree species postitioned along runoff line (photo by author)

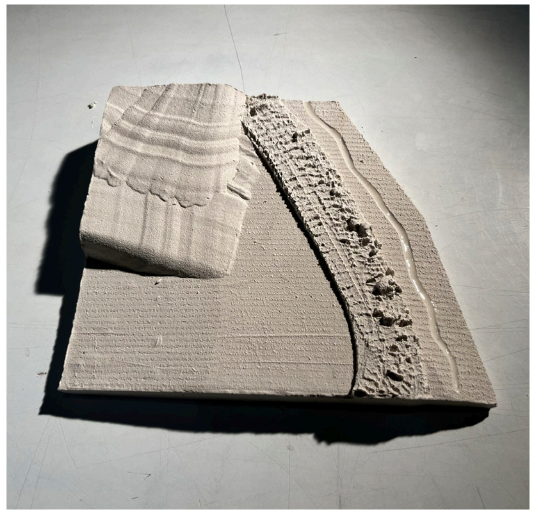
Tracing water: a landscape in motion

Creating a physical landscape model focuses on visualizing water flows and their impact. We explored various materials and typologies, with texture and depth as key elements. After experimenting with textures, colors and materials, gypsum proved to be the most suitable material. Its neutral color highlights the rivers effectively.

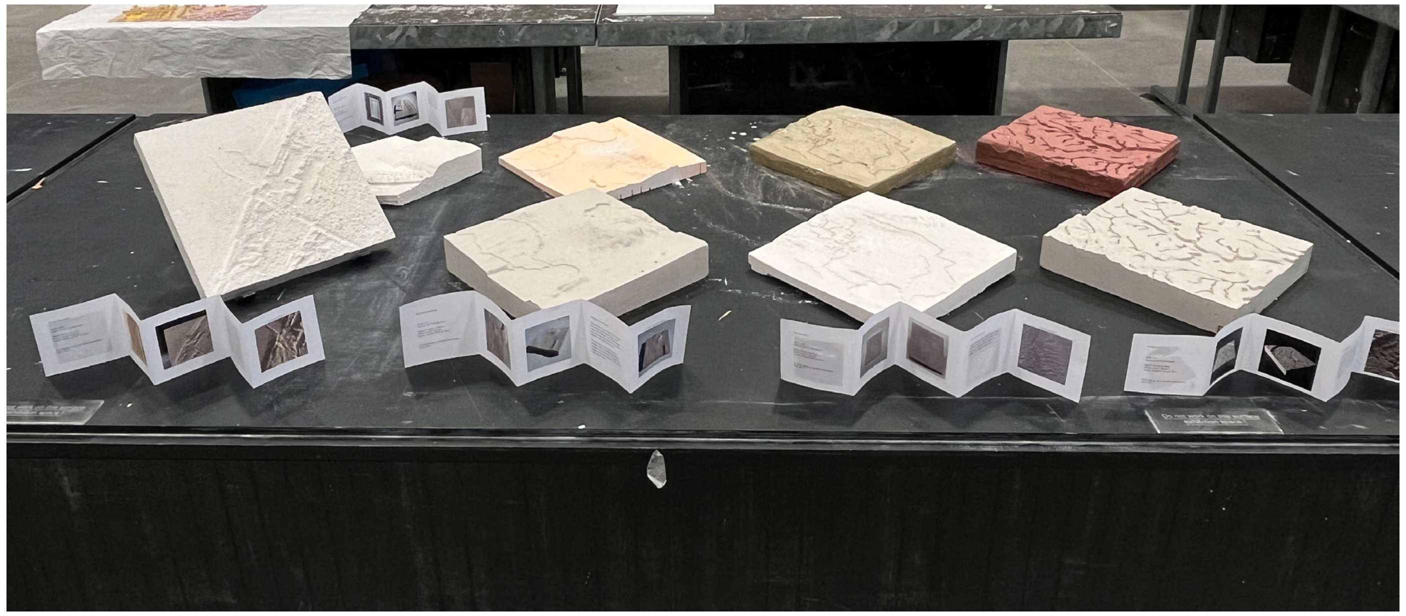
The water flows were subtly emphasized to showcase their movement without disrupting the natural balance of the landscape. The model demonstrates how water interacts with and shapes the terrain in a harmonious and tangible representation.

My model showcases the research area of my graduation project. It highlights the influence of waterflows on the lower parts of the region, from the higher plateau to the Menegai Caldera north of Nakuru town, Kenya.

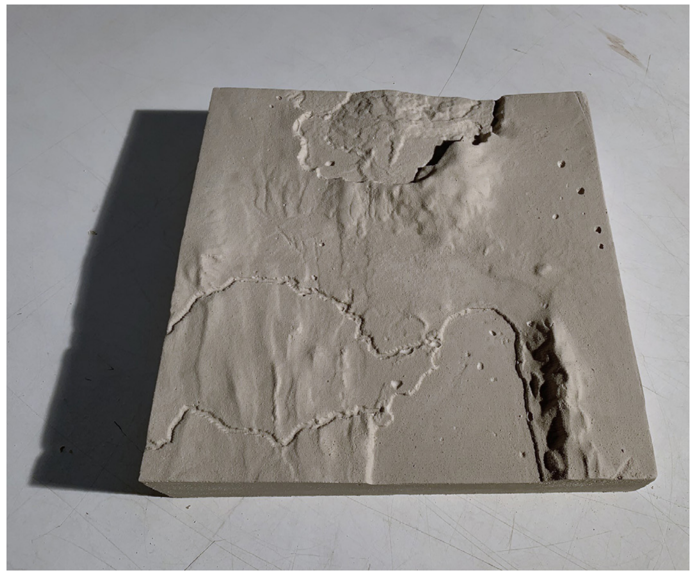
[Figure 174.] Developming a negative mal for the model.



[Figure 175.] First prototype of the gypsum model.



[Figure 176.] Exposition of the final result; displaying several types of tiles of different research locations, testing with colours, materials, different elevation profiles.



[Figure 177.] Final result of my gypsum tile of the catchment area of Lake Nakuru, showing how wat has shaped the landscape over time.

Adapting to the seasonal rhythm

Restoring and adapting to the natural flow to recharge
the fresh water availability in Nakuru, Kenya.

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2024-2025