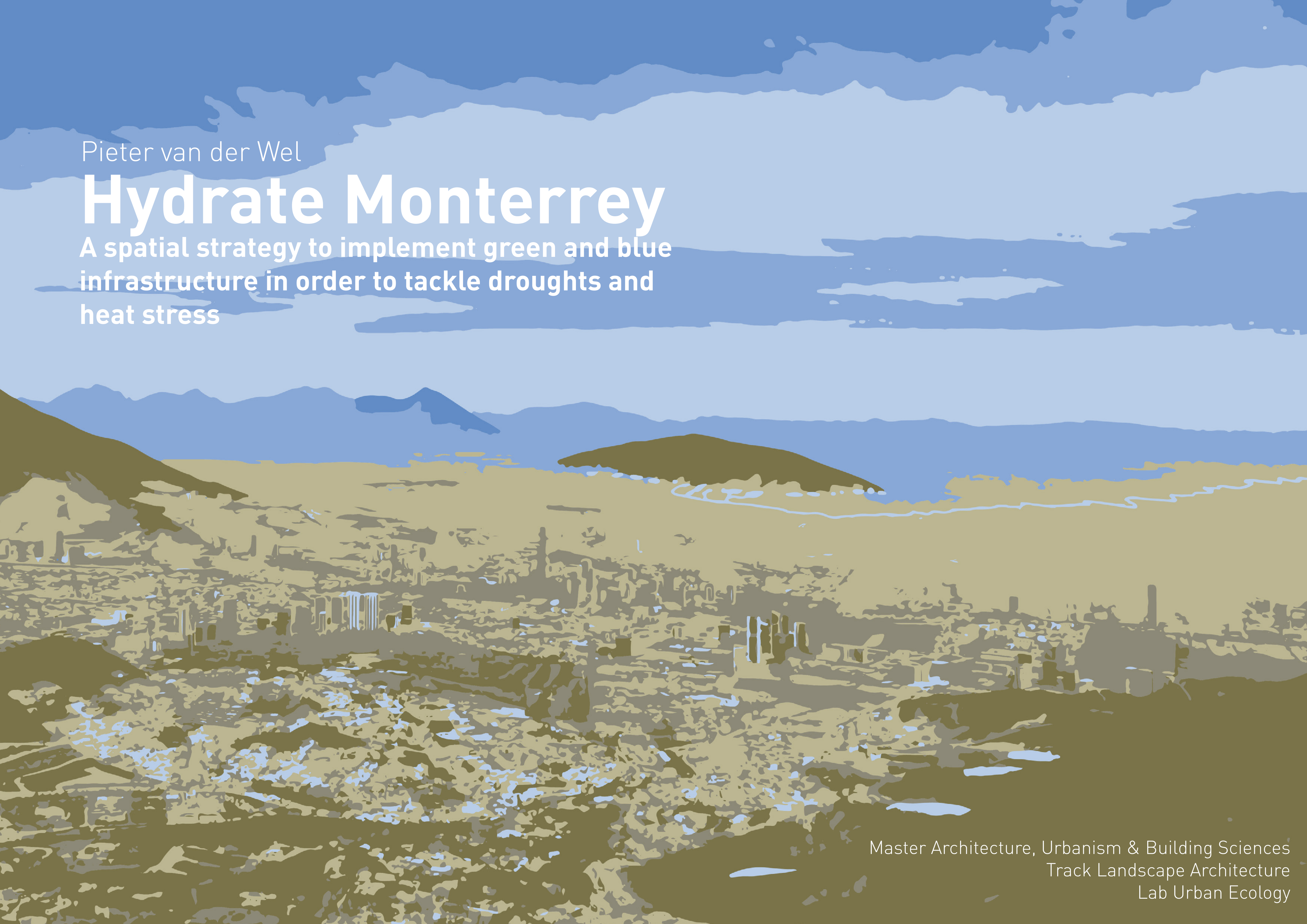

Pieter van der Wel

# Hydrate Monterrey

## A spatial strategy to implement green and blue infrastructure in order to tackle droughts and heat stress

Master Architecture, Urbanism & Building Sciences
Track Landscape Architecture
Lab Urban Ecology

# Colophon

Hydrate Monterrey
A spatial strategy to implement green and blue infrastructure in order to tackle droughts and heat stress

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Author:
Pieter van der Wel
4685393

University:
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Master:
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Track:
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Lab
Urban Ecology

First mentor:
Nico Tillie

Second mentor:
Michiel Brouwer

On-site mentor:
Rob Roggema

Collaboration
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This recognition is for the following funding companies that has made my trip to Monterrey possible and all the activities which could be done with their help.

STICHTING N·H·BOS
ter bevordering van de landschapsarchitectuur

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STYLOS

# Preface

My thesis case is about the metropolitan area of Monterrey, situated in Mexico. The focus is on mitigating the environmental challenges of heat stress and droughts by implementing green and blue infrastructure in the metropolitan area with the perspective of landscape architecture.

My name is Pieter van der Wel, and I have studied Architecture and the Built Environment at the Technical University in Delft. With this thesis, I am graduating with a Master's in Landscape Architecture in the graduation lab Urban Ecology, guided by my first mentor Nico Tillie.

My personal drive in writing this thesis involves the challenge of working with the complexity of a city and making better spaces in the perspective of landscape architecture. For this opportunity, I have chosen Monterrey, located in Mexico, to cope with the increasing environmental challenges and to work outside the boundaries of temperate climates in western Europe. Furthermore, this opportunity allows me to explore new cultures and learn how people live in cities around the world.

This thesis aims to inspire the residents and authorities of Monterrey by showcasing the potential of landscape architecture within the urban environment. This implementation, grounded in literature, can enhance the quality of human life in a big city like Monterrey.

While writing my thesis, I worked towards a specific subject, making several topic modifications along the way. It involved an interplay between writing the text and producing the right products and outcomes. This thesis ends with a reflection about my experiences, learnings and the relations to my master and my graduation lab.

I want to express my gratitude to my first and second mentors, Nico Tillie and Michiel Brouwer, for guiding me from the beginning to the conclusion of my thesis. They provided me with valuable new knowledge, offered helpful advice, and gave me the space to grow within my own subject.

I am also grateful to my on-site mentor, Rob Roggema, for supporting the unforgettable experience in Monterrey and introducing me to many helpful contacts for inspiring knowledge which has made my thesis project more integrated. Thereby, I appreciate the valuable collaboration with several professors and students from the Tecnológico de Monterrey University.

Furthermore, I would like to thank Merel Schouten and Kinou Visser for checking my text, ensuring my thesis project is understandable and comes to a successful outcome.

I give you, the reader, the chance to allow yourself to become inspired by reading my thesis about Hydrate Monterrey that I have worked on over the past year.

*Pieter van der Wel*
*10th june, 2024*

# Abstract

This thesis addresses the spatial strategy for designing green and blue infrastructure in the metropolitan area of Monterrey (MAM), responding to the increasing environmental impacts of climate change. Droughts and heat waves in the MAM are already affecting residents, causing heat stress and water scarcity. These challenges can be mitigated through the implementation of green and blue infrastructure within the city.

The main research question is: "What spatial strategy can be used to implement green and blue infrastructure in order to tackle droughts and heat stress in the metropolitan area of Monterrey?" By doing so, the thesis aims to enhance both the ecological improvement and the quality of public space to improve residents' quality of life.

Initially, the study focuses on understanding the natural systems in and around the MAM. An integrated approach analyzes terrain, water structures, soil, vegetation, and ecosystems to create landscape and ecological design principles as the foundation for green and blue infrastructure.

Subsequently, new design principles are derived to mitigate heat stress and drought in the MAM, emphasizing the restoration of ecological balance through the creation of an ecological mosaic consisting of green patches and corridors connecting them.

Specific strategies, such as the 300-meter rule for green space accessibility, are tested and implemented to transform urban areas into a network of recreational green spaces and green corridors.

The case study focuses on San Bernabé, chosen for its significant socio-economic and environmental challenges. By leveraging the watershed beneath this district as a foundation, the strategy integrates upstream water storage and downstream water retention. Therefore, six green and blue infrastructure principles guide the spatial design for San Bernabé, emphasizing upstream water storage and collection in reservoirs and downstream cooling and retention with continuous flowing streams and vegetation.

The resulting metropolitan vision, spatial design, and detailed plans and a phasing program, envisions a transformed urban landscape with increased accessible green spaces and corridors supported by sustainable water resources. This comprehensive approach aims to mitigate the increasing environmental challenges Monterrey is facing.

# Glossary

**Arroyo:** Stream (Spanish translation). e.g. Arroyo Topo Chico

**Daylighting:** Removing the concrete cased storm drains and transforming these waterways in natural streams with the implementation of vegetation and encouraging soil infiltration.

**Ecosystem:** Natural system of all organism interacting with each other in a certain area.

**GIS:** Geographic information system. It is a spatial system that creates and analyzes maps. Several maps in this booklet has been created by GIS.

**Habitat:** The natural environment a plant or animal lives in.

**Informal settlement:** A residential area or settelement which is built outside of the regulations of the government.

**MAM:** Metropolitan area of Monterrey

**Metropolitan area / Metropolis:** A region with a densely populated area. It shares industry, housing, commercial area, transport networks and infrstructure, often contains multiple municipalities.

**Microclimate:** Atmospheric conditions on a small scale that are different than the surrounding area.

**Prominence:** Topographic prominence is the relative height of a mountain. It is the height difference of a mountain in relation to the surrounding area.

**Río:** River (Spanish translation). e.g. Río Santa Catarina

**Storm drain:** A stream or river that is cased by concrete walls and floors

**UATC:** Upstream Arroyo Topo Chico

**Urban area:** An area which can be categorized as a city or a suburb.

**Urban fabric:** An urban structure. It describes the physical characteristics of an urban area, such as the layout of the streets or the dimensions of buildings.

**Watershed:** A drainage area bounded by other drainage areas of streams and rivers. Precipitation that falls in this area creates runoff and groundwater that flow to a certain point downstream.

# Content

# 1 Introduction

**Location**

Monterrey is a municipality situated in the northeastern part of Mexico and the capital of the state Nuevo León. It is part of the bigger metropolitan area of Monterrey (MAM).
Within this metropolitan area, there are eightteen municipalities located. In 2020, the population number was 5,341,177 and has still been growing since (Data México, n.d.). With this population number, the MAM is the second largest metropolitan area of Mexico, after the capital Mexico City. Monterrey is expected to expand more and will have a bigger population number in the future (Monterrey, Mexico Metro Area Population 1950-2024, n.d.).

This urban area is situated at the foothills of the Sierra Madre Oriental. This is a mountain range spanning across 1000 kilometers from the northeastern part to center parts of Mexico.

Monterrey is known for its thriving industry and several remarkable mountains in the area. For instance, Monterrey is the product leader of Mexico, because it controls more that half of Mexico's total industrial assets (U.S. Commercial Service Mexico, n.d.). Furthermore, mountains, such as the landmark of Cerro de la Silla, are visible at the horizion of the city, as seen in figure 1. This mountain is historically and culturally considered as a representative symbol of Monterrey (Téllez, 2001).


**Figure 2:** Mexico, Nuevo León and the location of the Metropolitan area of Monterrey.

**Figure 1:** intersection next to Tecnologico de Monterrey (TEC), facing southeast. The landmark of Cerro de la Silla is seen on the horizon (picture: Pieter van der Wel).

The topographic locations are seen in figure 2. The location of the MAM and its topographic context is seen in a satellite image in figure 3.

**Environment**

The environment of the metropolitan area is semi-arid with hot summers and relitavely dry winters. The mean temperature is recorded as 23.3 degrees Celcius. The hottest month is in August with a recorded maximum of 29.4 degrees Celcius. The average precipitation is 590 millimeters per year, with the wettest month in September with 150 millimeters of rainfall (Climates to Travel, n.d.).

**Figure 3:** Satellite image of the Metropolitan area of Monterrey (MAM).
**GIS Sources:** Google Earth

0 2,5 5 7,5 10 km

# 2 Problematization

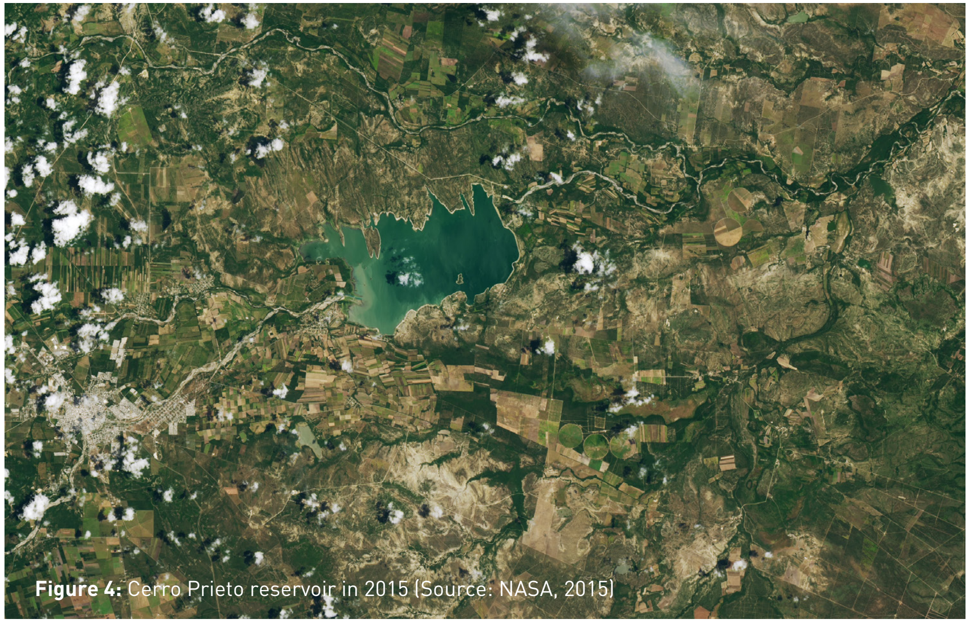


**Figure 4:** Cerro Prieto reservoir in 2015 (Source: NASA, 2015)

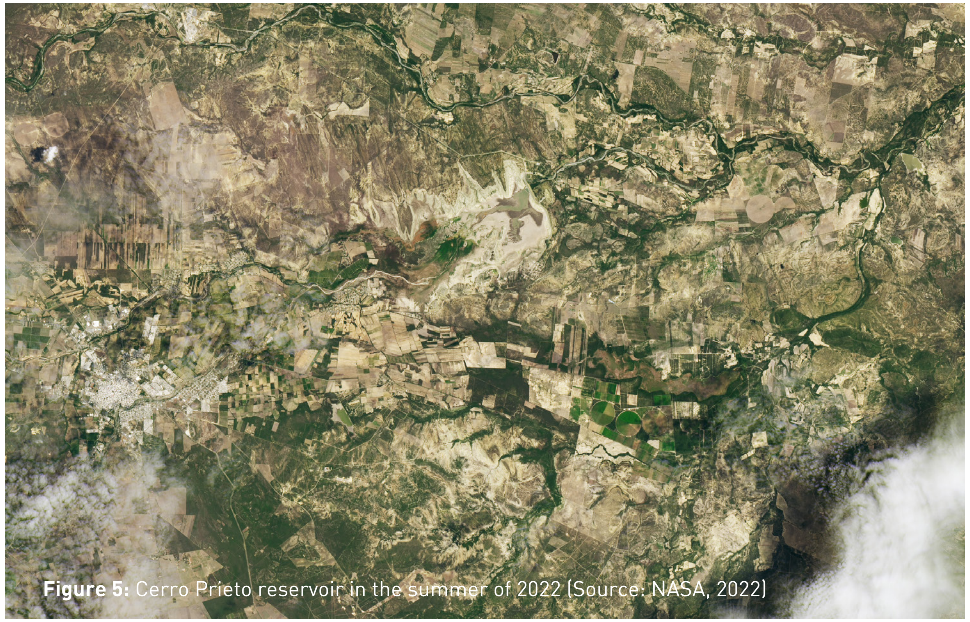


**Figure 5:** Cerro Prieto reservoir in the summer of 2022 (Source: NASA, 2022)

Situated in a semi-arid environment, the metropolitan area struggles to cope with the extremes of the environmental impacts. These environmental impacts are mostly related to water shortages during droughts and the heat waves which impact the lives of the residents.

**Droughts**

In the summer of 2022, there was a big and severe drought in Nuevo Léon. Residential areas, industry and agriculture were highly dependent on water during these moments. The water service authority which is responsible for providing residents, industry and agriculture of water in the MAM is called the Servicios de Agua y Drenaje de Monterrey (SADM). This authority is acting under the government of the state of Nuevo León.

The MAM is mostly dependent on the water supply from reservoirs. Approximately 67 % of the water supply comes from reservoirs (SADM, n.d.). In figure 4 and 5, one of the reservoirs, the Cerro Prieto reservoir, is shown on two different stages in time. The big and severe drought in 2022 shows the the amount of water that has been extracted or evaporated, observed from space. The capacity of this reservoir had dropped to 0.5%. This is because the water demand is higher during a severe drought and it evaporated significantly when the tempratures reached 40°C during this period (NASA, 2022).

Another example of a drought experience is the Santa Catarina River which flows through the MAM. This is the biggest river of Monterrey and flows from the west in the Sierra Madre Oriental to the east. But this river is almost dry most of the year. In figure 6, the riverbed of the Santa Catarina is seen with only a small stream. Also the lack of water in this river is due to extraction by industry upstream (D. F. Lozano-García, Santa Catarina excursion comment, March 4th 2024).

**Hurricanes**

Hurricanes are the other variants of extreme weather events which can happen during summer. Hurricanes that impact Monterrey originate in the Gulf of Mexico (National Weather Service, n.d.). They appear at land with big destructive forces and a relatively high amount of precipitation. Hurricane Alex was an example of such a hurricane which happened in 2010 between June 30th and July 2nd. It had reached wind speeds up to 169 kilometers per hour, by the time the moment it reached the mainland. When Alex approached Monterrey, precipitation taht has fallen and was discharched mostly through the Santa Catarina River which has endangered the city through floodings and destroyed all the buildings and infrastructure that were build on riverbed (Aguilar-Barajas et al,. 2019). In 48 hours, a precipitation amount of 800 millimeters had fallen and a minimum of 15 people were killed during this extreme event (Alcántara-Ayala et al., 2019).

In figure 7 the aftermath of the hurricane is seen with the result of a big supply of water behind the Rompe Picos Dam. This dam is located 22 kilometers upstream in the Sierra Madre Oriental and blocks storm water from all the cayons in the Santa Catarina Watershed. It has been built to withstand storms with a return period of 10.000 years (Aguilar-Barajas et al., 2019).

**Figure 6:** An almost dry riverbed in the Santa Catarina (Picture: Pieter van der Wel)

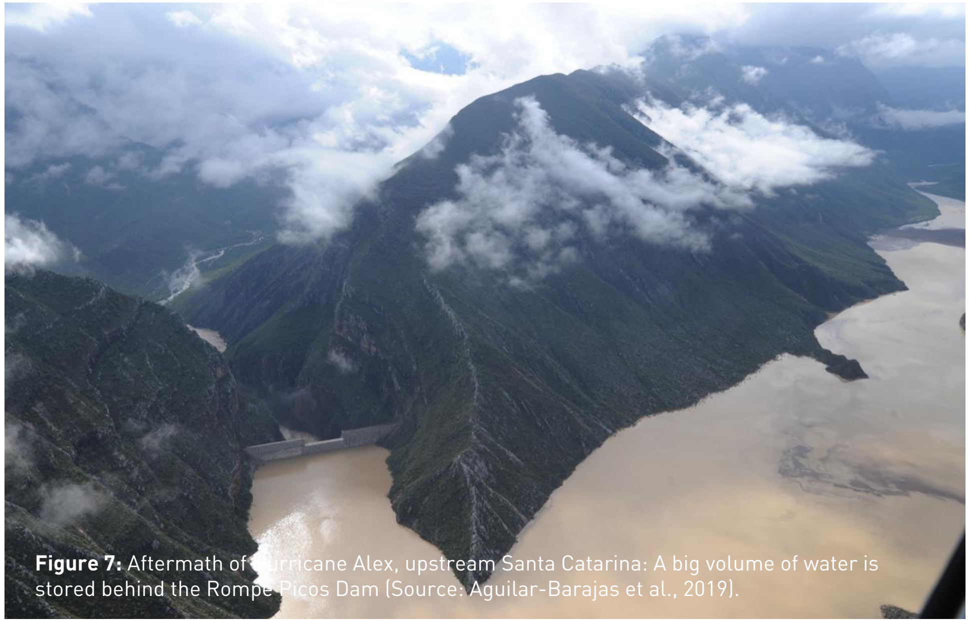


**Figure 7:** Aftermath of Hurricane Alex, upstream Santa Catarina: A big volume of water is stored behind the Rompe Picos Dam (Source: Aguilar-Barajas et al., 2019).

**Figure 8:** Residents gathering for water , which is brought by trucks (Picture: Cesar Rodriguez)

**Figure 9:** Residents protesting against the water scarcity in the city of Monterrey (Picture: Daniel Becerril)

**Water shortages**

During the drought of 2022, there was no tapwater available anymore in several places in the city. Residents of rich neighborhoods were still provided with tapwater half a day, but residents of poor neighborhoods were solely dependent on water from distribution trucks (Tuckman, 2022). Therefore, residents had to gather in specific places in the city to collect the water from trucks for their homes. These extra water supplies is were not drinkable for most people and were brought from other places in Mexico (figure 8). People from the most poor neighborhoods bore the hardest circumstances, because it was dfifficult for them to buy drinkable water from supermarkets and some of them were suffering from a water shortage for 75 days in total (Ahmed & Villegas, 2022). Big compagnies such as Heineken and Coca Cola still had access to clean water. They have private wells to limited underground aquifers, which created controversy among the public because of unequil distribution with the residential areas (Tuckman, 2023). People were threathening truck drivers to bring water to their homes and were protesting on highways (figure 9).

**Conclusion**

Long periods of droughts lead to water shortages in the MAM because the current watersystem is not build for these exceptional environmental impacts. With a predicted urban expansion in the future, more demand for water will come. Furthermore, fresh water is not equally distributed in the city and there are moments with shortages of water and moments where people are endangered because of the impacts of hurricanes. So, there is both not a sustainable as well as not an equally dsitributed watermanagement in the Metropolitan area of Monterrey.

**Heatstress**

During the summer months, hot days caused by heat waves are causing heat stress for the MAM. According to studies of One Billion Resilient (n.d.), the temperatures in Monterrey can be 5 to 10 degrees celcius more than the rural area, which could increase in the future due to climatic change. Urbanization and its building masses causes heat stres. In figure 10, a satellite image from Google Earth is shown, that gives an indication of the amount of concrete and stone the urban area contains which replaced the natural environment. Figure 11 shows a heat stress related situation on ground level.

Heat stress gives economic, social and health problems for the MAM. In summer the energy demand is highest because of the use of fans and airconditioning. This could even lead to power shortages in the hottest regions of Mexico (Agren, 2023).

The impacts of heat stress can lead to unbearable circumstances for the residents of Monterrey. Without shadow and bad insulation of houses, the health of inhabitants can be endangered. And because of power shortages, the lack of airconditioning makes the life in houses unbearable. In one week in June in 2023, 69 people died in Mexico because of the heat (Agren, 2023). During heat waves, heatstrokes is the first reason people pass out and dehydration is the second reason (Deutsche Welle, 2023).

Labor losses can also happen because of unbearably hot circumstances in the industrial work environment. Monterrey as an industrial city has 29% of its emplyment concentrated in manufacturing. This sector has relativey low levels of air-conditioning and is depending on residents working in physical, heavy circumstances on the workplace. These employers get affected by more heat stress and by power shutdowns (onbillianresillient). Without adaptation to the heat or the reduction of emissions in the future, productivity losses are estimated to increase with 1.5% by 2050.


**Figure 10:** Urban Heat Island (UHI) (Source: Google Earth)

**Figure 11:** Wide streets assigned to cars and narrow sidewalks (Picture: Pieter van der Wel)

# 3 Methodology

## 3.1 Problem Statement

**Climate change**

Climate change is underway and that brings increased environmental challenges in longer and short-term. For the MAM, climate change translates into bigger environmental risks in the future (Meteoblue, n.d.). Throughout the years, precipitation levels have declined and temperatures have increased in the MAM. In figure 12, the trend lines from average temperature and annual precipitation is shown from 1979 untill 2022 in Monterrey. The trend lines show a decrease in precipitation levels and an increase in temperature in the last decades.
Trend lines and other models suggest a prediction of less precipitation and higher temperatures in the future. The expectation will be that the environmental problems of Monterrey will be worse than the problems the city is facing today (Meteoblue, n.d.).

**Impacts**

According to the international non-profit organisation the Carbon Disclosure Project (CDP), cities are currently facing big environmental impacts. These are categorized into heat waves (which results into heat stress), droughts and floodings. It is expected that environmental hazards like these will already happen on the medium and short-term in the coming years. (CDP, n.d.). By 2050, science shows that eight times more residents will be exposed to high temperatures of which the poorest residents will be hit the hardest.

**Conclusion**

In conclusion, climate change brings increased environmental challenges for Monterrey in the near future, wherby residents are facing the consequences. The environmental risks are endangering their lives and makes life uncomfortable. Water shortages will happen due to longer and heavier droughts and the heat stress caused by bigger heat waves will be more frequent. These are the biggest environmental challanges Monterrey will have to cope with in the future.

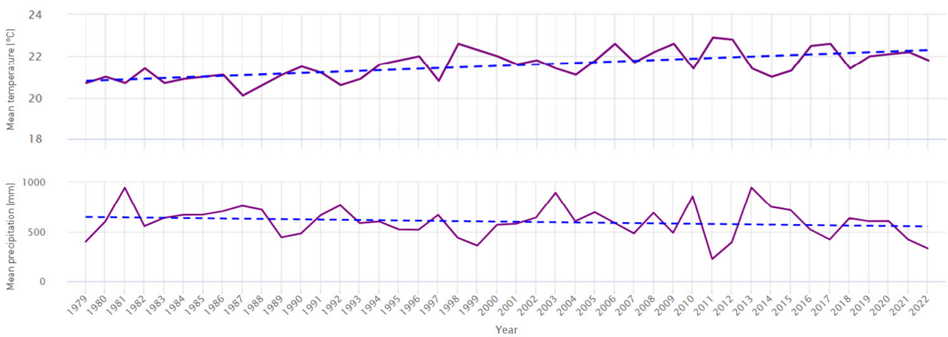



**Figure 12:** Temperature and precipitation trend lines from 1979 untill 2022 (retrieved and modified from Meteoblue, 2023)

Droughts

Figure 13 Picture: Gabriela Pérez

Water scarcity

Figure 14 Picture: Daniel Becerril

Heat stress

Figure 15 Picture: One Billion Resillient

Floods

Figure 16 Picture: Aldo I. Ramirez

## 3.2 Monterrey at risk in 2074

If action is not taken to cope with the increasing environmental issues, the city of Monterrey will be more uncomfortable and more dangerous to live in. 50 years later in 2074, the medium and short term environmental problems can be adressed. The biggest threats Monterrey is facing are droughts, water scarcity, heat stress, and floods.

**Figure 17:** Image of the metropolitan area of Monterrey facing the problems in 2074 (Modified Picture: Pieter van der Wel)

## 3.3 Objectives

### 3.3.1 Landscape and nature based solutions

Wageningen University states that nature in the city is worthwhile because of the addes benefits. These benefits can be the mitigation of heat stress, the drainage of rainwater, the increase of biodiversity and the quality of life for animals and humans. This is expecially important when cities are growing and the needs for nature based solutions the needs become greater (Wageningen University & Research, n.d.).

Another statement from Wageningen University is that climate change is a threat to the nature's diversity. Nature based solutions in a landscape approach can bring back vegetation covers which result into a return of biodiverse nature and also helps cope with the impact of climate change (Wageningen University & Research, n.d.).

According to the World Health Organisation (WHO), ecological improvement is beneficial for human life. That is because biodiversity increases human health by directly improving the surrounding area and the social activities within. Indirectly, it is beneficial because it can ultimately provide ecosystem products and health services (World Health Organisation, n.d.).

To conclude, implementing landscape and nature-based solutions can address future environmental challenges in Monterrey. These strategies effectively reduce heat stress and mitigate the impacts of droughts (figure 18 & 19).

### 3.3.2 Problematization solution

In order to create a more habitable Metropolitan region, now and in the future, the implementation of landscape-based and nature-based solutions is crucial. Greening the city by smart use of implementing more vegetation in the Metropolis can reduce the heat island effect while simultaneously enhancing the quality of public space and the ecology.

Furthermore, reconsidering the water management in the Metropolis is necessary to ensure a sustainable water supply that can cope with the rising water demand. Green and blue infrastructure can provide a sustainable water management in the MAM. So a the water supply can be improved by a new system which is using landscape based solutions.

**Figure 18:** Implementation of green infrastructure as a bridge crossing the Santa Catarina river in Monterrey, Mexico (Picture: Pieter van der Wel)

**Figure 19:** Implementation of greenery in a public community center in Monterrey, Mexico (Picture: Pieter van der Wel)

### 3.3.3 Design objectives

The ultimate goal is to create a spatial design which is tackling the two main environmental challanges: mitigating heat stress and tackle drought in order to reduce the water scarcity.
At the same time, it improves the spatial quality of public spaces and the ecology of a city. Eventually, it should create a better health environment and quality of life for the residents of Monterrey (figure 20).

A spatial design with careful implementation of green and blue infrastructure will eventually cope with all the objectives. It will be about providing water for the people of Monterrey and cool then off in the hot climatic city: Hydrate Monterrey.

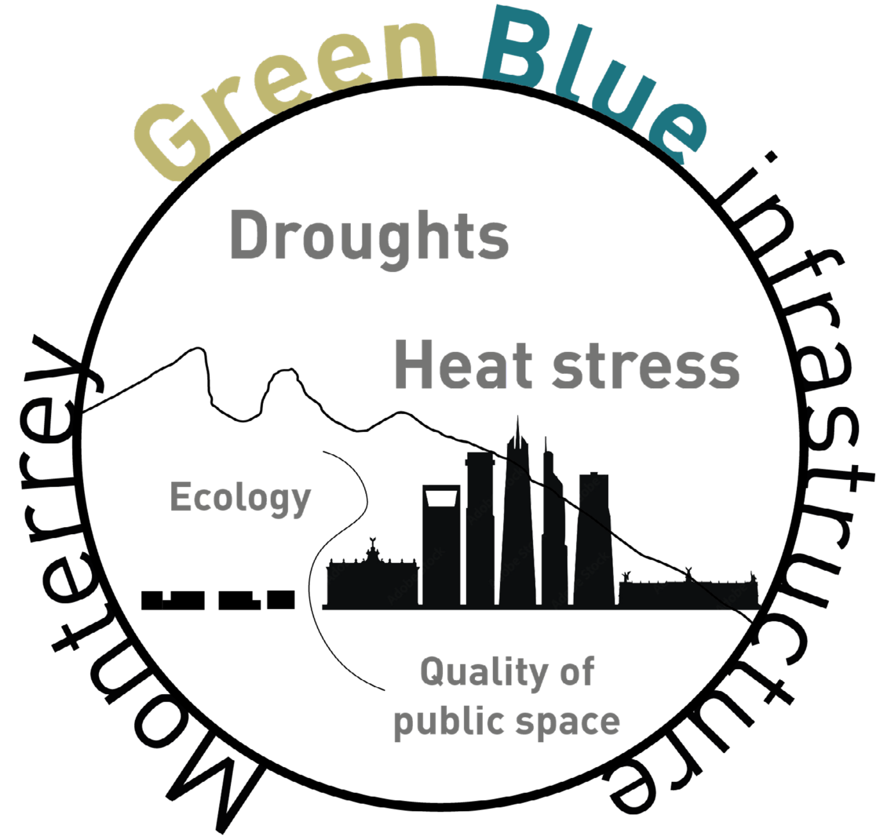



**Figure 20:** The objectives for this thesis: Tackle droughts and heat stress with green and blue infrastructure. The ecology and quaity of public space will also be enhanced by the implementation.

## 3.4 Research Questions

The following research question for this thesis project states:

“What spatial strategy can be used to implement green and blue infrastructure in order to tackle droughts and heat stress in the metropolitan area of Monterrey?“

The following sub research questions are made in order to answer the main research question:

1. "What are the (natural) systems of the landscape in and around the Metropolitan area?"

2. "What are the design principles translated from the analysis?"

3. "How are the design principles implemented in the metropolitan area leading to the new metropolitan vision?"

4. "What strategy is used for designating the design location?"

5. "What strategies are used to implement green and blue infrastructure into a spatial design?"

## 3.5 Research Methods

In order to answer the research question, methods are used to move from the analysis to the design and eventually to the conclusion of this thesis project. In figure 21, the schematic overview of the research methods are shown.

**Analysis**
From the problem statement follows a relevant and comprehensive research for design with geographical information systems (GIS), literature and other sources to create maps, systems and concepts. From this system analysis and providing literature, solutions are argued and translated into design principles. These design principles have a spatial implementation in the MAM.

**Metropolitan vision**
A metropolitan vision map is made in order to show the solutions which is relevant for the whole metropolitan system. Within the metropolitan area, maps of critical location are gathered for designating a location for making a spatial design through all the scales. The location choice is based on the social problems, environmental problems and the potential for a landscape based design.

**Site visit**
A site visit is taken between the 12th of February and the 10th of March in and around the Metropolitan area of Monterrey. Whereby, a more in depth analysis is made by going on field trips, taking pictures and videos ad having discussions with local experts. Furthermore, the site visit gives the possibility to learn from the urban design on a human scale to use in order to make spatial and perceptional analysis. Eventually by observing on-site, the critical location can be chosen for a spatial design.

**Spatial Design**
A spatial design can be created by implementing the design principles on a local level. Therefore, more research is made by analyzing the context of the concerned locations.
The spatial design can be tested, whereby the design is improved regularly.

**Conclusion and discussion**
The research question is answered by the new spatial design and systems. Discussions highlight cases where analyses can be improved in the future or where additional analysis is needed.

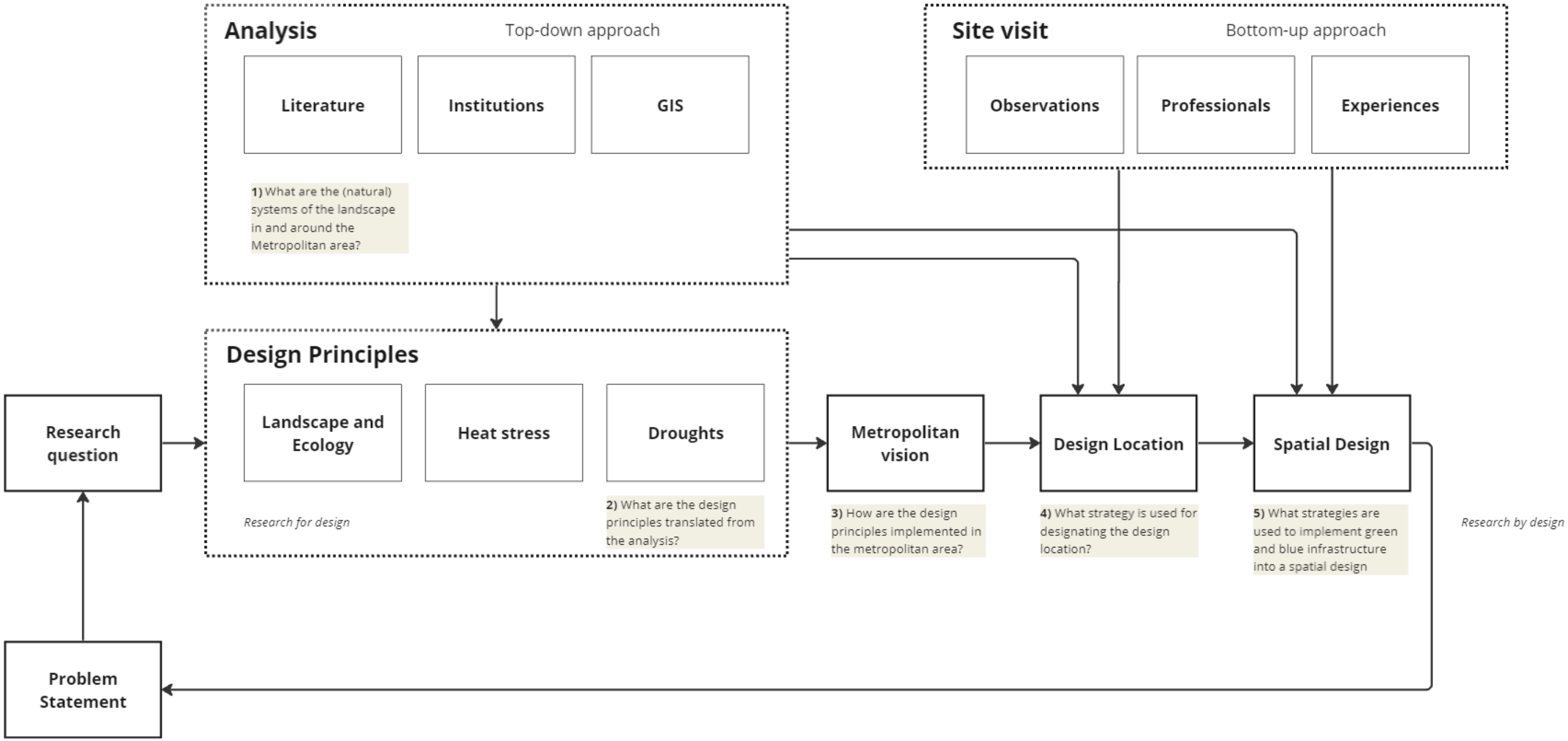



**Figure 21:** Methods scheme Hydrate Monterrey

## 3.6 Theoretical Framework

The theoretical framework in Figure 22 shows the literature used for this thesis project, which defends the design principles and concepts.

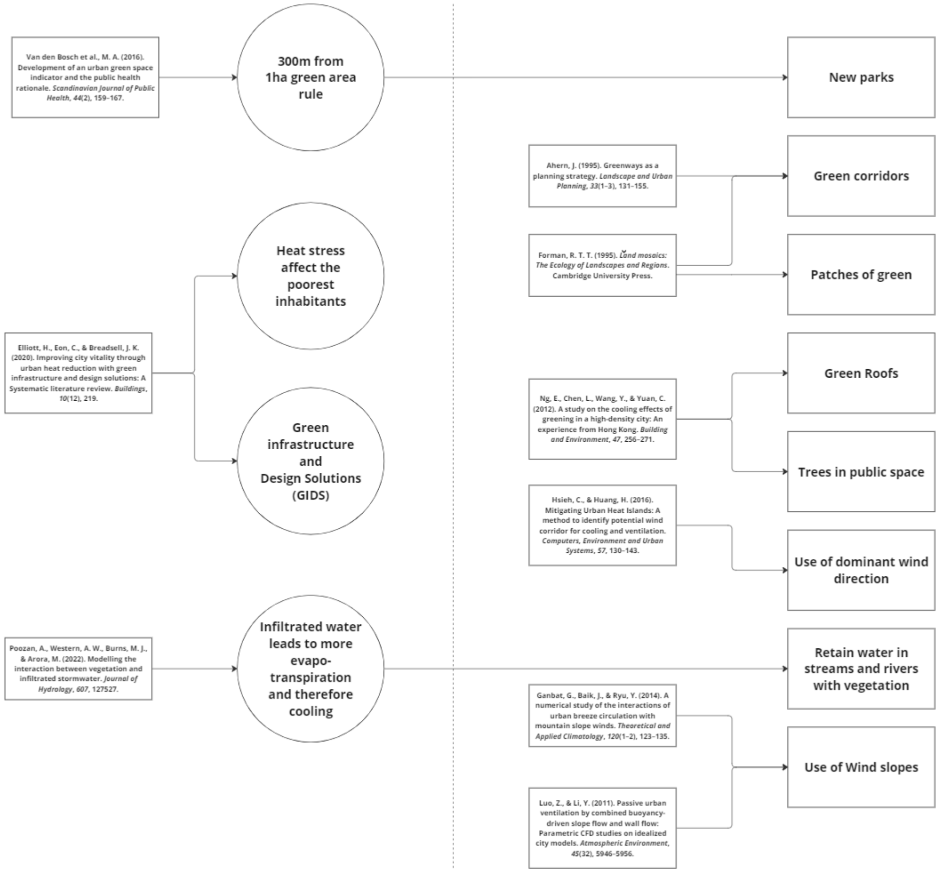



**Figure 22:** Theoretical framework Hydrate Monterrey

# 4 Analysis and Design Principles

## 4.1 Climate

### 4.1.1 Climate in Mexico

Mexico has a big diversity of climate zones. There are relatively wet and tropical areas in the south and more dry and hot areas in the north of the country. In figure 23, Mexico is visualised and divided in climate zones following the Köppen climate classification. The metropolitan area of Monterrey is situated in Nuevo Léon, in the the northeastern part of Mexico. In this region, the climate zones are generally semi-arid.

### 4.1.2 Climate in the Metropolitan region

According to the Köppen climate classification, The Metropolitan area of Monterrey is situated between four different climate zones: a temperate climate with dry winter; a hot semi arid climate; a cold semi arid climate and arid and hot climate (figure 24).

The weather can shift very quickly because of these different climate zones. The time between extreme temperature is only a matter of days. Change in direction of the wind can cause these events to happen on a short-term (Phys, 2016).

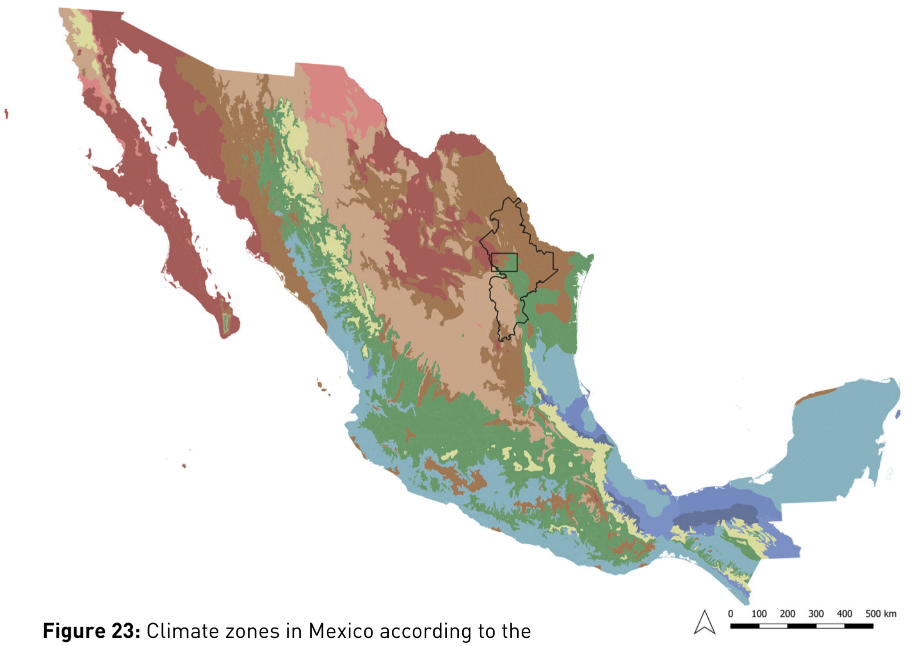


**Figure 23:** Climate zones in Mexico according to the Köppen climate classification.
**GIS sources:** Conabio

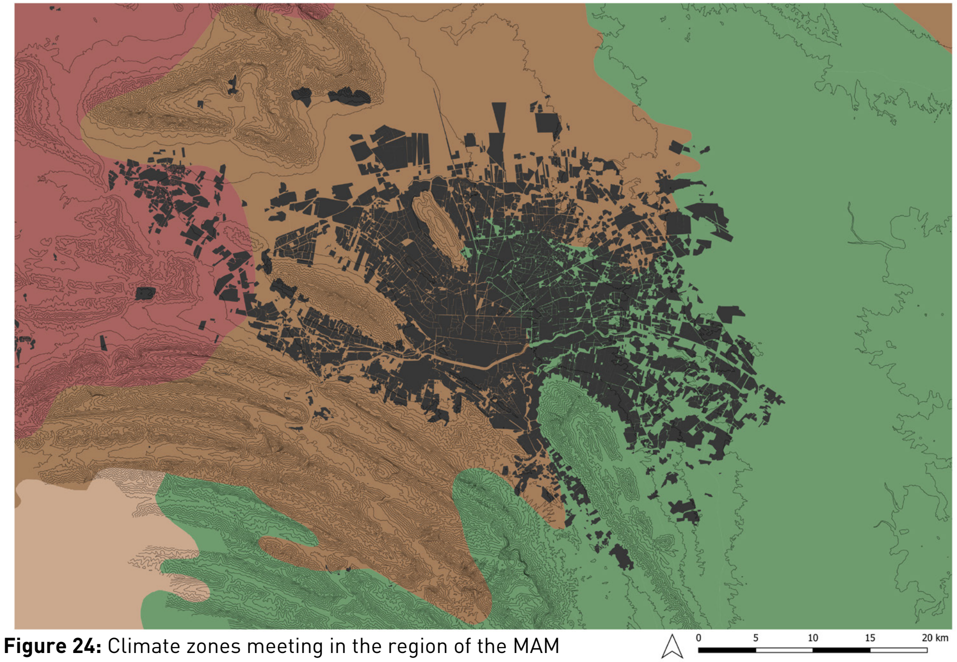


**Figure 24:** Climate zones meeting in the region of the MAM
**GIS sources:** Conabio, Openstreetmap

### 4.1.3 Precipitation

Because of the difference in climatic systems, the amount of precipitation declines from east to west. But according to the GIS sources of Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO, n.d.), which is seen in figure 25, relatively more precipitation falls in the mountains of Sierra Madre Oriental. This is because humid air from the sea, an eastern wind, collides with the mountains at the western side if the MAM. The air is forced upwards and cools down whereby the air is not able to carry the water vapor in the air and it starts to condense in the form of clouds. In other cases it starts to rain (University Corporation for Atmospheric Research n.d.). Averagely, there is around 590 millimeters of precipitation on an annual basis in the MAM (Climates to Travel, n.d.).

**Montly rainfall**

Every month, there is a different average amount of rainfall. The driest months are in the winter and the wettest in September. For instance, December has an average rainfall of 15 millimeters and September 150 millimeters of rainfall (ClimatesToTravel, n.d.).

### 4.1.4 Evapotranspiration

The amount of evatransporation is approximately as high as the precipitation throughout the year. This evapotranspiration is the amount of water that is evaporated from the soil and transpirated by vegetation. This amount of evapotranspiration declines from east to west (figure 26). The places which have more precipitation amounts and have a relatively less dryer climate zone are also the places where the amount of evaporation is lower. That is because the amount of evaporation is dependednt on the amount of water storage in the soil and vegetation cover (National Centre for Climate Services, n.d.).

Due to the minimal differences between precipitation and evapotranspiration in the MAM, it can be presumed that there is an almost balanced watercycle.

Evaporation of water in an area is dependent on the climatic circumstances. The evaporation rate is higher when there is solar radiation present with higher temperatures and dryer air and when there is more wind (Evaporation and Climate, z.d.). The biggest factor for evaporation is the temperature which is also dependent on the amount of solar radiation. So that means, during summer with the biggest temperatures and the most amount of sun hours (ClimatesToTravel, n.d.) the biggest evaporation rates will be visible.

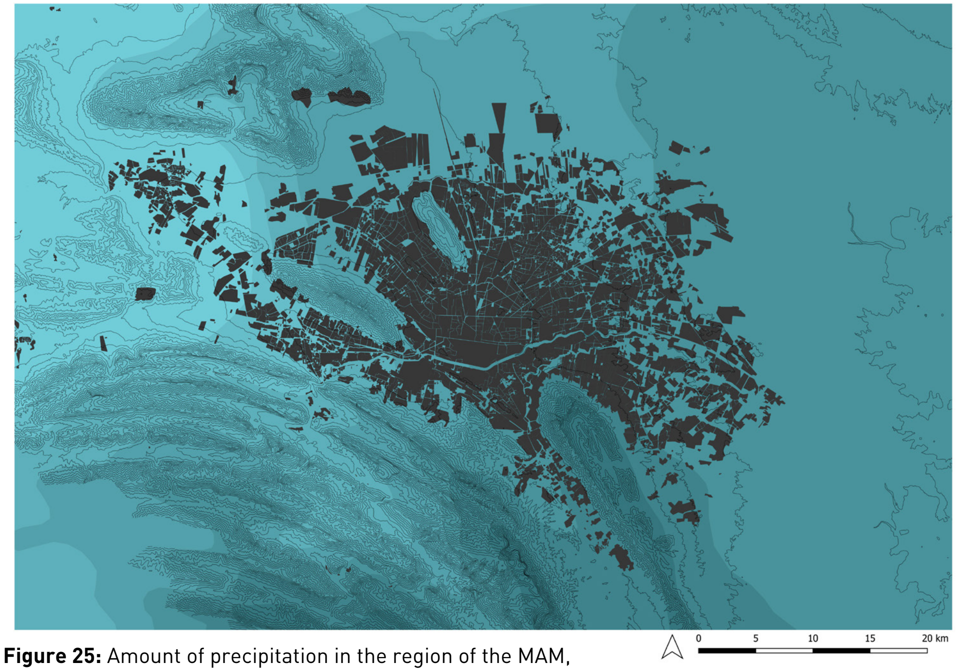


**Figure 25:** Amount of precipitation in the region of the MAM, the dark gray area is the built area of the MAM
**GIS sources:** Conabio, Openstreetmap

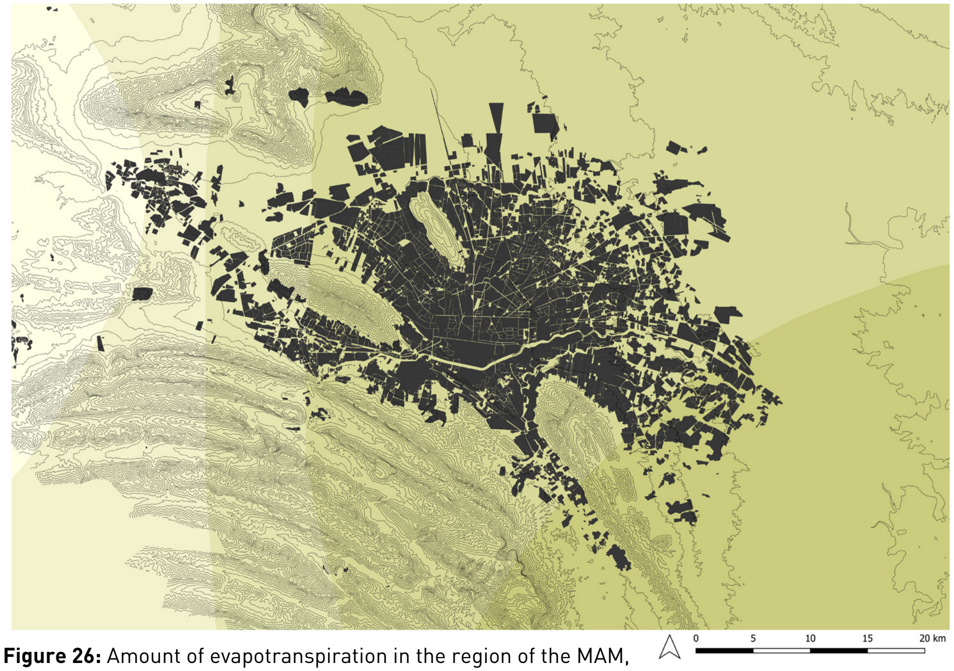


**Figure 26:** Amount of evapotranspiration in the region of the MAM, the dark gray area is the built area of the MAM
**GIS sources:** Conabio, Openstreetmap


**Figure 27:** Terrain and landuse in the MAM. The gray area represents the land use and the contours have an interval of 100 meters in altitude.
**GIS Sources:** Monterrey government, Inegi, Openstreetmap

Figure 28 Picture: Pieter van der Wel

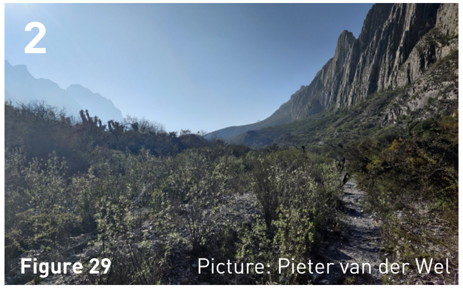


Figure 29 Picture: Pieter van der Wel

Figure 30 Picture: Pieter van der Wel

Figure 31 Picture: Pieter van der Wel

## 4.2 Landscape and Ecology

### 4.2.1 Terrain and the Build environment

The terrain map of Monterrey in figure 27 shows the elevation in the area in relation to the built environment of the MAM. It shows that the built environment (in gray) has been developed untill it has reached the foothills of the mountains which are part of the mountains surrounding the MAM. In figure 28 and 29, an experience of the mountain range is shown. Figure 30 shows the urban expansion around the mountains.

The map also shows an elevation difference of 200 meters from the east of the build area to the west with a span over 30 kilometers.

There are several mountain peaks around the MAM. For instance, the mountain Cerro de la Silla consists of a top of 1820 meters above sea level and has a prominence of around 1200 meters. The boundaries of the municipalities from the Metropolitan region is also shown in the map. The municipality of Monterrey ranges from the northwest between the mountains Mitras and Topo Chico to the southwest between Cumbres and La Silla. In figure 31, the urban expansion can be seen on the slope of the Cerro de la Silla.

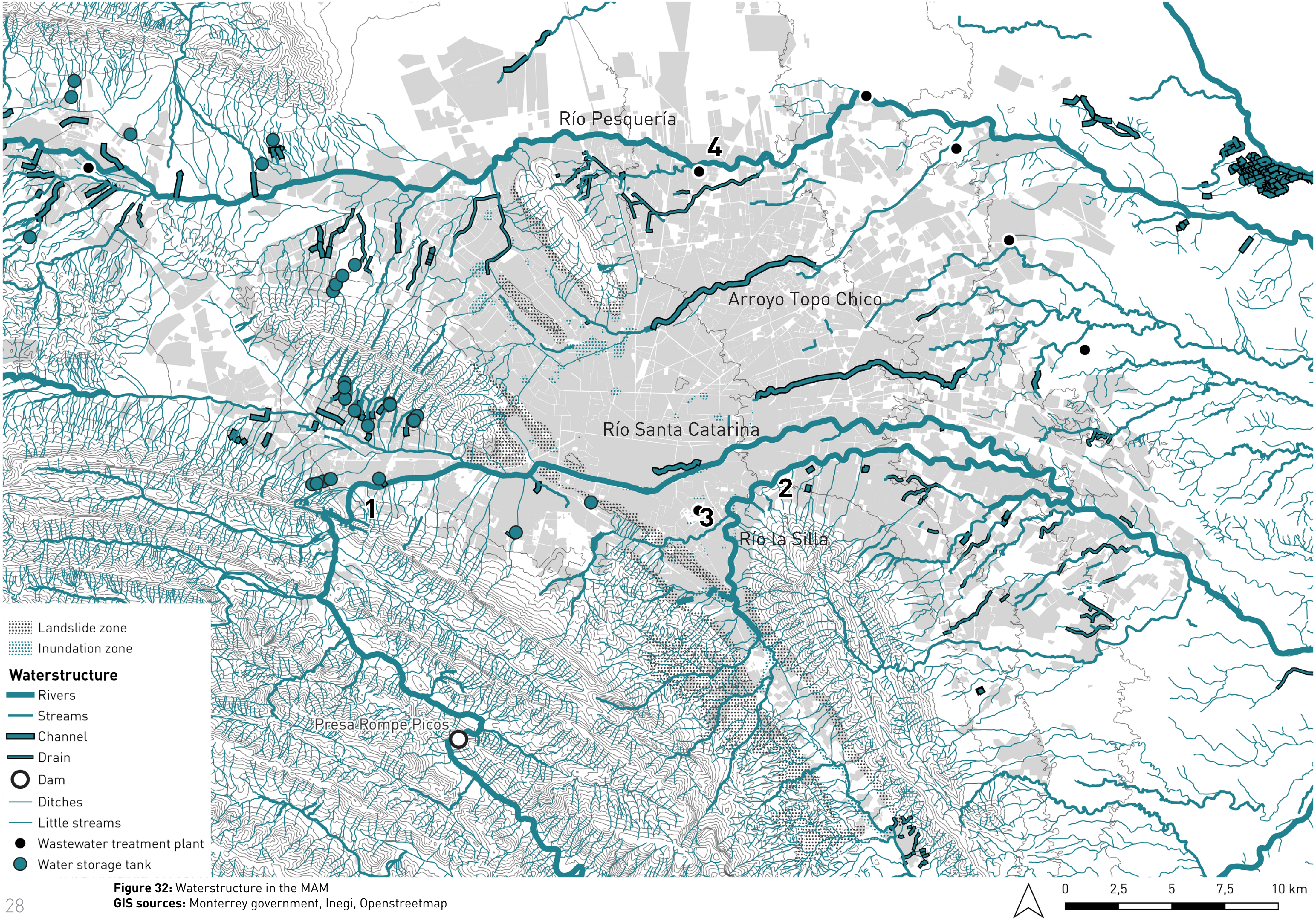



**Figure 32:** Waterstructure in the MAM
**GIS sources:** Monterrey government, Inegi, Openstreetmap

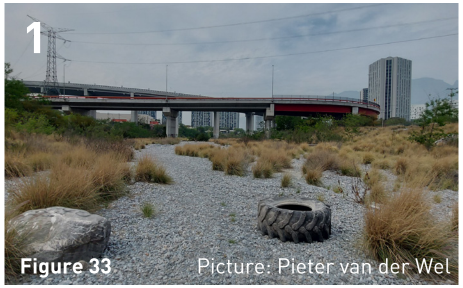


Figure 33 Picture: Pieter van der Wel

Figure 34 Picture: Pieter van der Wel

Figure 35 Picture: Pieter van der Wel

Figure 36 Picture: Pieter van der Wel

### 4.2.2 Waterstructure

There are three main rivers in the natural waterstructure of the Metropolitan region (figure 32). In the middle of the MAM, the rivers Río Santa Catarina and the Río La Sillia (figure 33 and 34) are located and in the north of the MAM the Río Pesquera is located. The first two rivers spring in the mountains of the Sierra Madre Oriental in the nature reserve Les Cumbres and take their course to the east in direction of the Mexican Gulf. In Les Cumbres, the watershed of the Río Santa Catarina overlays 80 percent of the area of the nature reserve (Ayala et al., 2013).
Along these rivers lots of side streams are connected coming from different canyons and mountains. These rivers and streams are part of the big Río Grande watershed. This river flows in the north of the country to the Gulf of Mexico in the east.

**Storm drains and inundation**

Urbanisation has changed the way people lived with the water and it has changed a lot in the current waterstructure since. For example, the river Santa Catarina and several other streams, such as the Arroyo Topo Chico are canalized and transformed into storm drains (figure 35). The primary idea was to remove stormwater quickly and efficiently. Nevertheless, it leads to bad quality of the water running through the concrete channels. And because of rapid urbanisation, the systems cannot sustain the increased stormwater volume, which leads to floods. (Typeset, n.d.). These inundation zones are also visible in the map and are mostly located along rivers and streams, the places where the storm drains overflow during heavy rainfalls.

**Landslides**

The map shows the risk of landslides which are more common along the slopes of mountains and hills when there is urban development. According to recent studies, urban areas are more likely to create landslides than rural areas when there is rainfall. Also, urban development built next to mountain slopes that are sensitive for landslides, exposes more people to the hazardous of landslides (Phys, 2021).

**Treatment plants**

Water treatment plants are located in the northeast of the MAM (figure 36). The reason for this is that the elevation slowly goes down from southwest to northeast. Therefore, sewerwater is following the region's slope and eventually enters the treatment plants. After the treatment, the water is cleaned and discharged in the Río Pesquería (Excursion comment at Planta Norte, March 4th 2024).

**Rompepico Dam**

The map also shows the location of the Rompepico Dam. It is the dam that is retaining the water durnig a hurricane. Hurricane Alex has caused 2,700 cubic meters per second of water flowing through the Santa Catarina River (Alcántara-Ayala et al., 2019). Without the dam, the peak flow would be at least 750 cubic meters more (Aguilar-Barajaset al., 2019).

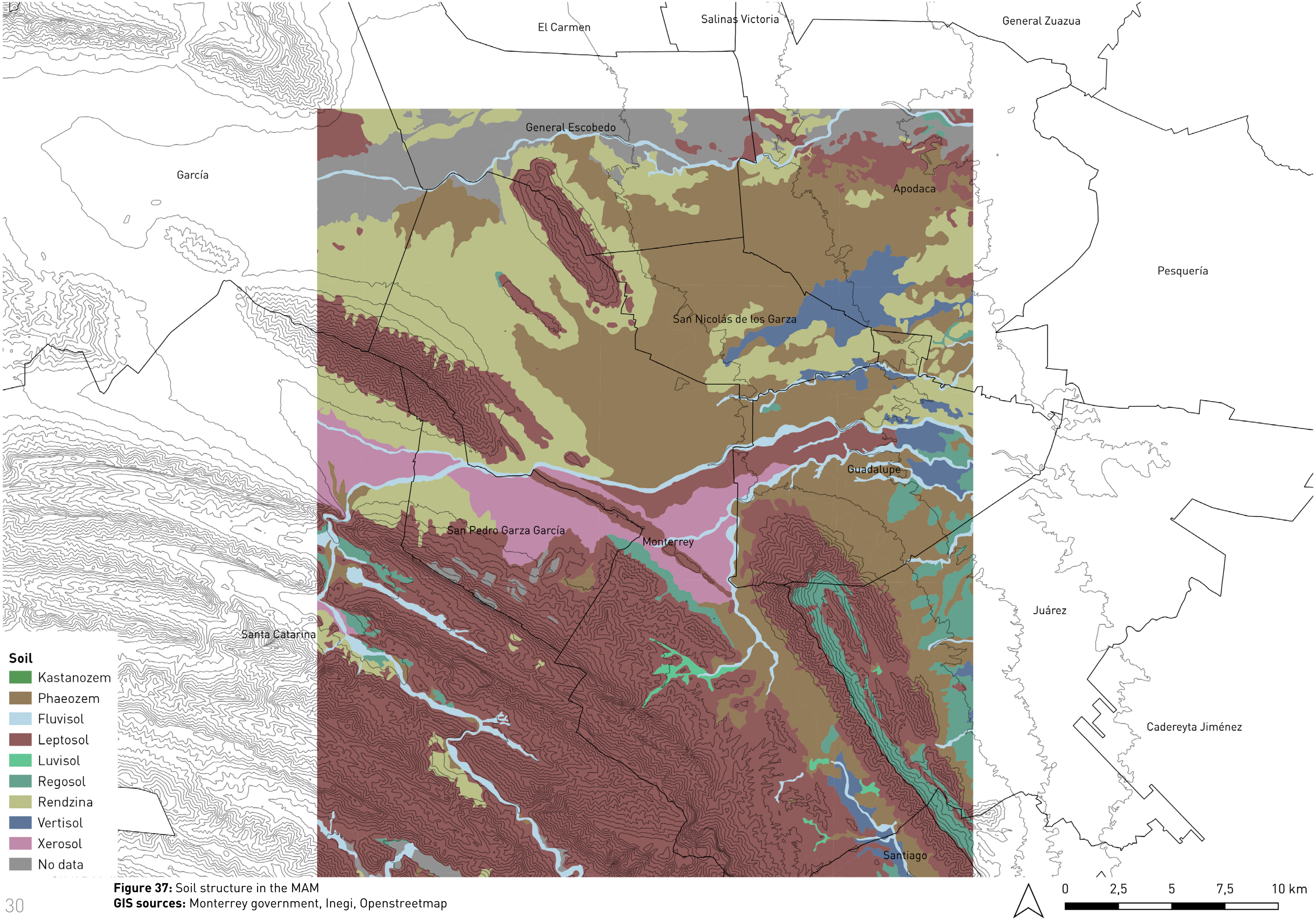



**Figure 37:** Soil structure in the MAM
**GIS sources:** Monterrey government, Inegi, Openstreetmap

### 4.2.3 Soil

The soil map in figure 37 shows the different types of soil according to the FAO soil classification. FAO stands for Food and Agriculture Organization. The soil creates conditions for types of vegetation to grow which results into different kinds of ecological habitats.

In the GIS map, it is visible that there are relatively more Leptosol present than other soil types. These are present on the mountainous regions. Fluvisol for example, which is a relatively young soil deposited by water movement, is following the course of the main rivers and other streams.

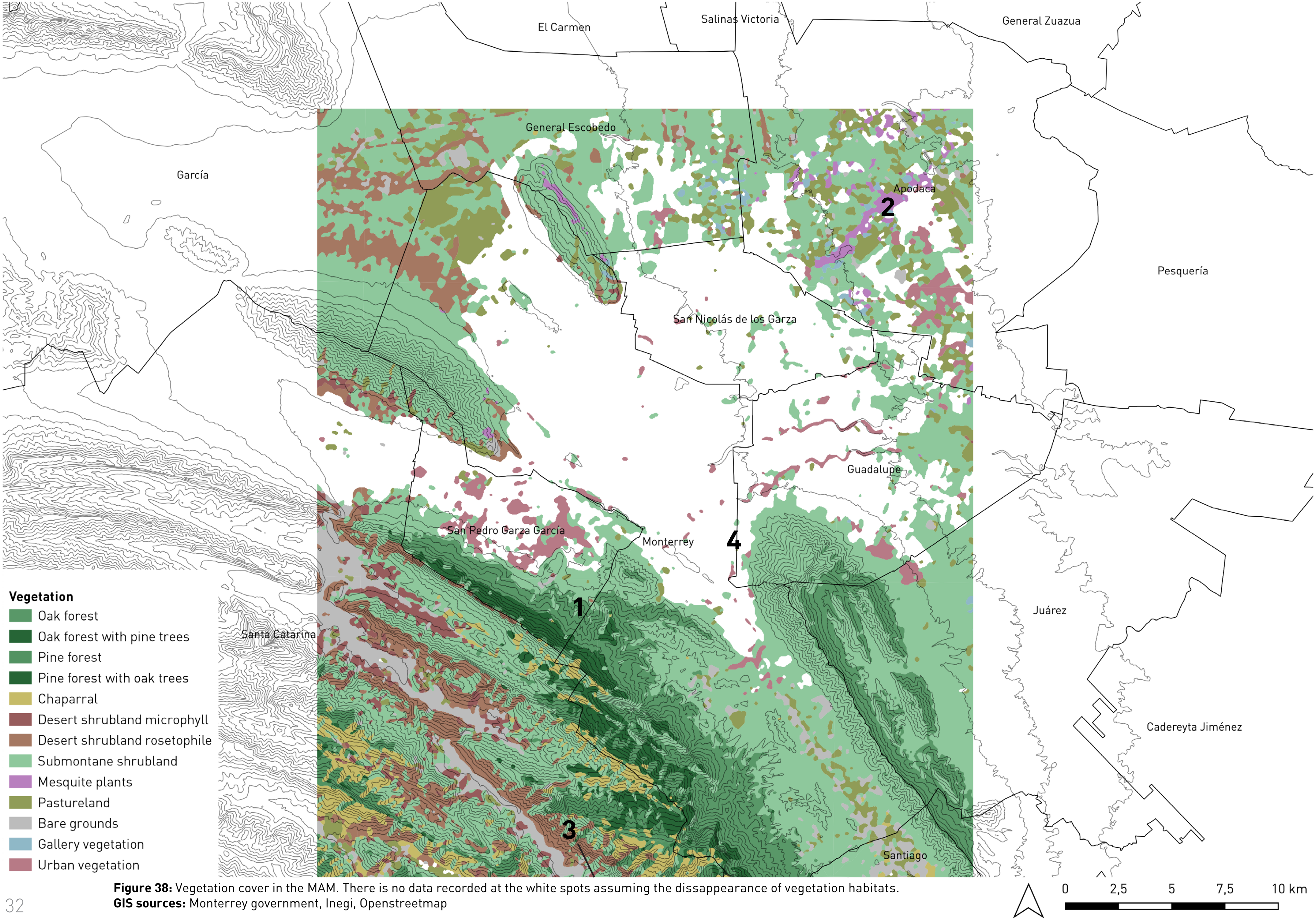



**Figure 38:** Vegetation cover in the MAM. There is no data recorded at the white spots assuming the dissappearance of vegetation habitats.
**GIS sources:** Monterrey government, Inegi, Openstreetmap

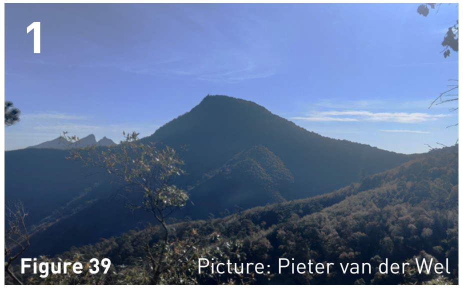


Figure 39 Picture: Pieter van der Wel

Figure 40 Picture: Pieter van der Wel

Figure 41 Picture: Pieter van der Wel

Figure 42 Picture: Pieter van der Wel

### 4.2.4 Vegetation

In figure 38 the vegetation map is shown consisting of different vegetation types. Urbanization causes primary vegetation habitats to fragment or to loss (Forman, 2008). Therefore, it is possible that the middle parts of the GIS vegetation map, the vegetation types are not registered. The vegetation types around the MAM are visible nevertheless.

On the mountains there are more pines and oaks and in the lower area there is more shrubland according to the map. In figure 39, a picture of ecological park Chipinque shows the pine and oak forests covering the hilly area. Also, the native plant Mezquite is shown in particular parts in the area. In figure 40, a Mezquite forest is shown, which is located in the northeast of Monterrey. Along natural waterways, such as the Río la Silla, more forest types are present (figure 42).

The geological processes of the Sierra Madre Oriental that has been formed resulted into different variations of (micro) climates in the area with a big diversity of species. The humidy, which is depended of the orientation of the mountains and climate patterns, highly determines the distribution of the habitats. In the nature reserve Les Cumbres for example, the leeward side of the mountains creates dryer conditions for vegetations to grow. The size and vigor of the plants depends on the water availability in the soil. Trees that became smaller are known as chaparral and are also shown on the map and shown in figure 41. Another plant that covers a relatively large space is submontane shrubland. These are characterized by species branching directly from the ground and are mostly found on the lower slopes (Parque Nacional Cumbres de Monterrey, 2006).

### 4.2.5 Ecology design principles

In order to make ecological environments stable and preserved, biodiversity has to increase. Because the diversity of species makes the living world function properly (Wageningen University & Research, n.d.). To increase the quality of the ecological environment in a city, design principles have to be made in order to make a design that can restore or preserve the ecology.

Richard Forman introduces the role of landscape ecology in his book Urban Regions in 2008. He describes the definition of a patch and a corridor and describes its mechanisms and use in landscape based design in order to enhance the urban ecology.

As Forman states, a patch is defined as an area which is relatively different than its ecological surroundings. For a city, a patch as green space translates into a park or a nature reserve for example. For a green space, the amount of biodiversity is higher if this patch is bigger, because each species needs a minium size habitat for survival. Also, bigger patches have the ability to protect water quality and garantee safety for species during sudden environmental changes. A corridor is defined as a linear feature which has a different habitat than its surroundings and link patches together. It helps species to migrate from one patch to te other and helps mitigate the negative effects of habitat fragmentation caused by urbanization (Forman, 2008). It could also exist of a linear repetition of small patches. For a city, a connection as a green space translates into a waterway or other green corridors, such as linear parks, tree-lined streets or riverbanks.

According to Forman, patches and corridors are interdependent and together form a mosaic that sustains both ecological and social functions in urban regions. Social functions are evident when green spaces include recreational purposes. This can be done by transforming waterways and green corridors into different kinds of parks. They have to be integrated into the urban planning in order to improve both ecology and human quality of life in metropolitan regions (Forman, 2008).

To restore the ecological environment and enhance the quality of life for residents in the metropolitan area of Monterrey, both patches and corridors must be acknowledged. They can be improved upon in existing green spaces or transformed from other urban areas. Together they form the new ecological mosaic in the city (figure 43 & 44).

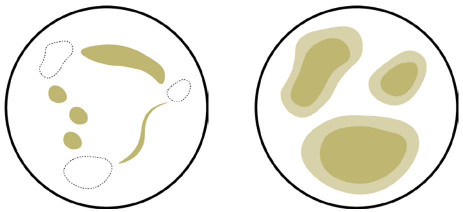


**Figure 43 & 44**: Make corridors and patches to enhance the ecology in the urban area.

### 4.2.6 Patches and corridors in Monterrey

In and around the Monterrey, there are nature reserves located, which are more or less overlapping the mountainous areas (figure 47). Nature reserves are spaces delimited by the federal government in order to make the conservation possible for both the diversity of ecosystems, species, genes, habitats, landscapes and notable geological formations, as well as the cultural heritage of the country for the benefit of the current and future generations. Each nature reserve has its own geological characteristics and ecological environment (Cantú et al., 2004).

According to Forman, the nature reserves are seen as big ecological patches where species can thrive because of their relatively big size. In order to restore the ecology in the area, the isolated nature reserves should be connected with each other, through the urban region.

There are four main nature reserves in the MAM which can be used to interconnect with each other. These nature reserves are called Cumbres de Monterrey National Park, Cerro de la Silla Natural Monument, Sierra las Mitras and Cerro del Topo chico.

To connect these, waterways and other green corridor types can be used. The spreaded waterways from the waterstructure in the MAM gives an opportunity to connect the patches with each other, while simultaneously create possible recreational purposes for the residents of Monterrey.

In nature reserves, the rivers and streams flowing through the MAM orginate and could therefore be used as sources for quality water.

**Design Principles Landscape and Ecology in Monterrey**

As new design principles, it is important to both restore the vegetation habitats and waterstructure in Monterrey to improve the ecological environment and quality of life (figure 45 & 46).

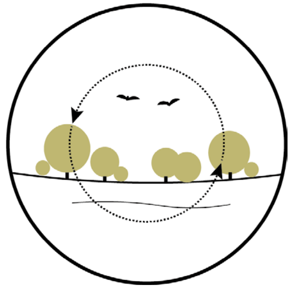


**Figure 45**: Restore the ecosystem my making green patches.

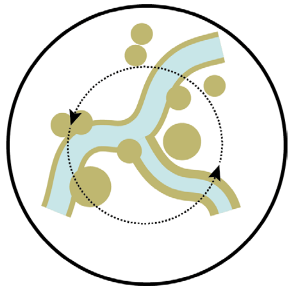


**Figure 46:** Restore the waterstructure by transform them in green connections.

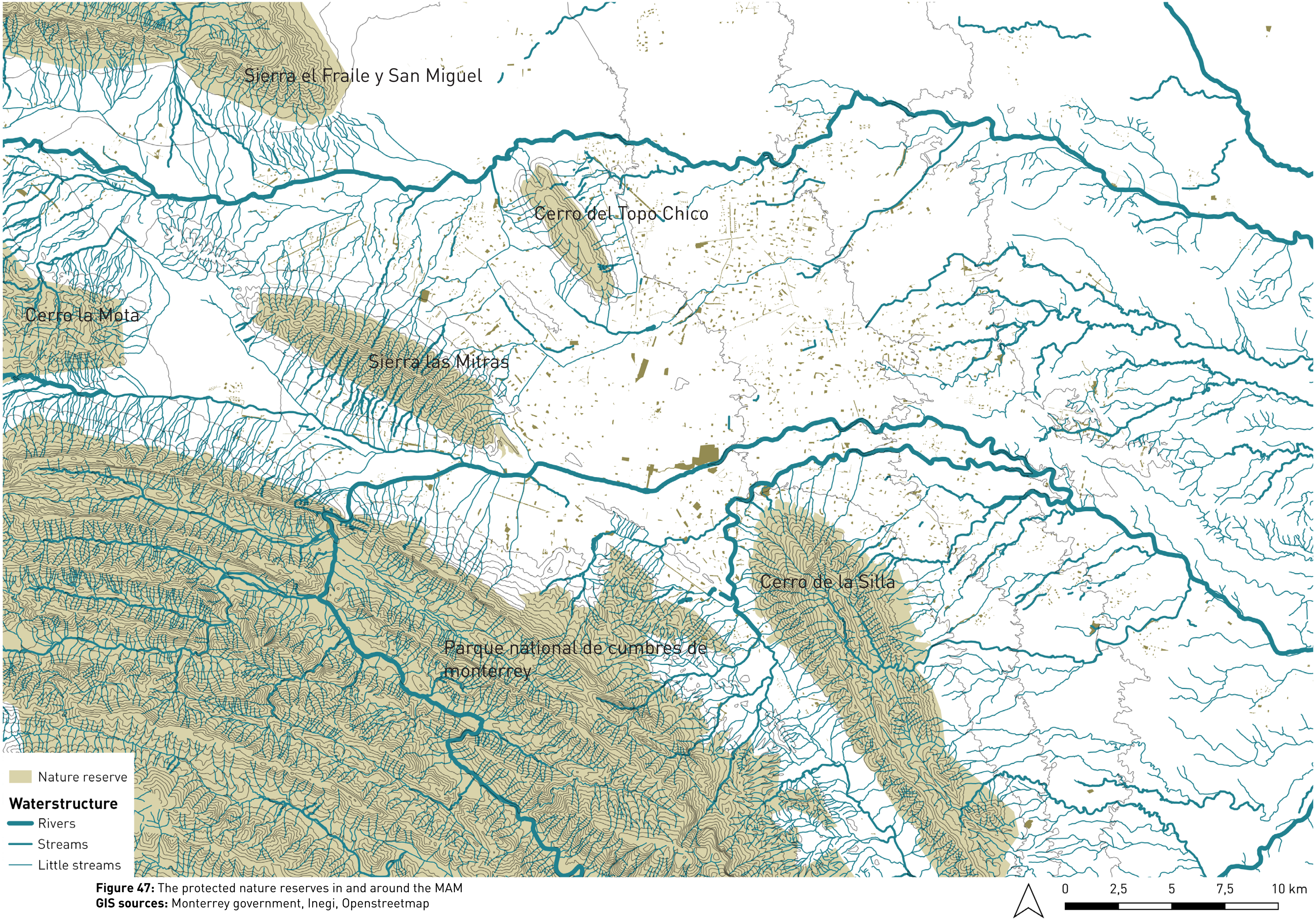



**Figure 47:** The protected nature reserves in and around the MAM
**GIS sources:** Monterrey government, Inegi, Openstreetmap

### 4.2.7 Parks and plazas in Monterrey

There are several parks and plazas in the metropolitan area, which can be seen as patches of green within the urban environment. These locations are shown in the map in figure 52. These are places where residents can recreate and find shade during heat waves (figure 48 & 49). Not all plazas are specifically observed as green spaces, but they still have the potential to serve as habitats for animals in the canopy of trees or to be transformed into greener spaces.

In a study of space and time analysis for urban green areas in the MAM by Manzanilla-Quiñones et al. (2021), it was elaborated that urban green areas provide important ecosystem services. These areas are vulnerable to urbanization because they have declined by 0.29 square meters per year between 2000 and 2019. Therefore, they need to be protected and conserved by the authorities of the municipalities within the metropolitan area (Manzanilla-Quiñones et al. 2021).

**Ecological park Chipinque**

One of the most biodiverse and preserved parks in Monterrey is Chipinque (figure 50). This park has many hiking trails for those looking to escape and enjoy the richness of its nature. The park is a refuge for numerous species. There are multiple types of forests and plants in the area. As a result, the amount of fauna species is relatively high compared to other parks. Currently, there are 1,750 fauna species registered, and the number is still increasing (Parque Ecológico Chipinque, n.d.).

### 4.2.8 Nature reserves in Monterrey

**Cumbres de Monterrey National Park**

The biggest national park around Monterrey lies in the northern part of the Sierra Madre Oriental mountain range (figure 51). It protects the flora and fauna from urbanization. In this park, the Río Santa Catarina and Río Pesquería originate. It is also known for its rough terrain with steep mountains, canyons, and waterfalls (LacGeo, n.d.). The mountains vary from 600 meter up to 3,400 meter above sea level. It was established in 1939 to protect the area from urbanization, and since 2006, it is known as a biosphere reserve. The vegetation commonly consists of coniferous forests with oaks and shrubs. Because of the variety of different microclimates, the nature reserve provides a big variety of species (LacGeo, n.d.).

**Cerro de la Silla Natural Monument**

Cerro de la Silla is known for its saddle-shaped profile. There are threats to the ecosystem's wildlife, such as irregular settlements that threaten the habitats on the slope. In the longer term, there are threats such as quick water runoff, a declining water table, and the overuse of natural resources due to climate change (Téllez, 2001).

**Sierra las Mitras**

Mitras is situated in the west of the MAM. The mountain is also known for the damage caused by quarrying. The quarries were excavated for concrete to build various types of infrastructure in Monterrey to ensure public services (Santuarios Naturales, n.d.). The mountain has a prominence of around 1300 meters.

**Cerro del Topo chico**

This mountain has a prominence of around 600 meters and is a protected area due to its isolated situation. On this mountain alone, 1,249 species have been recently found in this nature reserve (iNaturalist, n.d.). It is also a very stressed ecosystem because of its isolation (M. Manzano, presentation discussion, February 2024).

Figure 48 Picture: Pieter van der Wel

Figure 49 Picture: Pieter van der Wel

Figure 50 Picture: Pieter van der Wel

Figure 51 Picture: Pieter van der Wel

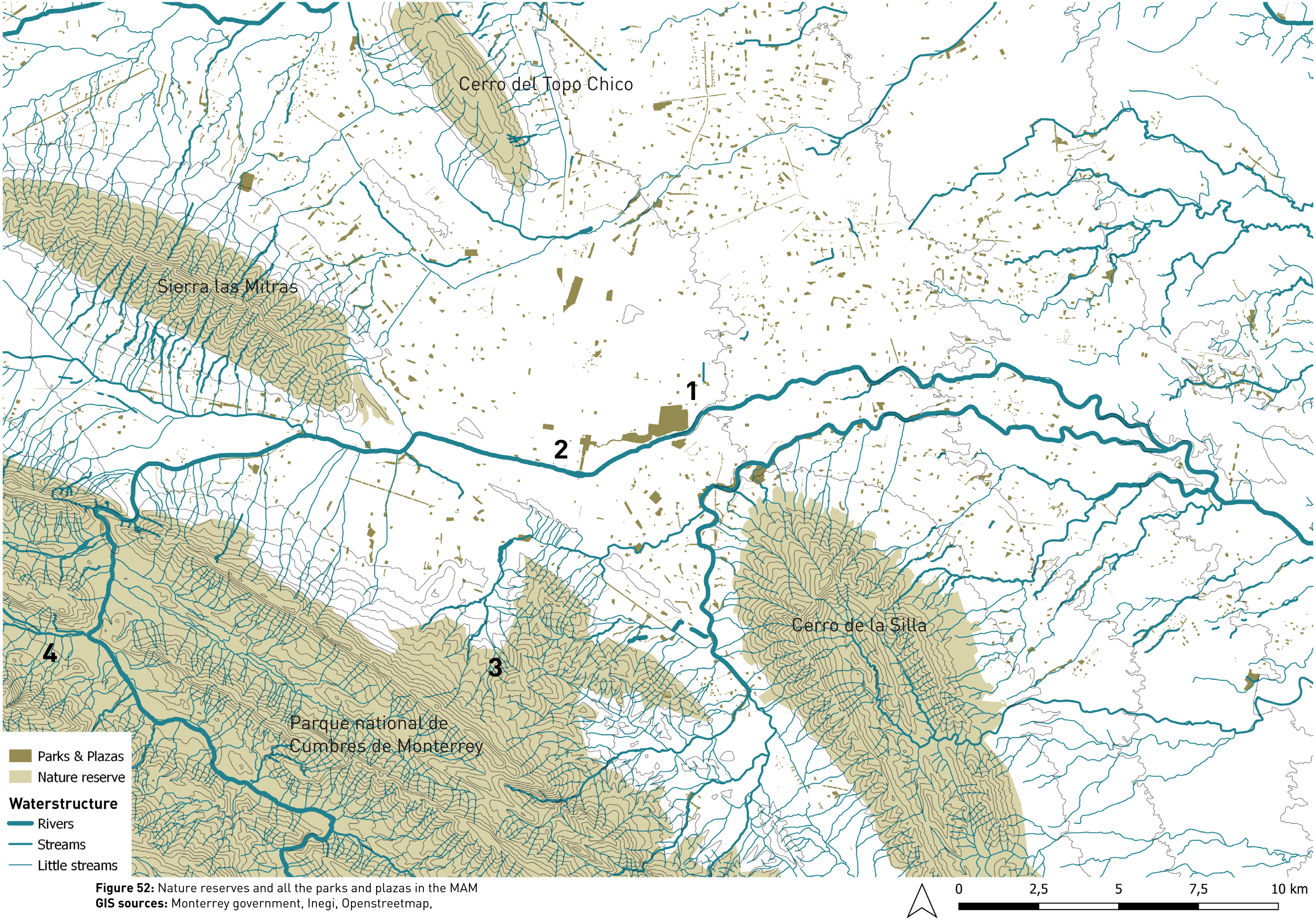



**Figure 52:** Nature reserves and all the parks and plazas in the MAM
**GIS sources:** Monterrey government, Inegi, Openstreetmap,

## 4.3 Heat stress

### 4.3.1 Heat stress in cities

Heat stress in the city is the result of the Urban Heat Island effect (UHI). This effect occurs when an urbanized area warms up due to the sun and retains heat in the man-made structures within the city. Urban areas typically experience higher temperatures than the surrounding rural areas, especially during heat waves with calm winds.
Approximately 65% of the global population are expected to live in cities by 2050 (Phelan et al., 2015). Therefore, heat stress is a growing concern for the future due to climate change and the expectation of increasing urbanization.

**Mechanisms day and night**
At night, heat is more trapped in the city than during the daytime because there is more convection during the day than at night (C.J.G. Morris, 2000). This phenomenon is illustrated in figure 55 and 57. During the day, constant sunshine causes heat to rise, drawing cooler air from rural areas and pushing the heat higher into the atmosphere. At night, without sunlight, convection reduces, trapping urban heat within the urbanized area. This results in a larger temperature difference between rural and urban areas during the night (Phelan et al., 2015).

**Causes**
Land use change from natural areas into man-made structures made of stone and concrete is the main cause of the UHI effect. Vegetation is lost, reducing the microclimate cooling effect of evapotranspiration in natural areas (Gkatsopoulos, 2017). Replaced man-made structures such as buildings, parking lots, and pavement contribute to the heat capacity of the urban environment. Heat capacity is the amount of heat required to raise the temperature of a unit mass. These structures together create a heat reservoir. Therefore, buildings in cities with high heat capacity also cool down slowly at night (C.J.G. Morris, 2000).

Furthermore, heat stress can also lead to higher pollution levels in the atmosphere from motorized vehicles and industrial areas (C.J.G. Morris, 2000)."

Also, the materials of the man-made structures have certain thermal conductivity and albedo. Thermal conductivity is the ability to transfer heat into and out of a man-made structure. Sunlight that radiates on a mass with high thermal conductivity, such as steel, transfers warmth very quickly into the building. Albedo is the amount of sunlight reflected by a surface, ranging from 0 to 1. Surfaces with high albedo reflect more sunlight.

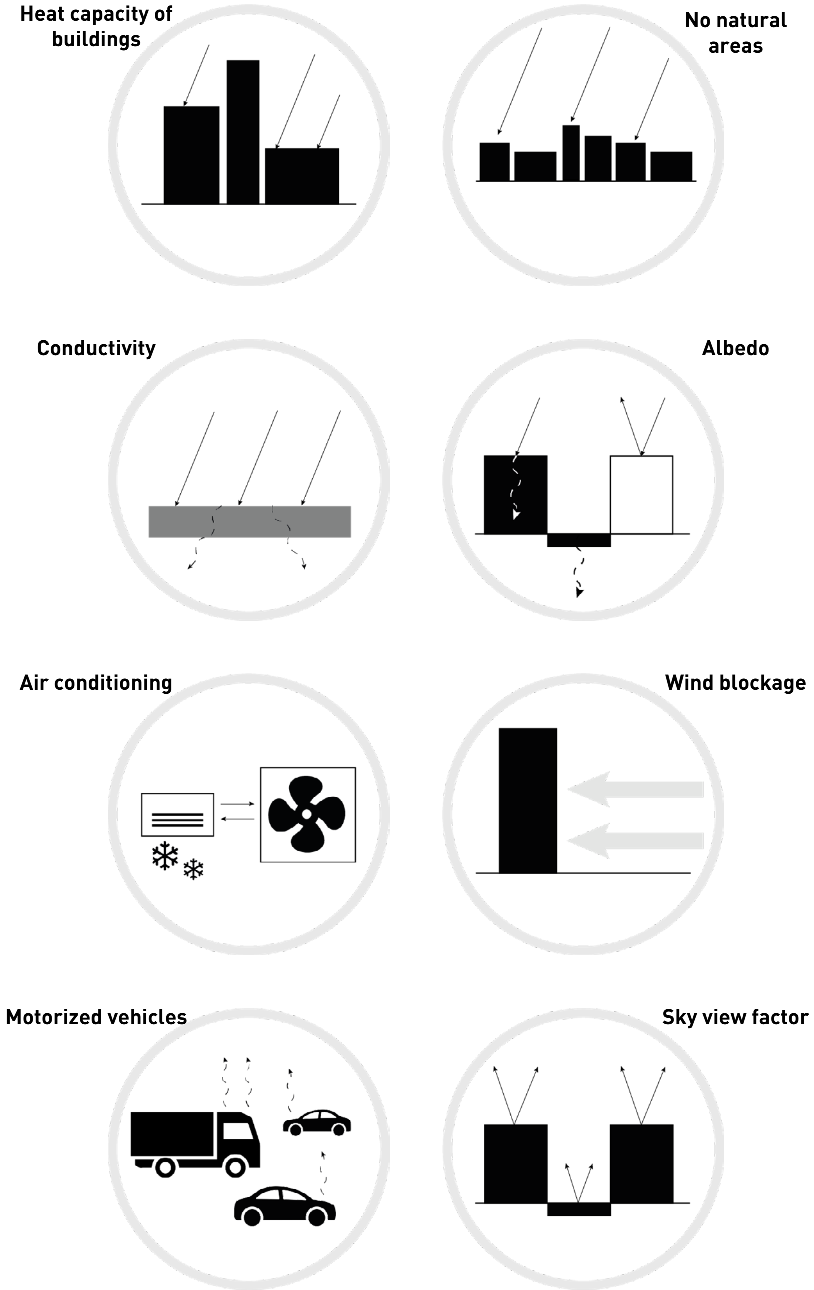



**Figure 53:** The causes of the UHI effect

Buildings with white roofs, for example, reflect more sunlight back into space, resulting in cooling both the city and the building itself. Black surfaces absorb more sunlight than lighter ones. These dark surfaces are mostly found on asphalt and rooftops.

The Sky View Factor also determines the amount of heat trapped within the city. Structures with relatively less exposure to the atmosphere due to tall buildings reduce the ability to release heat, especially during colder nights (Baghaeipoor & Nasrollahi, 2019).

Other sources that can warm up the city include air conditioning, motorized vehicles, and wind blockages such as buildings (figure 53).

With climate change occurring in the short term, heat stress levels will increase due to rising temperatures and longer periods of droughts (CDP, n.d.).

**Impacts on lifes**

A deficit of nature in urban areas results in more heat, which contributes to the Urban Heat Island effect. This leads to environmental conditions that are oppressive and dangerous for humans (OneBillionResilient, n.d.).

Heat stress mainly affects the lives of vulnerable people, including young children, elderly, people with low incomes, and those with health issues. Residents with low incomes often face poor housing conditions, such as lack of insulation, absence of air conditioning, or small living spaces. Additionally, they may lack adequate resources or places for shelter during a heat wave, such as tree canopy.
Increased morbidity occurs with higher levels of heat stress because excessive heat affects people's energy balance, reducing their ability to engage in public activities (Elliot, 2020).

**Solutions**

Thermally comfortable environments encourage more human activity, resulting in better public health. This also maintains social activities within the city and therefore improves the quality of life for residents (Elliot et al., 2020). Creating these thermally comfortable environments requires reducing the Urban Heat Island effect (UHI).

The most effective cooling strategy is to remove man-made structures and plant trees. Trees provide shade and transpiration through their leaves. Deciduous trees are recommended because they provide more shade in summer and allow sunlight through in winter when it is colder.

Additionally, increasing albedo by installing white roofs or using white-colored buildings can reflect more sunlight, reducing heat absorption (figure 54). This helps keep the interior of buildings cooler, increasing comfort and reducing the need for air conditioning.

Converting pavement areas into green spaces allows for more transpiration and cools the surrounding microclimate. Other practical options for reducing the heat island effect, according to the Environmental Protection Agency (EPA), include green roofs and cool pavement for both streets and sidewalks (Environmental Protection Agency, n.d.).


**Figure 54:** White colored buildings are reflecting more sunlight in the San Bernabé community center in Monterrey (Picture: Pieter van der Wel).

Water also has a cooling effect. Flowing water, waterfalls and water fountains create cooler public spaces because flowing water transports heat away. Additionally, the contact between water and air, particularly in air droplets, promotes evapotranspiration and thus cooling (Climate Adapt, n.d.).

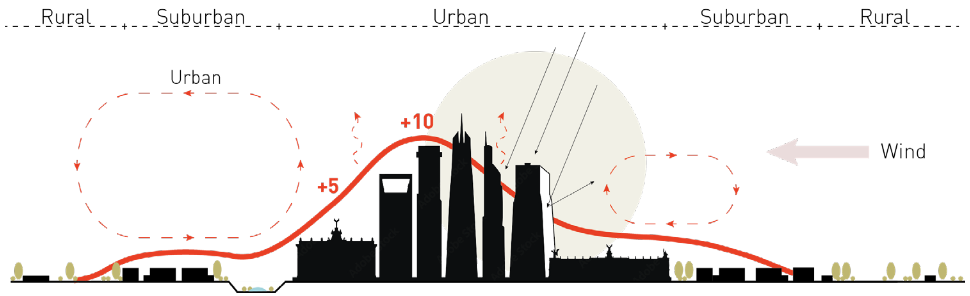



**Figure 55:** Heat stress mechanisms in the MAM during the day

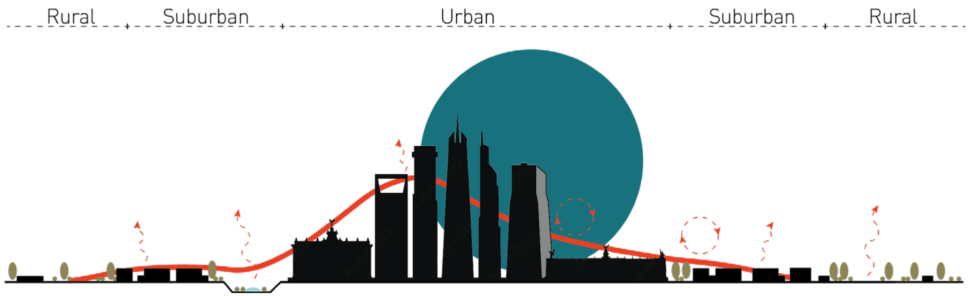



**Figure 57:** Heat stress mechanisms in the MAM during the night

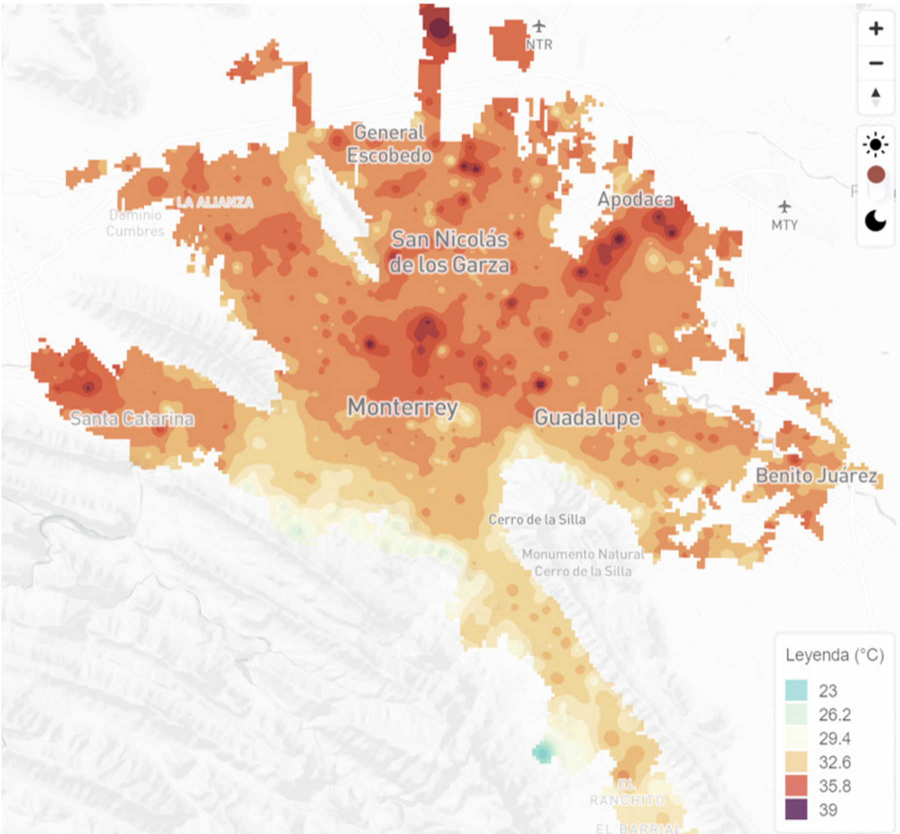



**Figure 56:** Amount of Heat stress in the MAM during the day. Landsat image modified and retrieved from CentroGeo (n.d.).

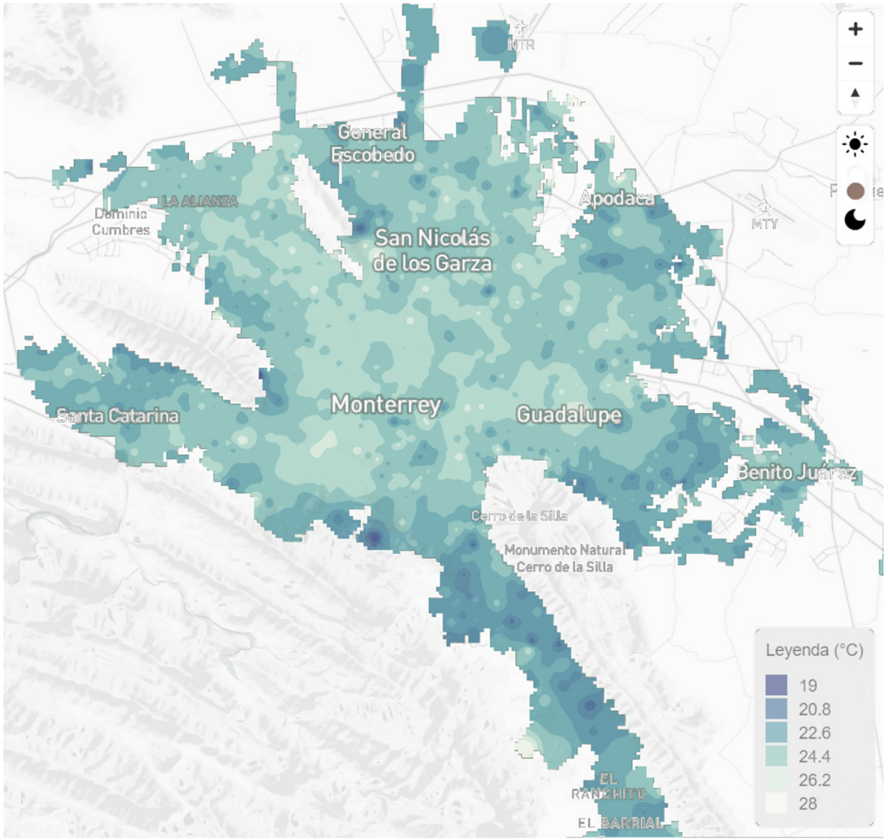



**Figure 58:** Amount of Heat stress in the MAM during the night. Landsat image modified and retrieved from CentroGeo (n.d.).

## 4.3.2 Heat stress in Monterrey

Heat stress maps of the MAM are shown in figure 56 and 58. NASA satellites are used to determine the amount of infrared radiation emitted by urban surfaces. The MODIS imaging processor measures nighttime temperatures, while Landsat satellites measure daytime temperatures to visualize temperature relative to the surrounding area (McCullough et al., 2013).

The maps illustrate that the urban core is generally hotter than the surrounding urban areas. In the southern part of the MAM, temperatures are relatively cooler compared to the northern part. This difference could be the result of the dominant southeastern wind in the region (WeatherSpark, n.d.).

Cooler spaces are also observed in the map in the foothills of the mountains in and around the MAM. In figure 59, an experience from the cooler forests on the edge of the MAM is shown.

The urban core of Monterrey experiences temperatures 5 to 10 degrees Celsius higher than the rural surroundings. This temperature increase is partly due to the low amount of natural green space. Currently, there is only 3.9 square meters of urban green space per inhabitant in the Monterrey municipality. This is 5.1 square meters less than the commonly referenced target of 9 square meters of urban green space per inhabitant recommended by the WHO (OneBillionResilient, n.d.).

**Heat stress and Ecosystems**

The Urban Heat Island (UHI) effect also impacts ecosystems. Rainwater falling on relatively warm surfaces increases the temperature of the water. As this warmed water enters rivers and lakes, it affects the metabolism and reproduction of many aquatic species. Implementing green infrastructure can help prevent water from warming up as it flows to lower lands, and thereby improving water quality (Environmental Protection Agency, n.d.).

In Monterrey, there are storm drains entirely made of concrete. These concrete drains, with significant mass, have replaced cooler natural vegetation. Thus, they contribute to the UHI effect and affect the water quality.

## 4.3.3 Mitigating Heat stress in Monterrey

Nature-based solutions can address heat stress challenges by implementing the following transformations: replacing parking lots underground and creating green spaces above ground; using canopies over exposed plazas; and maintaining an east-west orientation of roads to facilitate cooling winds for pedestrians (OneBillionResilient, n.d.).

A study by Elliott et al. (2020) describes how urban heat reduction through green infrastructure and design solutions (GIDS) improves city environments. The study argues that thermally comfortable environments encourage more human activity, resulting in better public health and maintaining quality of life for inhabitants.

This approach is particularly necessary in cities where urban planning forces car dependence. In such cities, wide car lanes and unfriendly or absent sidewalks contribute to dispersed settlement patterns, reducing connections between neighborhoods and increasing social isolation. Connecting with green spaces presents an opportunity to enhance the quality of life.

Given ongoing climate change, urgent action is needed to protect residents from excessive heat. Residents living in poor circumstances are particularly vulnerable due to their relatively lower health. GIDS not only addresses these challenges but also enhances social activites, improves equity, and sustains livelihoods, peace, and social order (Elliott et al., 2020).

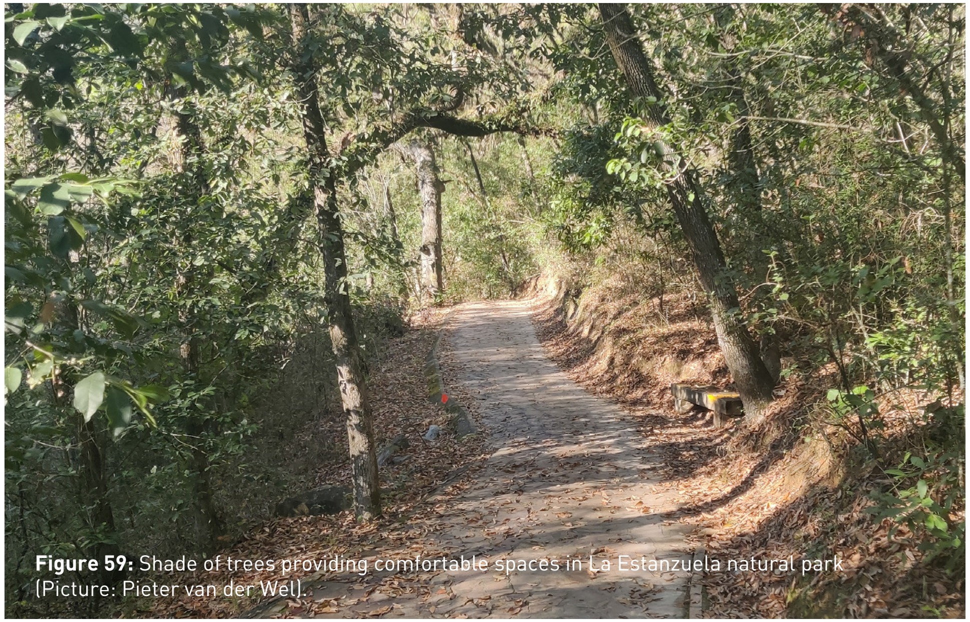


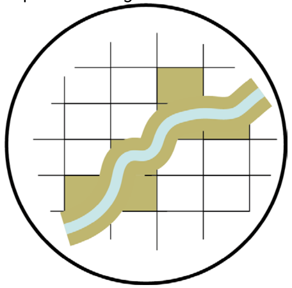
**Figure 59:** Shade of trees providing comfortable spaces in La Estanzuela natural park (Picture: Pieter van der Wel).

## 4.3.4 Design Principles

### Linear parks

The primary strategy to reduce heat stress in urban areas is to create new parks, which is about making streams and rivers accessible. Flowing water has a cooling effect, making it beneficial to integrate linear parks into the urban fabric by utilizing existing connectors in Monterrey, such as storm drains. There are several advantages by removing concrete from storm drains and restoring these into a natural state. This approach creates new habitats alongside the water, reduces heat retention in urban surfaces, and promotes cooler microclimates. Transforming storm drains into green waterways also helps maintain cooler water temperatures, which is healthier for ecosystems downstream (figure 60).

**Figure 60**: Make natural, connective and accessible parks along rivers and streams.



### Ecology

By making rivers, streams and storm drains more natural, new connections will be made between green patches in the urban environment. This will mean a stronger ecological mosaic in the city with a more species migration and therefore bigger diversity of species.

### Implementation

Making linear and accessible parks can be implemented on the bigger rivers, streams or in existing storm drains in the metropolitan area (figure 61).

### Connective park

Figure 62 depicts the case study of Park Clouthier. This example illustrates a linear park connecting multiple neighborhoods and intersecting streams (Proyecto Espacios Verdes México, n.d.).

### New parks

Parks provide shade, cooling, and social activities for residents. Creating new parks means that areas covered in concrete, with their heat capacity, decrease, while the amount of cool green space increases. Therefore, transforming other areas into parks is a strong and effective way to increase the square meters of green space

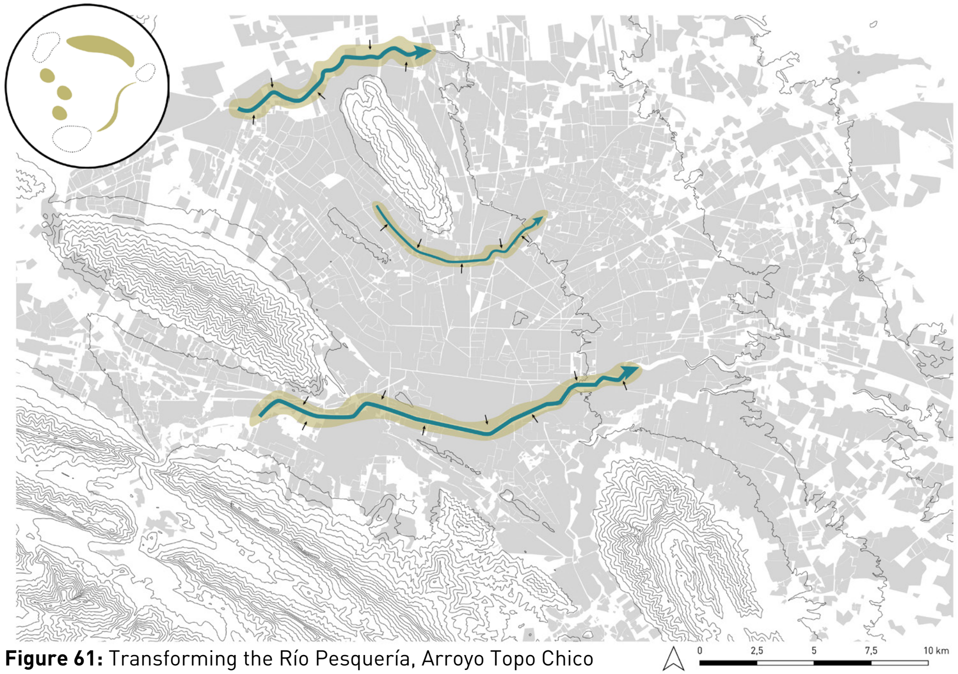



**Figure 61:** Transforming the Río Pesquería, Arroyo Topo Chico and Río Santa Catarina into new linear parks.

**Figure 62:** Parque Clouthier (Proyecto Espacios Verdes México (n.d.).

per inhabitant (figure 63). This can be achieved by transforming roads or parking lots into green spaces.

Current public parks can also be enlarged (figure 64), for instance, by removing surrounding roads to create more pedestrian-friendly space between buildings and the park (figure

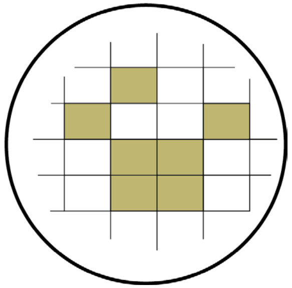


**Figure 63**: Make new parks.

### Implementation

Creating new parks, or enlarge these, is possible around existing parks or on concrete areas such as parkinglots. The best locations are the ones where heat stress is most significant in the city (figure 65).

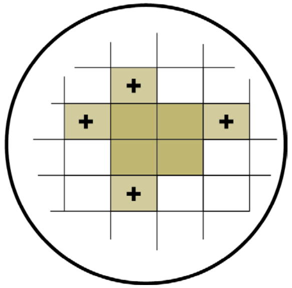


**Figure 64**: Expand and improve existing parks.

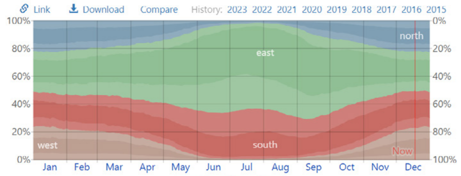
### Dominant Wind direction

New design principles can harness wind patterns. For example, during summer months when heat stress is most present, the dominant wind direction in Monterrey is east-southeast (WeatherSpark, n.d.) (figure 66). A new design principle involves creating wind corridors aligned in the east-southeast direction (figure 67). These corridors facilitate the flow of cool winds through the streets (Hsieh & Huang, 2016).

### Implementation

This principle of wind corridors can be implemented on existing streets or other connective routes in directions between west and south (figure 68).

**Figure 66:** The dominant wind direction during summer is east-southeast (WeatherSpark, n.d.).



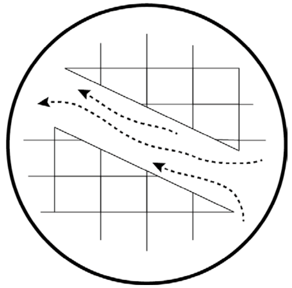



**Figure 67:** Make smart use of wind corridors.

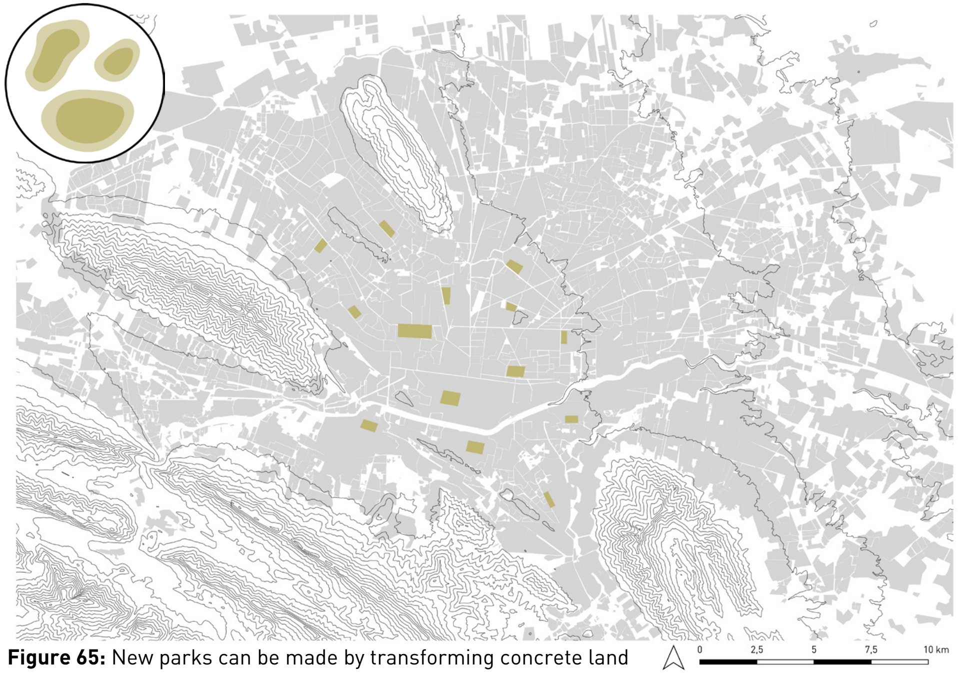



**Figure 65:** New parks can be made by transforming concrete land use such as parkinglots.


**Figure 68:** Existing streets used for wind corridors

### Wind slopes

Another design principle involves utilizing wind slopes. Slopes on the rural side, especially those covered with vegetation, have the ability to cool down. As the air on the slope or hill cools, it descends towards the ground, creating a downwind effect (Ganbat et al., 2014). If an urban area is situated downhill, these cooler winds can provide a refreshing breeze in the urban environment (figure 69). However, it is important to ensure there are no blockages present, such as buildings or large trees, which could block the cool airflow (Luo & Li, 2011).

### Implementation

This principle of wind slopes can be implemented next to slopes of high altitudes (figure 70). These altitudes can be reached on the slopes of the four nature reserves in the MAM. By creating corridors with no tall blockages, the wind slope wind can go through the urban fabric.

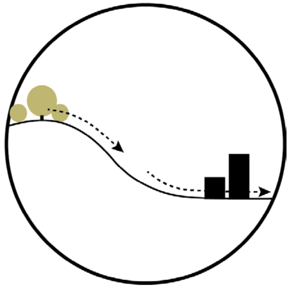


**Figure 69:** Make use of slope winds

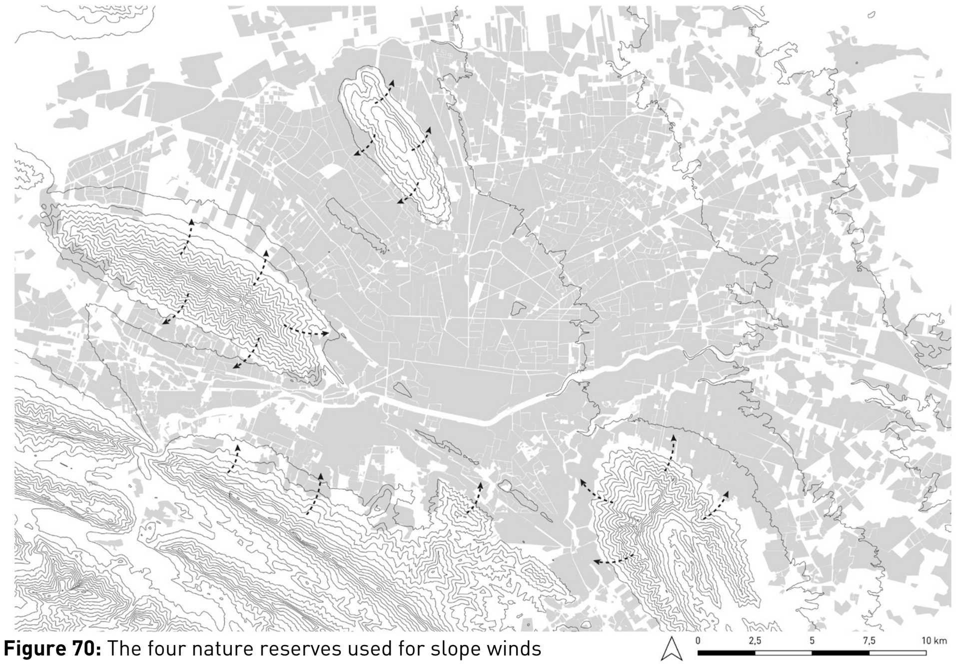



**Figure 70:** The four nature reserves used for slope winds

### Planting trees

To reduce heat stress, trees are an effective solution that also enhances urban ecology. Trees can be planted in both public and private spaces (figure 71). In public spaces, treelines provide shade for building facades, particularly for those facing south.

### Ecology

Trees can put in a treeline on a street for example, can create conditions for habitats to migrate. If the treelines are implemented between green spaces they can motivate exchange of animal species.

### Implementation

Treelines can be located next to facdes of buildings with a significant amount of heat problems within the building. The common place will be right next to southern and western facades to block the sunlight during the afternoon, when the day is the most hot. Treelines can also be placed between existing or new build parks or plazas in order to create bigger ecological connections within the city (figure 72).

**Figure 71:** Plant new trees in front of facades


**Figure 72:** Tree lines as a connector placed between parks in the MAM.

## Green roofs

Green roofs are an effectve way to keep buildings cool on the inside. The green rooftop works as an insultation layer against heat outside. It can also retain rainwater on the roof, whereby the sewage system is less under pressure because of excessive runoff (Wageningen University & Research, n.d.) (figure 73).

## Ecology

Green roofs can also work as a patch of green space. This green space could be a habitat for animals species, depending on what tyoe of vegetation is put on the roof (Wageningen University & Research, n.d.).

## Increasing albedo

By increasing the albedo of the buildings. The more light is reflected back into te air. It can also be applied for sidewalks or other pavement areas (figure 74).

## Implementation

These nature-based solutions can be applied to existing buildings where heat stress is most present (figure 75). Adding a new insulation layer or reflective coating will decrease the amount of heat entering the building (Wageningen University & Research, n.d.).


**Figure 75:** Green rooftops and white buildings are solutions which are implemented on buildings within the MAM.

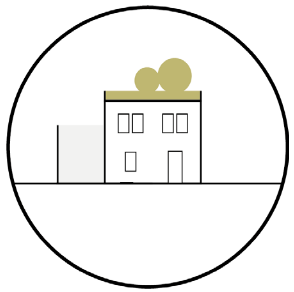


**Figure 73:** Make green rooftops

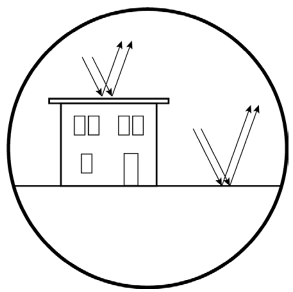


**Figure 74:** Increase the albedo of materials

### 4.3.5 Applying the 300 meter rule

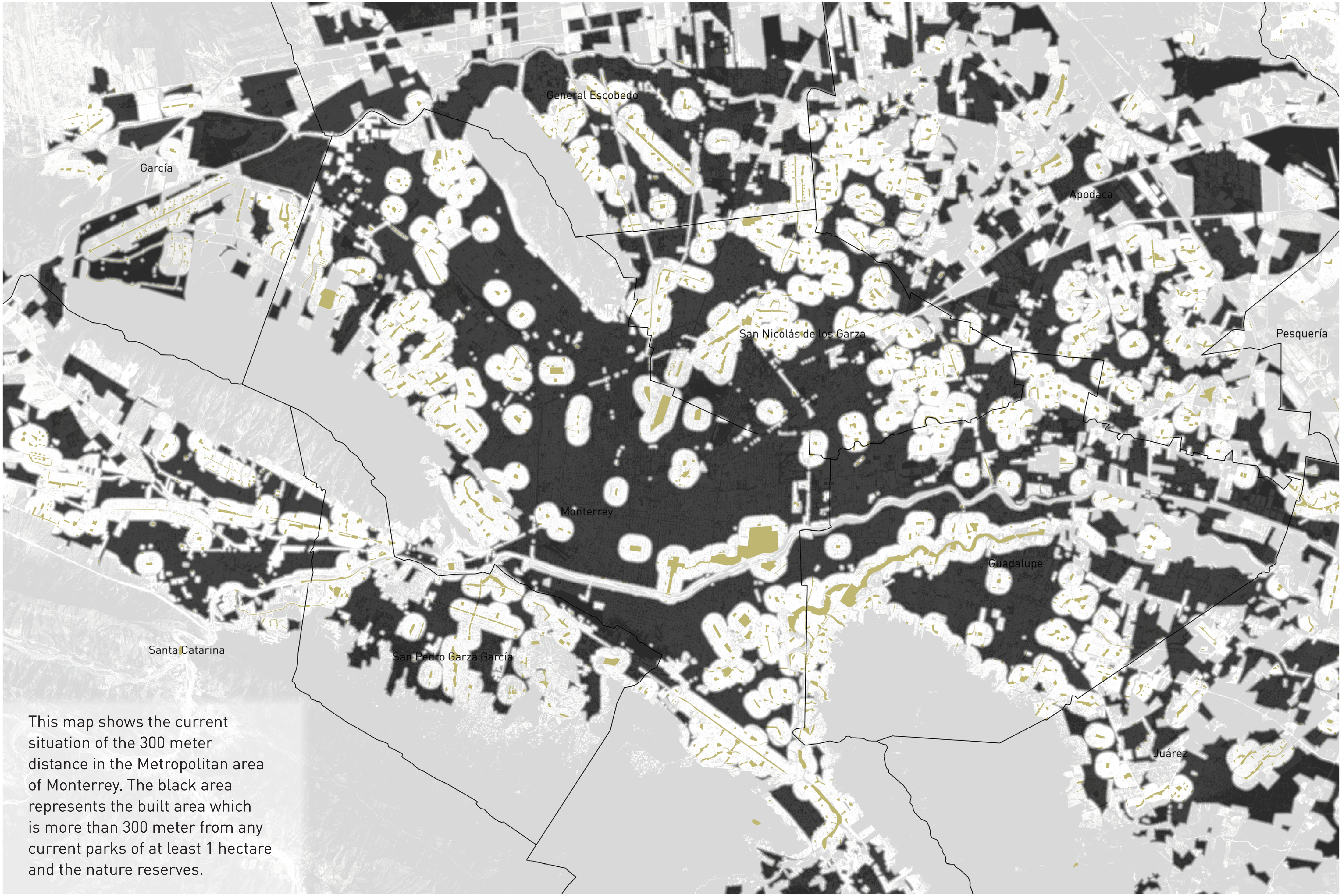
Cecile Konijnendijk (2021) introduced a new guiding principle known as the '3, 30, 300 rule' to promote biophilic and healthy cities. According to this rule, '3' indicates that every inhabitant should have a view of at least 3 trees from their home. '30' indicates that 30% of a city should be covered by tree canopy, or at least 30% vegetation cover in arid areas. '300' stands for the distance of 300 meters to the nearest green space larger than one hectare. This green space should be a quality and accessible area like a park (C. Konijnendijk, 2021).

For the metropolitan area of Monterrey, the 300-meter rule is particularly relevant. This rule is geographically based and has sufficient available data to be accurately calculated.

According to Konijnendijk, implementing the 300-meter rule ensures that a stroll of five to ten minutes from a home to the nearest green space is feasible. Moreover, creating parks larger than 0.5 hectares is acceptable in existing urban areas, considering the challenges of implementing new green spaces (Konijnendijk, 2021).

The following maps of the MAM illustrate a series of interventions for adding more green spaces. Each map and new step introduces a design principle aimed at mitigating heat stress. This illustrates a progression from the current situation to an better scenario.

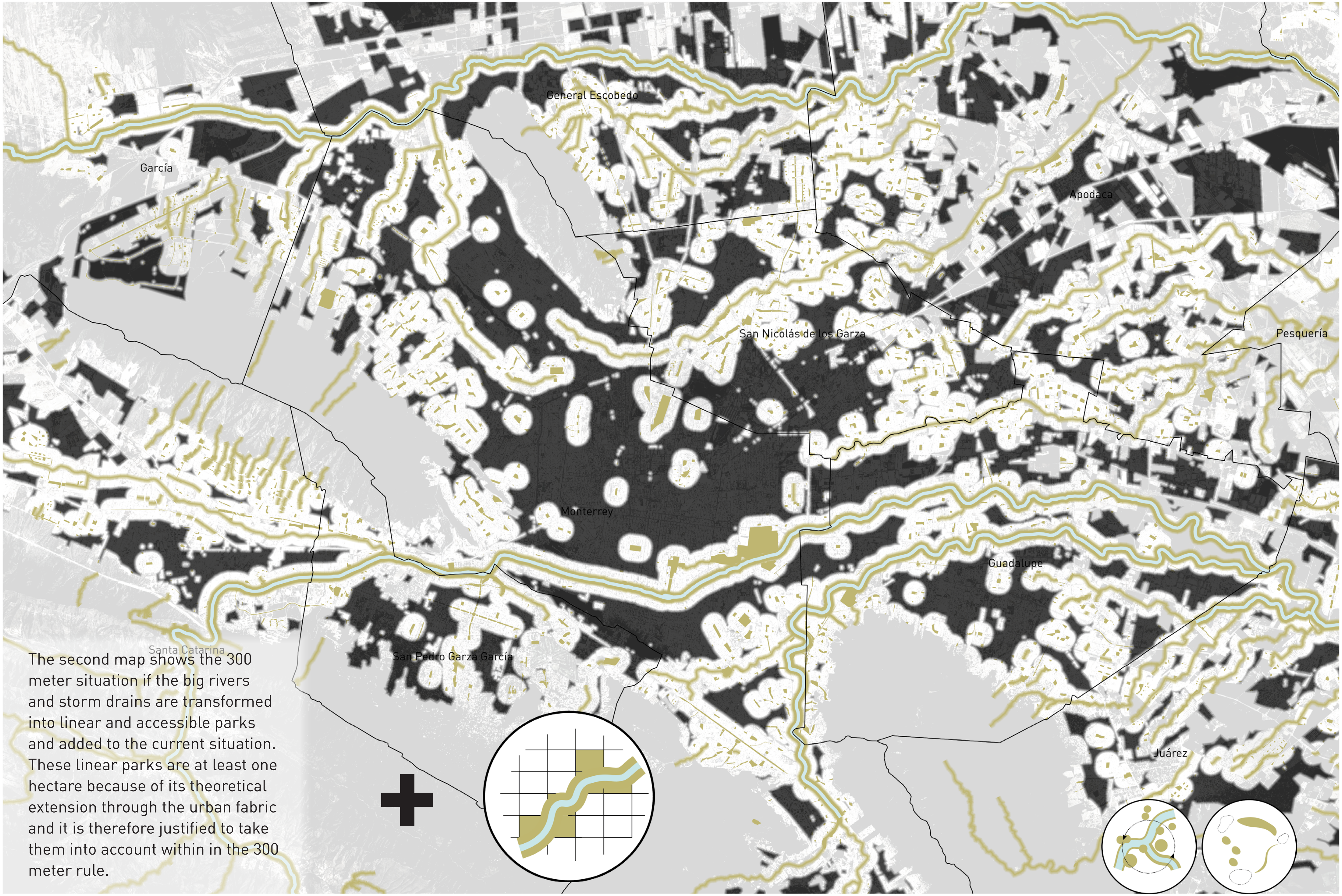
The final map represents the ideal scenario where green spaces are maximized. This conceptual metropolitan vision for Monterrey focuses on mitigating heat stress effectively.




This map shows the current situation of the 300 meter distance in the Metropolitan area of Monterrey. The black area represents the built area which is more than 300 meter from any current parks of at least 1 hectare and the nature reserves.

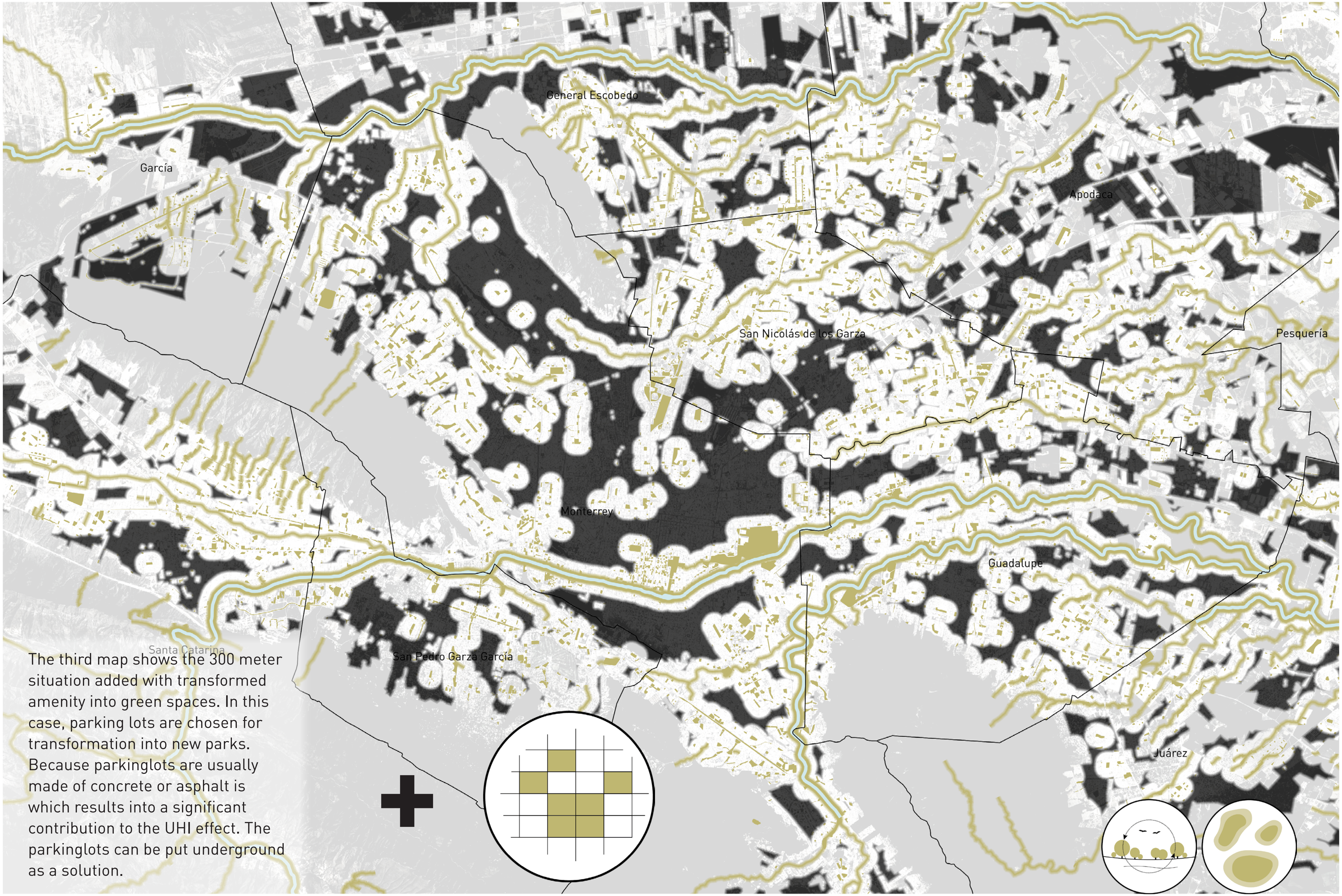
**Figure 76:** The 300 map of the current situation: the black represents a farther distance than 300 meter of the green grid.
**GIS sources:** Monterrey government, Openstreetmap

0 2,5 5 7,5 10 km



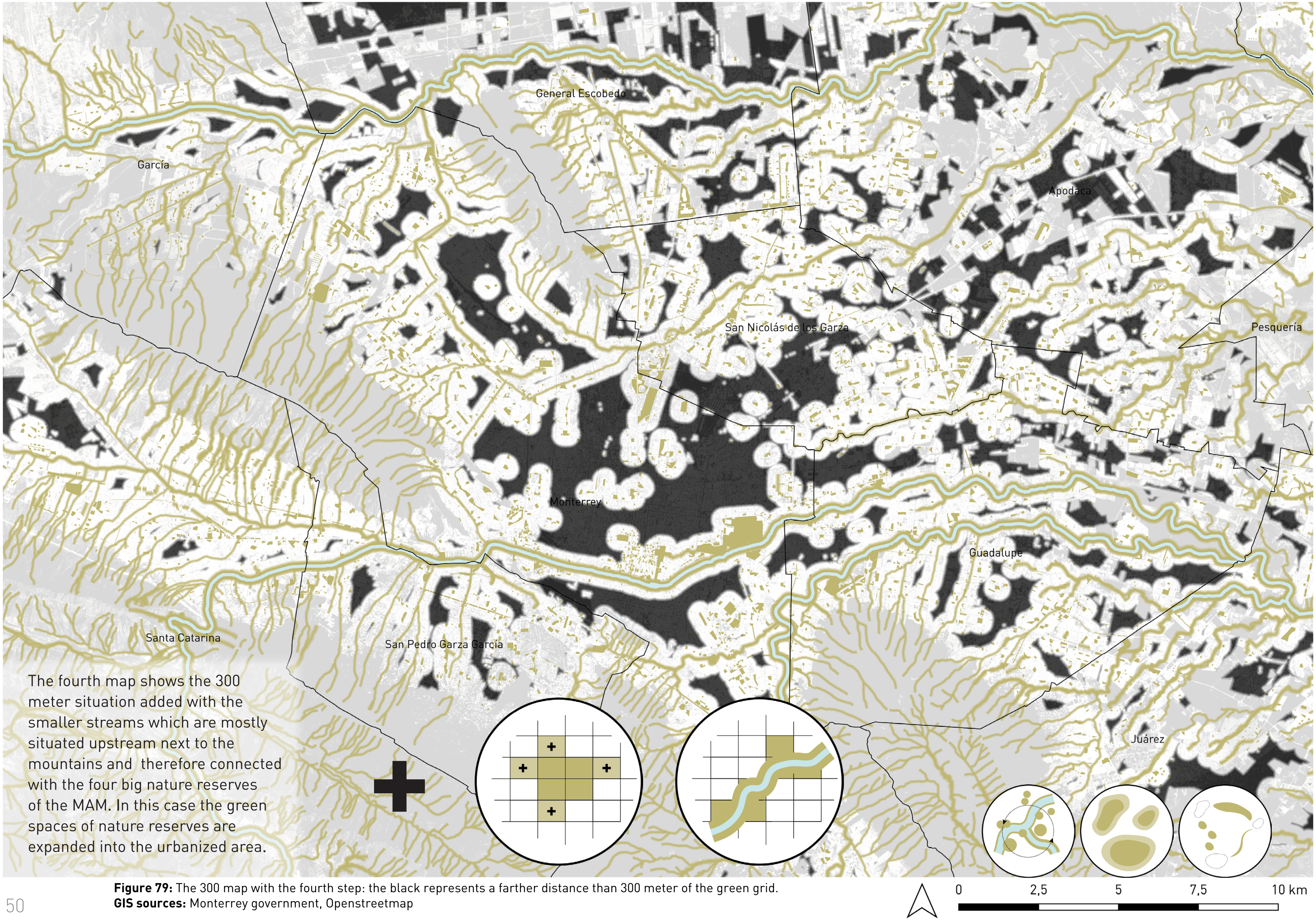

The second map shows the 300 meter situation if the big rivers and storm drains are transformed into linear and accessible parks and added to the current situation. These linear parks are at least one hectare because of its theoretical extension through the urban fabric and it is therefore justified to take them into account within in the 300 meter rule.

**Figure 77:** The 300 map with the first step: the black represents a farther distance than 300 meter of the green grid.
**GIS sources:** Monterrey government, Openstreetmap




The third map shows the 300 meter situation added with transformed amenity into green spaces. In this case, parking lots are chosen for transformation into new parks. Because parkinglots are usually made of concrete or asphalt is which results into a significant contribution to the UHI effect. The parkinglots can be put underground as a solution.

**Figure 78:** The 300 map with the second step: the black represents a farther distance than 300 meter of the green grid.
**GIS sources:** Monterrey government, Openstreetmap




The fourth map shows the 300 meter situation added with the smaller streams which are mostly situated upstream next to the mountains and therefore connected with the four big nature reserves of the MAM. In this case the green spaces of nature reserves are expanded into the urbanized area.

**Figure 79:** The 300 map with the fourth step: the black represents a farther distance than 300 meter of the green grid.
**GIS sources:** Monterrey government, Openstreetmap

The fifth and last map shows the 300 meter situation if all the current parks and plazas less than 1 hectare are added. In this case all the parks are connected with each other with green corridors such as tree lines and transformed streets, for ecological and recreational purposes. Therefore these smaller parks are part of the bigger grid and therefore justified as the parks

To conclude, this map presents a conceptual vision for the MAM, highlighting the potential for increased green space, which would create a healthier urban environment for residents. However, not all areas of the MAM are free of black spots. These remaining black spots indicate limited possibilities for further green space implementation. To comply with Cecile Konijnendijk's (2021) rule everywhere, it would be necessary to demolish existing buildings and transform those areas into green spaces.
Making a recreational grid following the streams and creating connections between existing parks is the most efficient way to comply to this rule. This is because a linear park stretches a long area through an urban environment where green area could lack.
As a result, this new recreational grid works also as the ecological mosaic principle from Forman.

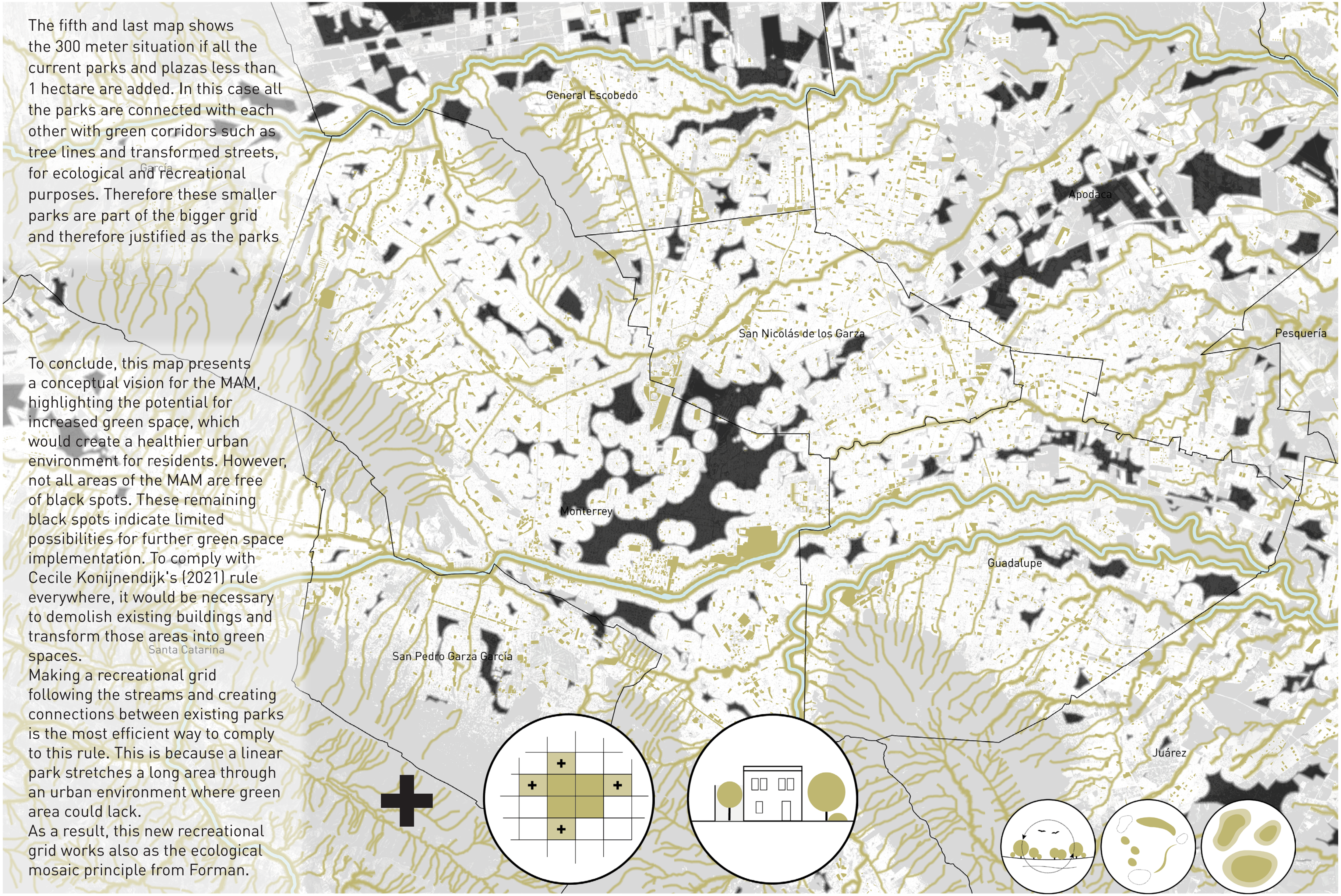



**Figure 80:** The 300 map with the last step: the black represents a farther distance than 300 meter of the green grid.
**GIS sources:** Monterrey government, Openstreetmap

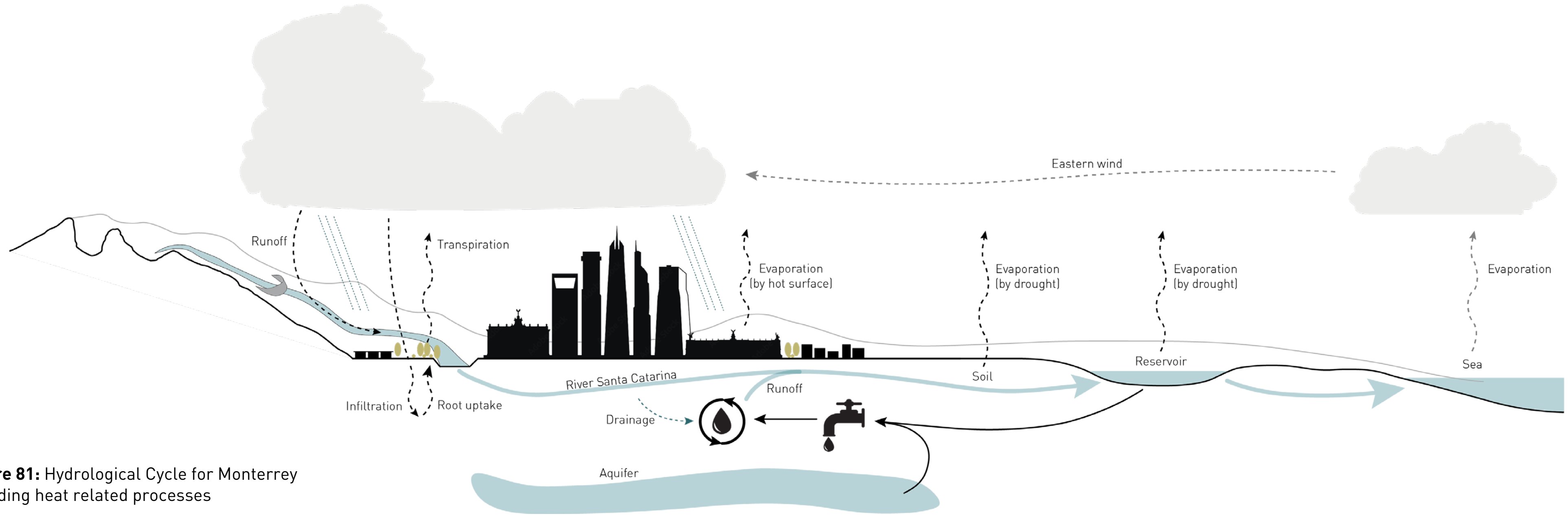



**Figure 81:** Hydrological Cycle for Monterrey including heat related processes

## 4.3 Hydrological Cycle

### 4.3.1 Hydrological cycle in and around the Metropolitan area

To develop new design principles to tackle droughts in the MAM, the hydrological cycle must be understood and managed where neccessary.

The hydrological cycle is primarily constructed using information obtained from SADM, a water management company that provides detailed data such as numbers and water flows in the system.

The general hydrological cycle of the MAM is shown in Figure 81. Its main components include precipitation in the mountainous area, influenced by eastern winds from the Gulf of Mexico. Rivers, streams, and storm drains transport water to reservoirs and eventually to the sea.

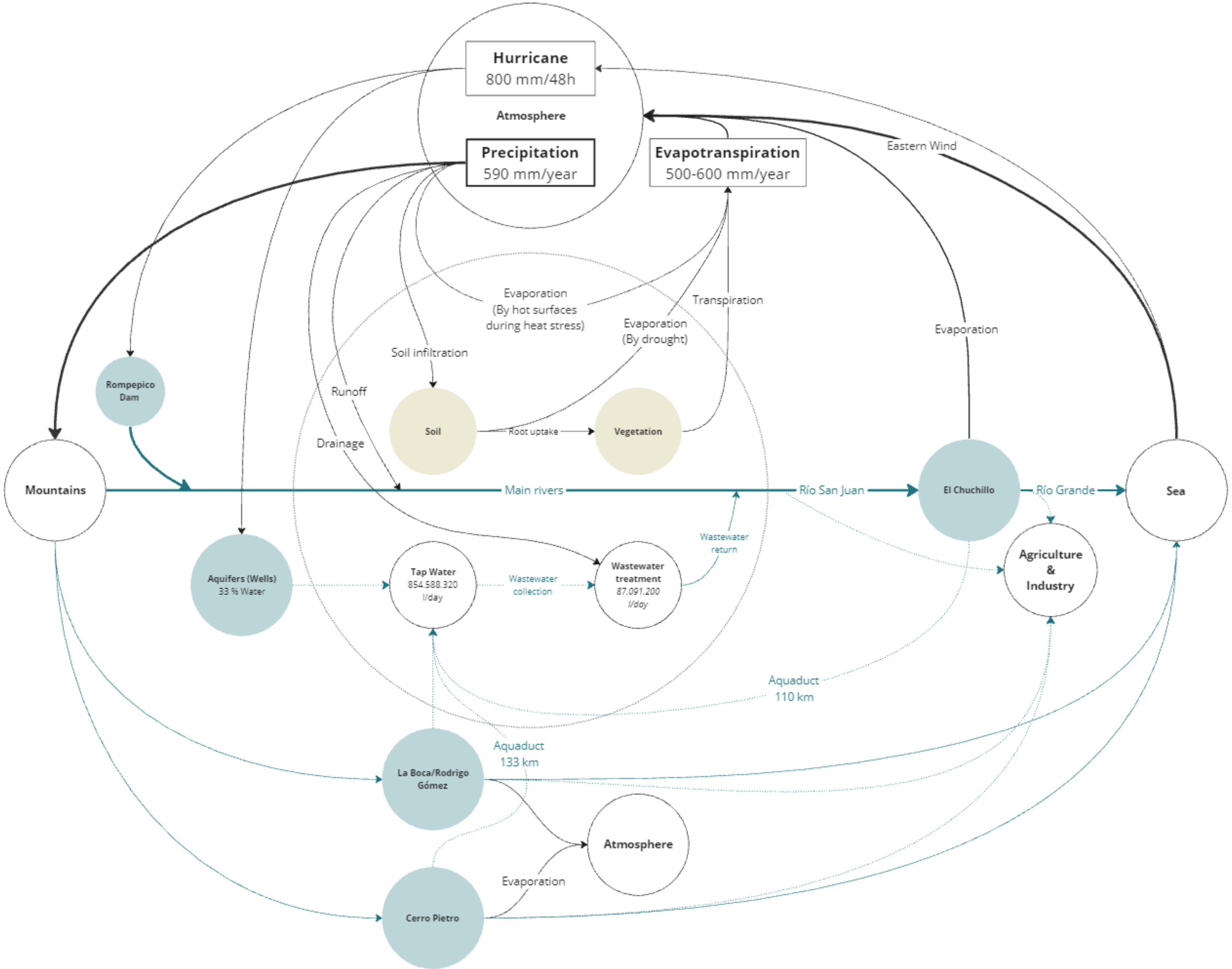
Rivers and streams, like the Río Santa Catarina, contribute water to reservoirs, which supply 67% of Monterrey's tap water. Additionally, there are aquifers underground, which provide 33% of the tap water supply (SADM, n.d.). Water from these aquifers is extracted via wells. However, aquifers are not a sustainable water supply, and according to Tecnológico de Monterrey Water Center, they may become depleted in the future (Tecnológico de Monterrey Water Center, discussion comment, February 2024). Only hurricanes can significantly replenish aquifers (Oesterreich & Aleman, 2002).

After use, tap water enters a sewage system that includes wastewater from buildings and runoff from streets. This sewage is directed to treatment plants for purification, and the cleaned water is discharged back into rivers (Planta Norte, excursion comment, March 4, 2024).

Water in Monterrey can follow different paths: it can infiltrate into the soil, enter the sewage system, run off through storm drains, streams, and rivers, or evaporate immediately from hot surfaces due to sunlight.

Water that infiltrates the soil is only possible in areas without impervious surfaces caused by urban development (Chowdhury et al., 2024). After infiltration, osmosis occurs if plant roots are nearby. These roots can absorb water and transpire it into the atmosphere. Otherwise, water collects in the soil and may evaporate during prolonged droughts.

Water collected in reservoirs, like the Cierro Prieto reservoir (figures 4 and




5), is also subject to evaporation into the atmosphere. These reservoirs are open and exposed, making increased evaporation likely in the future due to climate change (Helfer et al., 2012).

## Hydrological cycle visualised

The extensive and complex hydrological system in the MAM is shown in figure 82. This diagram integrates data from various sources including SADM, Tecnológico de Monterrey Water Center, and other studies and calculations specific to the MAM. Generally, it illustrates that water is stored outside the MAM in reservoirs and aquifers to supply tap water to residents. Within the boundaries of the MAM, water is primarily stored and retained by soil and vegetation, which benefits ecology and helps mitigate heat stress, but does not contribute significantly to tap water supply.

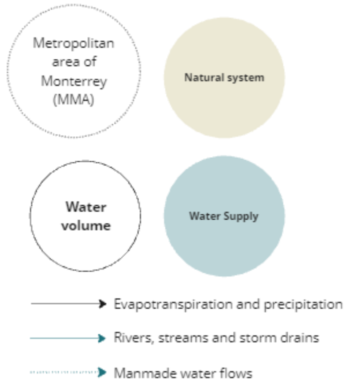



**Figure 82:** Extensive hydrological cycle scheme in and around the MAM (Sources: SADM, Tecnológico de Monterrey Water Center)

## 4.3.2 Adjusting the hydrological system

The system can be adjusted by identifying flaws in the hydrological system that result in unsustainable and unequal water management.

As shownn in figure 82, the hydrological cycle of the MAM extends beyond the borders of the Metropolitan area. This is primarily because water flows from treatment plants to rivers and ultimately to reservoirs located dozens of kilometers outside the MAM. During this journey, water can become contaminated and evaporate before reaching the reservoirs. Contamination often occurs due to garbage dumped along the riverbanks (figure 83). Even in rivers that appear clean (figure 84), contamination is present due to garbage along the banks (Río la Silla excursion comment, March 2nd 2024).

One potential solution to retain water within the MAM is to direct it directly into the tap water system after treatment. However, according to comments from Tecnológico de Monterrey Water Center, recycling water within the MAM is challenging because the reservoirs outside the MAM's borders need to be filled up by rivers. Therefore, water recycling is not considered feasible for this study's potential design.

**Other resources**

There are other flaws in the hydrological system of the MAM that cause unsustainable water management. Figure 85 illustrates that current water resources are limited: aquifers are not replenishing, and reservoirs are evaporating or being overexploited by industry and agriculture. This situation is concerning given the climate predictions for increased droughts and heat waves in the future. As a result, there is higher demand for water extraction and increased evaporation from the existing water supply. Therefore, it is crucial to explore alternative areas or solutions for providing water to the residents of Monterrey.

**Quality water loss**

In figure 86, it is shown that high-quality water flows into the city but flows quickly to the city's exit due to concrete storm drains located in the MAM. This water is more contaminated compared to water in natural reserves.

Figure also illustrates that concrete surfaces and exposed soil lead to water losses into the atmosphere, resulting in a reduction of high quality water available for ecosystem services. Keeping water in the soil can mitigate this issue. This process can be enhanced by implementing weirs

**Figure 83:** Downstream Santa Catarina. Water flowing alongside its embankment covered with garbage, resulting into contaminated water (Picture: Pieter van der Wel)

**Figure 84:** The flowing Río la Silla as a clean appearing river. Weirs are placed to encourage soil infiltration (Picture: Pieter van der Wel)

in water courses (figure 84) to raise the water table in upstream areas. This approach also offers additional benefits such as flood management and promoting vegetation growth (Energy Education, n.d.).

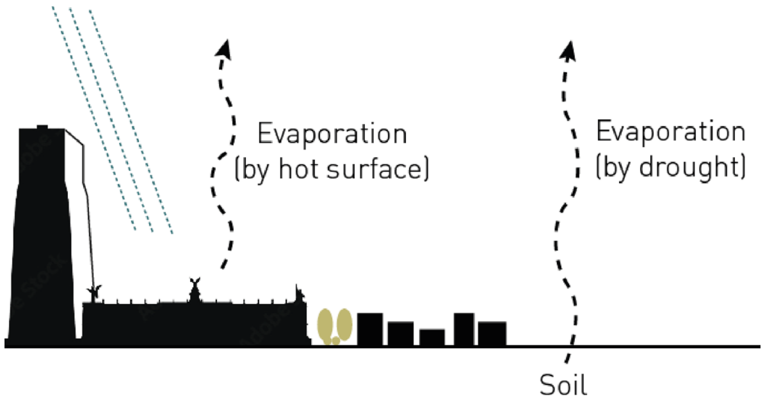



**Figure 87:** Rainwater falling on hot surfaces is a result of hot days. During heat waves, water also evaporates from the soil due to drought. This affects the ecology due to the lack of rainwater or relatively warmer water flowing downstream.

**Figure 85:** The current water supplies are under pressure. The aquifers are overexploited, and reservoirs are drying up due to overexploitation and evaporation.

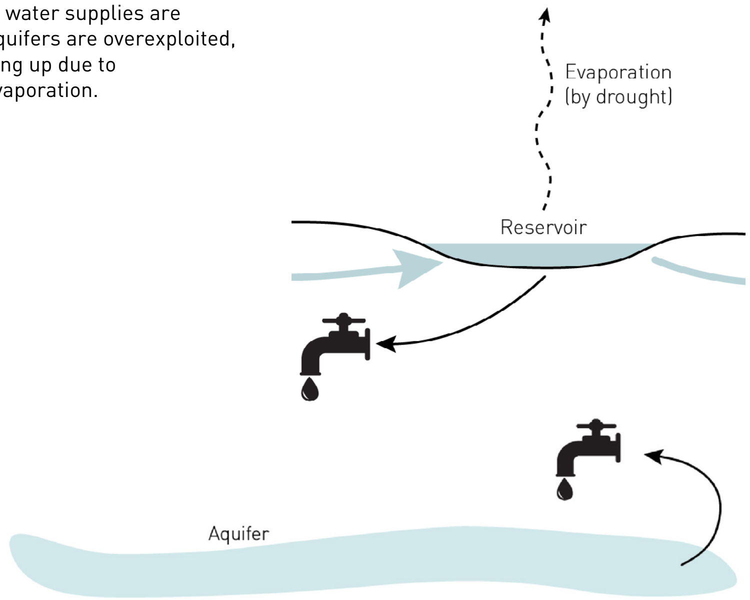
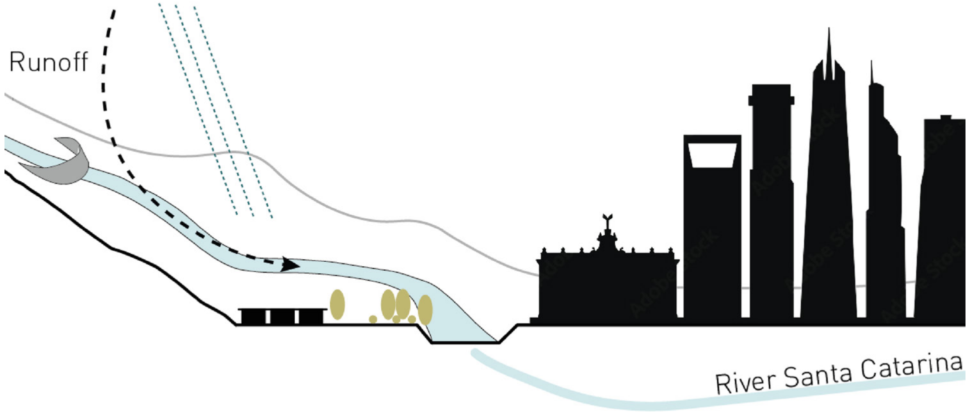



**Figure 86:** There is a loss of quality water running off the nature reserves. This water is mostly directed into storm drains, which flow directly into the bigger rivers downstream.



## 4.3.3 Design Principles: Water storage

### New upstream reservoirs

Storing water at the foothills of mountains can provide high quality water as a new water supply (figure 88). These reservoirs can function as buffers to control the downstream water flow, preventing both flooding and dry streambeds. Additionally, water collected in these reservoirs can be used as tap water with less intensive treatment required. These new reservoirs will increase the water supply for residents in Monterrey and can be allocated to specific groups based on their needs.

### Implementation

The new reservoirs can be constructed at the foothills of the four nature reserves surrounding the MAM (figure 91). These nature reserves can provide quality water because of preserved ecosystems located. But then it is important to continue protecting these ecosystems.

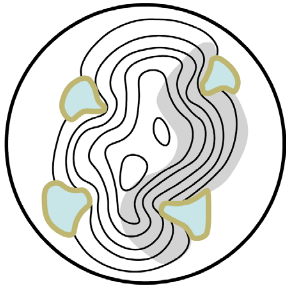


**Figure 88:** Create new reservoirs at the foothills of mountains.

### New water storage tanks

Also water can be stored in more cisterns or water tanks spreading accross the MAM. These cisterns can be connected to the tap water system for the concerned building (figure 90).

### Implementation

Water tanks can be constructed anywhere, as long as the catchment surface is not contaminated. In figure 89, a cistern is shown which is put into the ground.

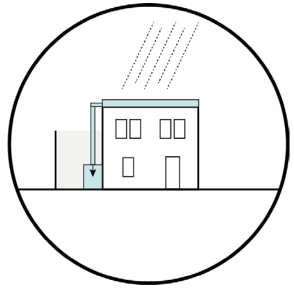


**Figure 90:** Catch rainwater in storage tanks.

**Figure 89:** Watertank placed in the ground serving as tapwater source, filled up by rainwater (Picture: Robert Maxwell)


**Figure 91:** Reservoir are placed at the foothills of the nature reserves in the MAM. Storage tanks can be placed anywhere.

## 4.3.3 Design Principles: Water retention

### Impervious surfaces

Water retention in the soil can be enhanced by increasing the permeability of surfaces to water (figure 92).

### Implementation

Water retention areas can be constructed at permeable areas, such as ashpalt on streets and parkinglots. Here rainwater falls on the concrete surfaces, which can also lead to inundation. The transformation of such areas could be mixed with designing new green areas such as parks or green streets. An example of a retention area is seen in figure 93, where the retention of rainwater results into a volume of water. This water contributes to the ecology of the surrounding area (Water retention ladnscape, n.d.).

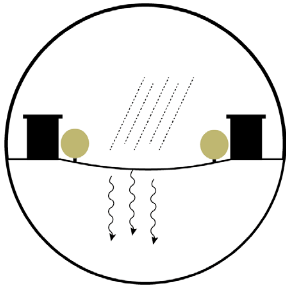


**Figure 92**: Let rainwater infiltrate into the soil.

### Slowing down rivers and streams

Water can also be retained in the current rivers and streams, which are often canalized with concrete casings. Implementing new weirs and curves can facilitate water infiltration into the riverbeds, as they concentrate water volumes in one area (figure 94). This saturation of the soil with water creates wetter conditions that are beneficial for trees and other plants. Additionally, flowing water creates cooling effects that mitigate heat stress.

### Implementation

These transformation can take place on all types of rivers, streams and storm drains in the MAM (figure 95).

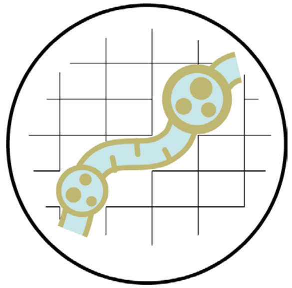


**Figure 94:** Slow down the water in streams and rivers.

**Figure 93:** A place transformed into a water retention area in a semi arid region (Water retention ladnscape, n.d.)

**Figure 95:** The water flowing in the Río Pesquería, the Arroyo Topo Chico and the Río Santa Catarina will be more retained.

## 4.5 Critical Zones

### 4.5.1 Poverty

There are zones in the Metropolitan area where the quality of life of inhabitants is lower compared to other areas. These areas are characterized by poor living conditions.

In figure 96, the colonias with poor living conditions are mapped for the MAM. The red areas indicate colonias with low average income, while the yellow areas represent colonias with high average income.

### 4.5.2 Heat

The lives of people living in poverty can be endangered by the Urban Heat Island (UHI) effect in their environment (figure 97). The residen often have poor insulation, small living spaces, and have the lack of green spaces in their surroundings.

### 4.5.3 Water accessibility

Furthermore, people living in poor conditions are also endangered by long periods of drought when the water accessibility has been decreased, like in the summer od 2022. Without intervening, it is likely that poor areas are becoming more vulnerable for water scarcity due to climate change in the future.

### 4.5.4 Critical zones

For this study, a schematic map highlighting critical zones has been created to identify potential locations for the implementation of green and blue infrastructure (figure 98). This map of the MAM identifies areas experiencing the highest levels of heat stress and poverty. It is assumed that these areas have the lowest quality of life and are most vulnerable to future environmental impacts. Therefore, prioritizing these areas is essential for the initial improvements of hydrating Monterrey.

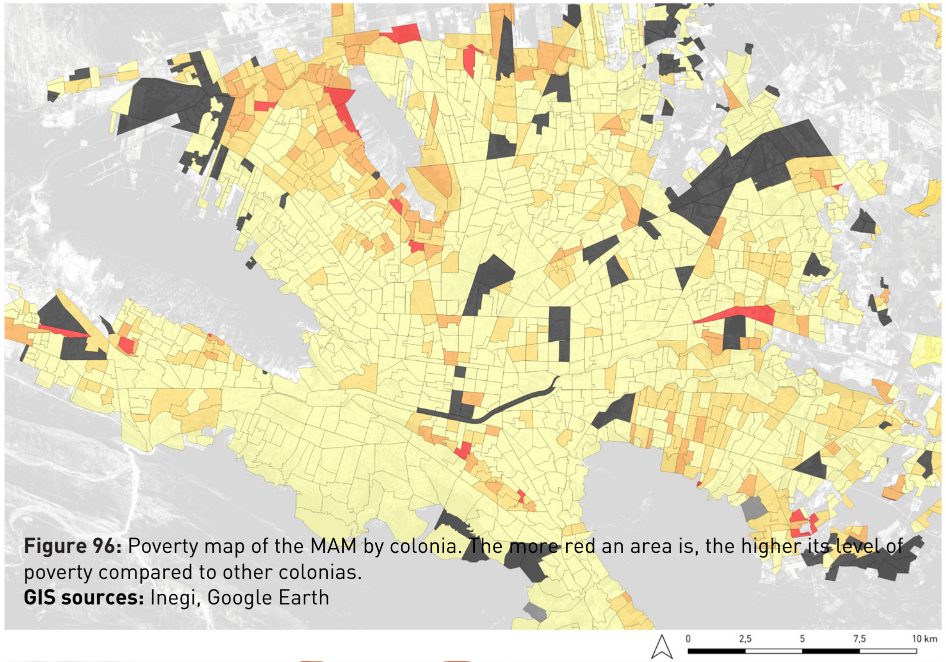



**Figure 96:** Poverty map of the MAM by colonia. The more red an area is, the higher its level of poverty compared to other colonias.
**GIS sources:** Inegi, Google Earth

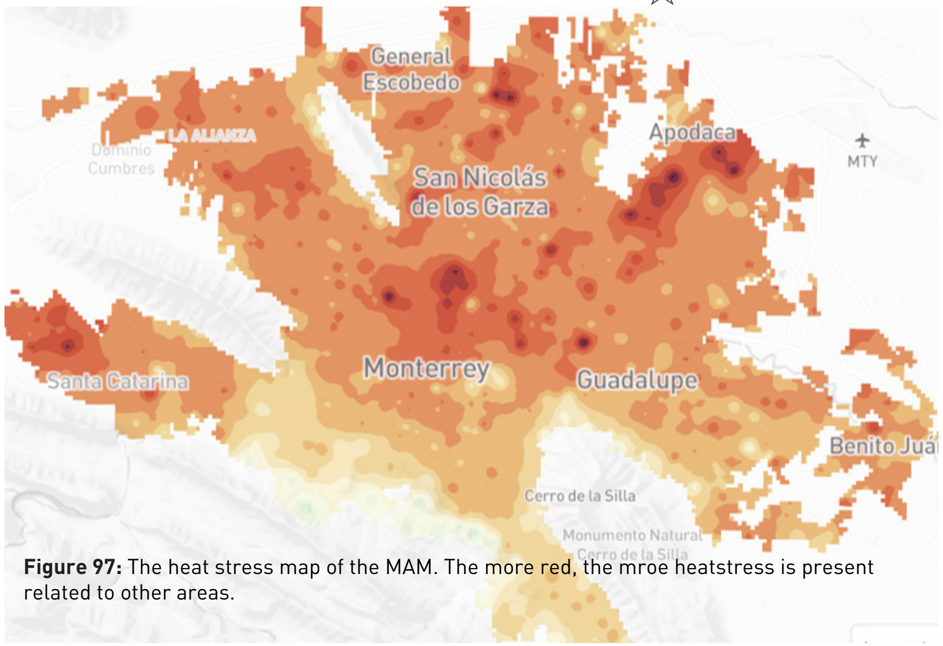



**Figure 97:** The heat stress map of the MAM. The more red, the mroe heatstress is present related to other areas.

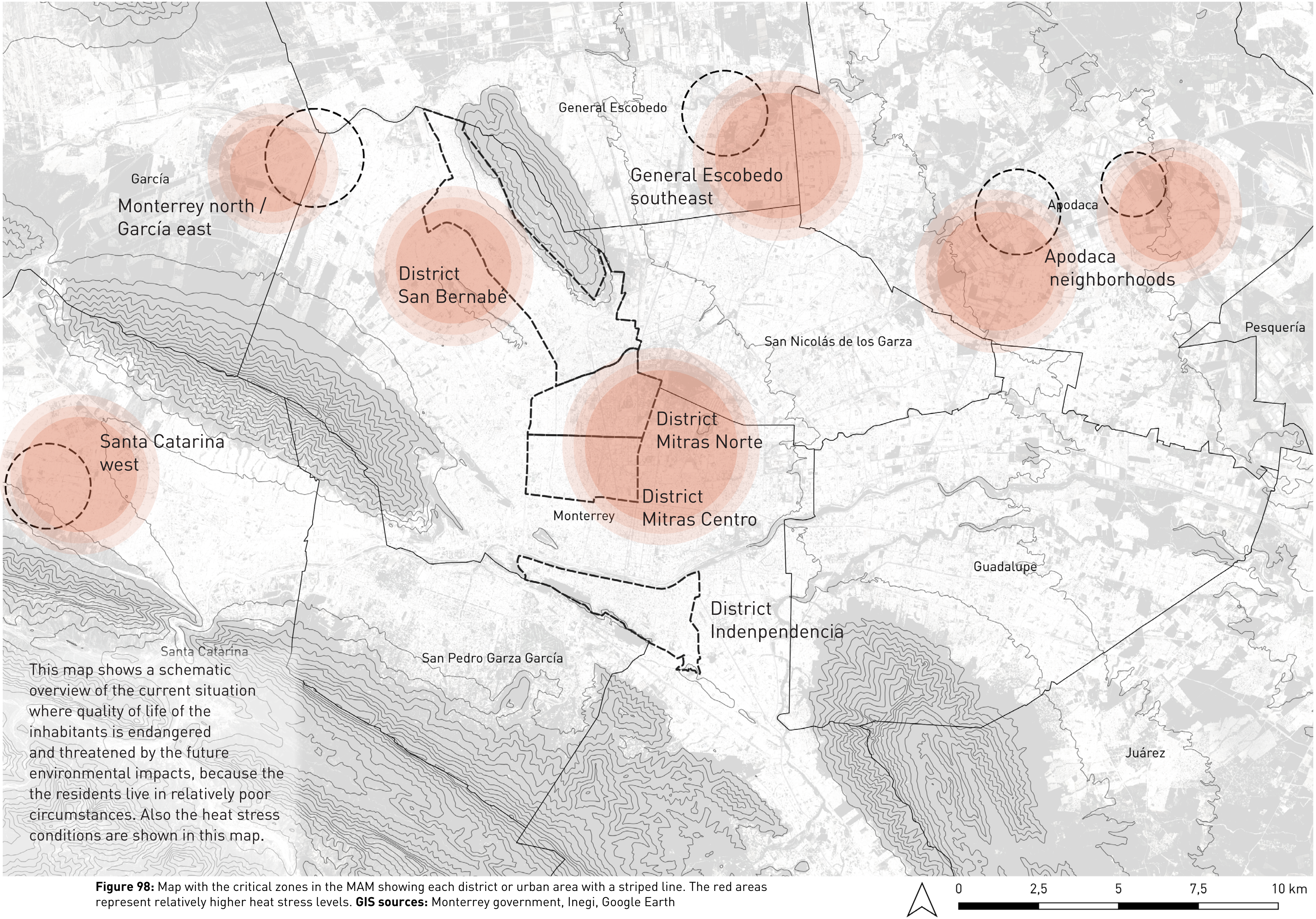



**Figure 98:** Map with the critical zones in the MAM showing each district or urban area with a striped line. The red areas represent relatively higher heat stress levels. **GIS sources:** Monterrey government, Inegi, Google Earth

# 5 Design

## 5.1 Metropolitan Vision

In this metropolitan map, the design principles are implemented in the urban area and result in a new metropolitan vision for Monterrey. The main metropolitan goal is that all residents live closer than 300 meters from a green space and have equal access to water.

This is spatially achieved by making new accessible parks and creating new reservoirs. The parks consists of both linear and irregular shapes to increase the amount of green space per resident. These parks are developed based on existing rivers, streams, transformed storm drains, and parking lots.
The four nature reserves spreading across the Metropolis are considered as part of the ecological grid in the urban area. These are ecological connected via new buffers surrounding the nature reserves and via the corridor exists along the streams.

In this map, water collection and retention is also part of the new vision. Water will be retained and collected downhill the mountains and the water will be retained and slowed down in the new rivers and streams flowing through the Metropolis. Water will also be collected in buildings by more watertanks and retained on other green spaces such as green street, permeable parkinglots and green

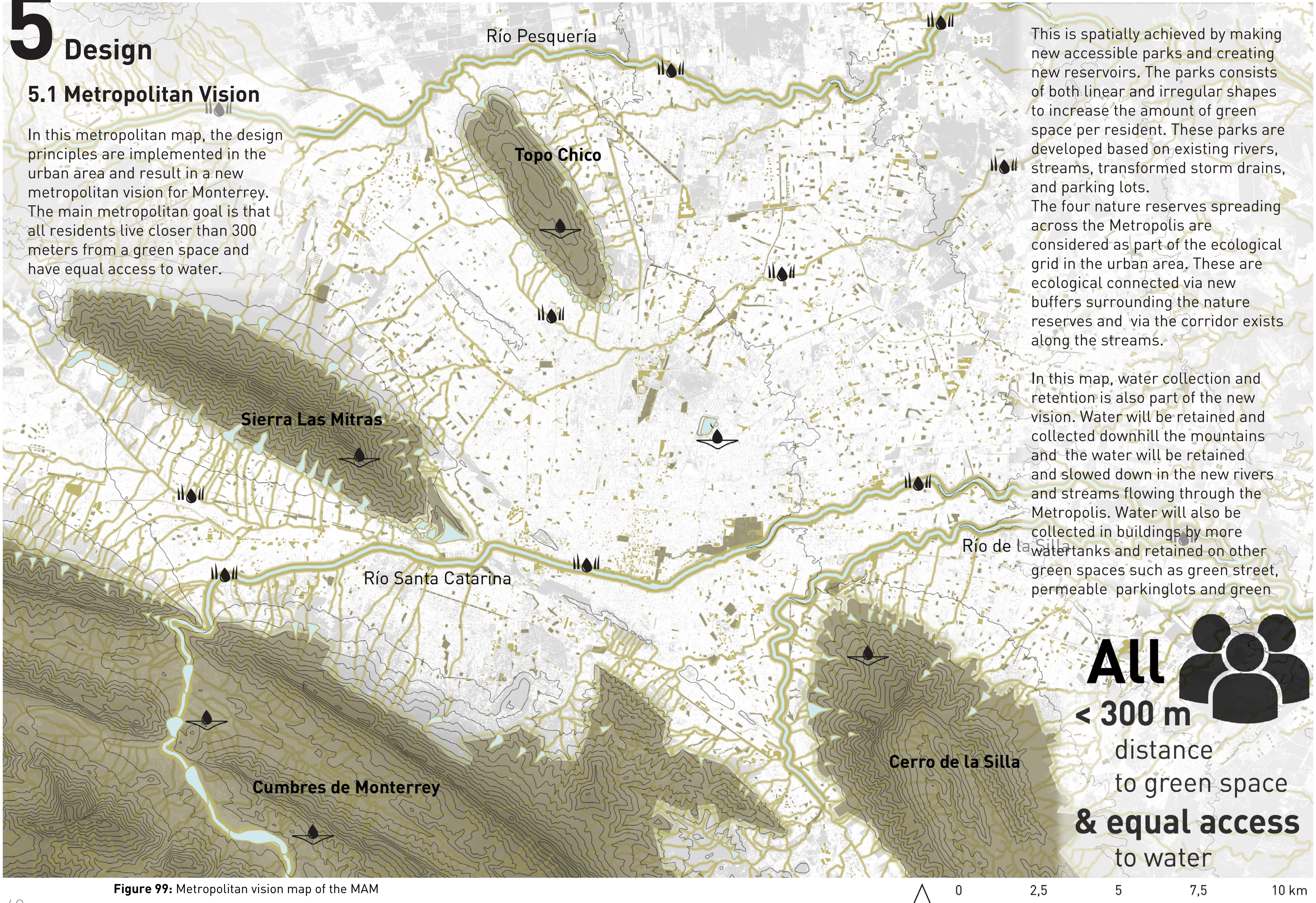



**Figure 99:** Metropolitan vision map of the MAM

## 5.2 Strategies

### 5.2.1 Vision Strategy

In order to accomplish this challenge, a strategy must be developed to initiate this metropolitan vision. In this strategy, a spatial design will be created on on a smaller scale.

The initiative for this vision will start with the critical San Bernabé district. This district is situated in the northeastern part of the municipality of Monterrey. As the previous analysis elaborates, this area contains environmental and social problems. San Bernabé copes with poverty, heat stress, lack of green spaces, landslides, and inundation.

The district is situated on the western side of the Topo Chico Mountain. This mountain is an isolated nature reserve and has the potential to be connected to the urban ecology. It also creates conditions for a base of green and blue infrastructure because of the underlying water structure, which can align with design principles based on hydrology.

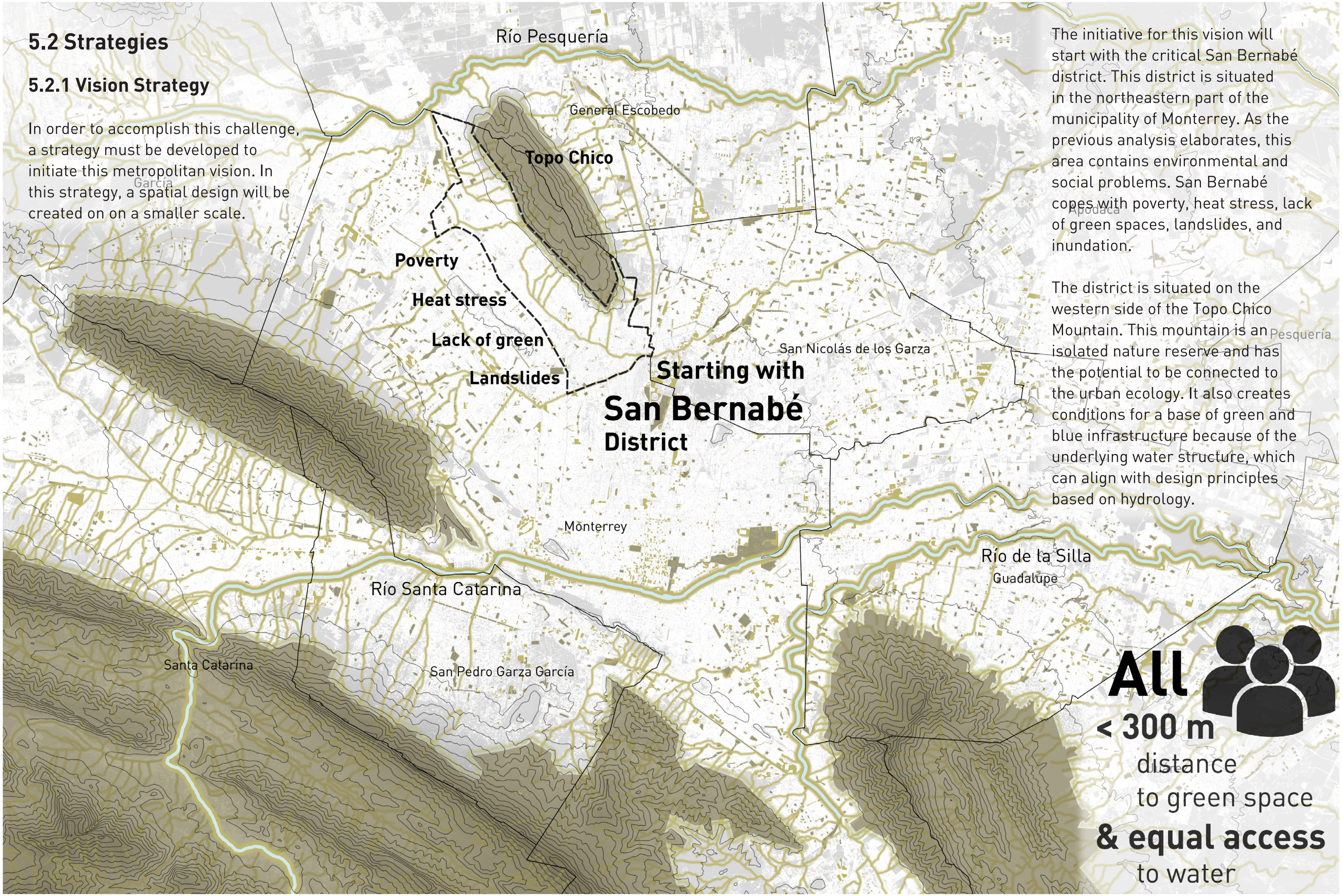



**Figure 100:** Metropolitan vision map and its strate

## 5.2.2 Watershed Strategy

In order to work with a new strategy for the implementation of green and blue infrastructure, it is important to work with the hydrology of the site, especially while designing with new hydrological infrastructure (commented by R. Fonseca from Tecnológico de Monterrey Water Center, May 11th 2024).

Working with the watershed provides more possibilities to the design. It makes new wet conditions for vegetation habitats and inundation zones can be controlled. Also, it gives the opportunity to make calculations with the watershed in order to make a design which could safely be implemented, especially during heavy rainfall.

In the southern part of the San Bernabé dictrict, the stream Arroyo Topo Chico is situated. This stream is mostly in the form of a concrete cased storm drain and is connected to the Río Pesquería in the north of the MAM.

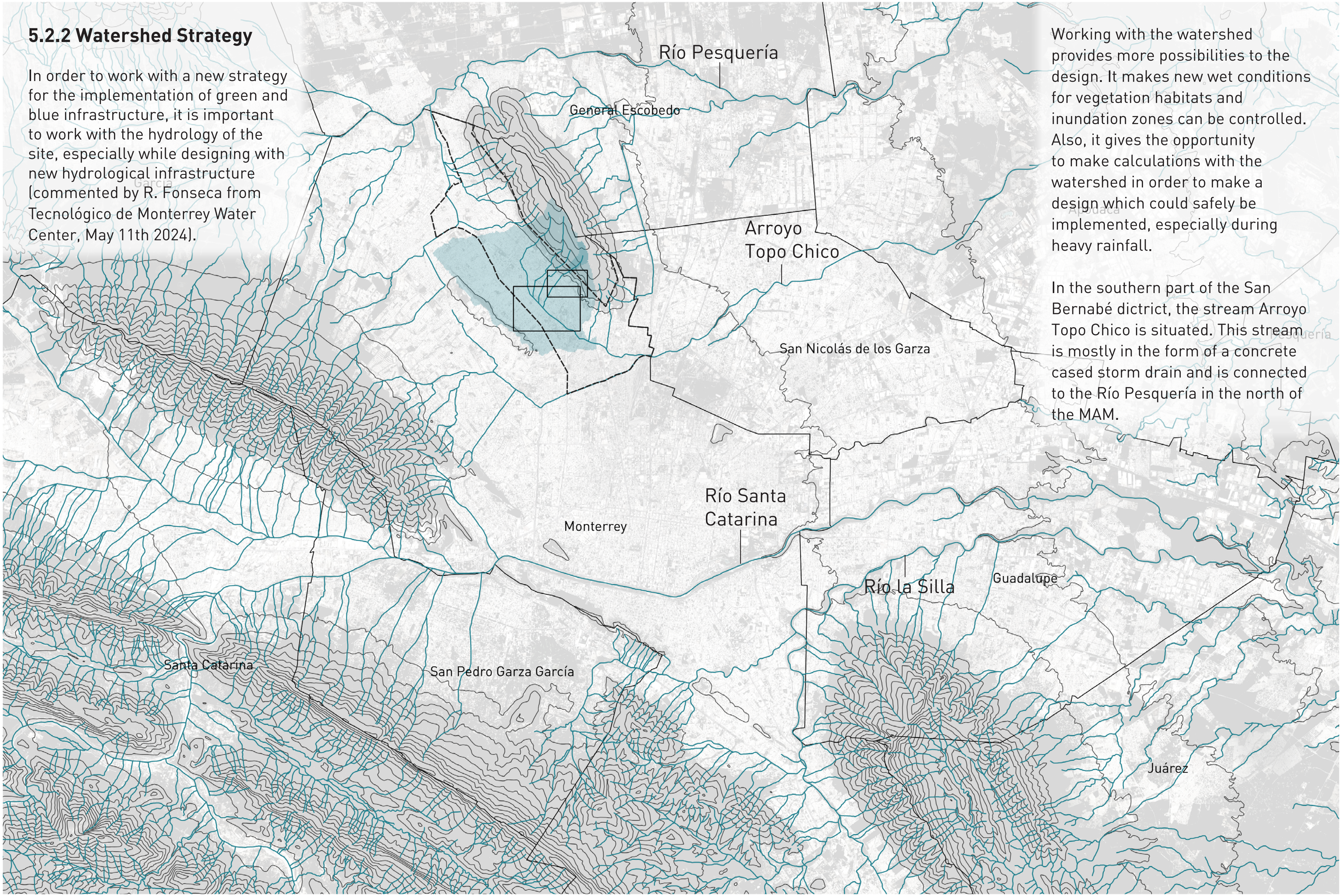



**Figure 101:** The river systems within the MAM
**GIS sources:** Monterrey government, Inegi, Google Earth

### 5.2.3 Upstream Arroyo Topo Chico

Underneath the southern part of the San bernabé district, the watershed of the upstream part of the Arroyo Topo Chico (UATC) is situated. In theory, without urbanisation, all the water in this watershed flows to the lowest point of the watershed in the streambed, which is located he southeastern side of the UATC. It is the start of the main course of the Arroyo Topo Chico. This includes the water from runoff and the groundwater.
(Groundwater Movement, 2020).

The main course is the most western watercourse in this watershed. The rest are the sidearms of this stream. These watercourses are set up by the National Institute of Statistics and Geography in Mexico (INEGI), which owns a simulator of the watersheds and their water mechanisms (SIATL). This information can be retreived and analysed in GIS.

This map shows the waterstructure of the UATC according to INEGI (n.d.). In reality, there are more streams flowing through the urban area of San Bernabé than what is shown in this GIS map.

In the map two rectangles are shown. These rectangulars are both a design location in San Bernabé on top of the UATC watershed. The upper one, location 1, is situated upstream and consists of a proposed design where water is stored and collected. The lower one, location 2, is situated downstream and consists of a proposed design where water will be retained and slowed down.

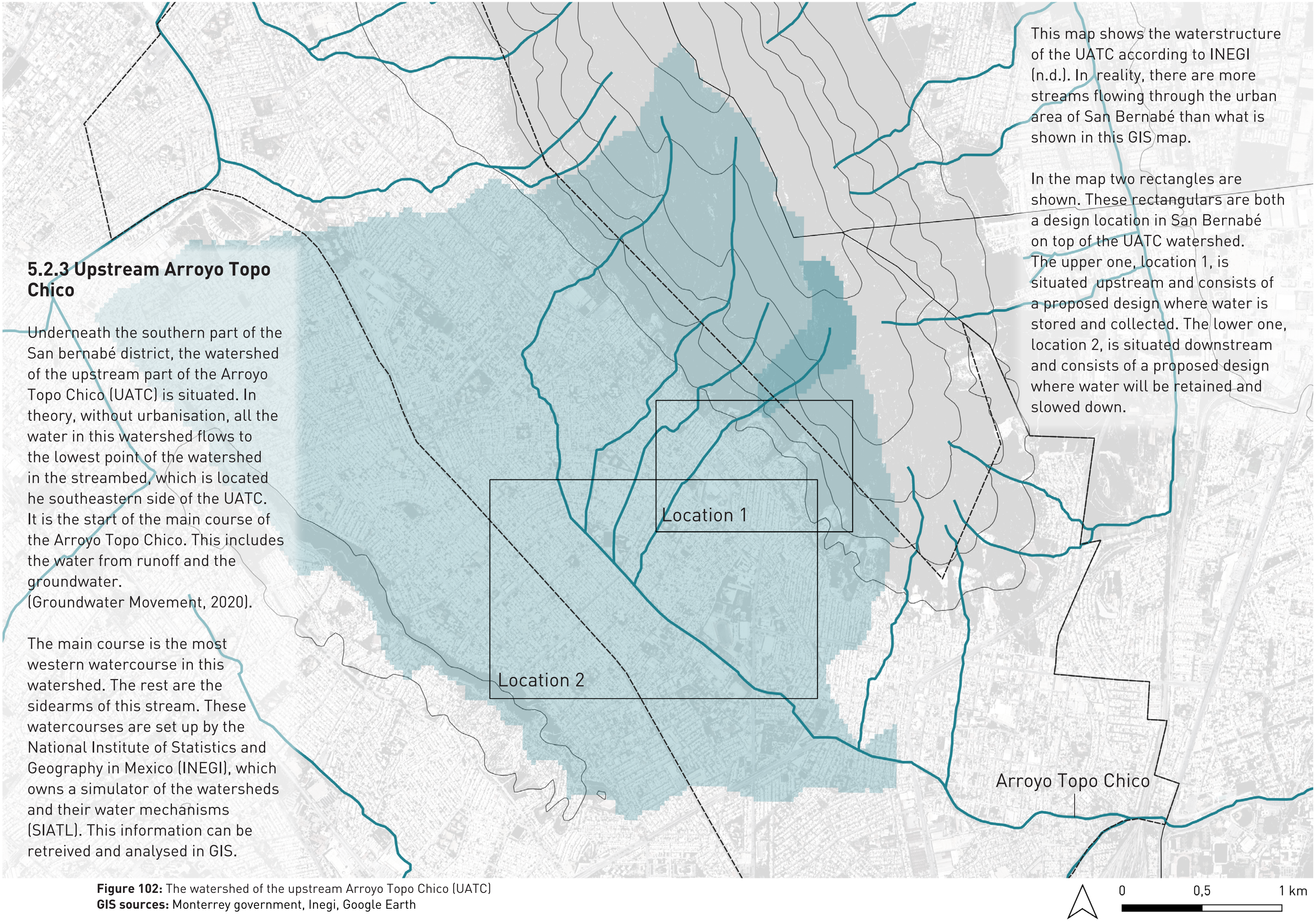



**Figure 102:** The watershed of the upstream Arroyo Topo Chico (UATC)
**GIS sources:** Monterrey government, Inegi, Google Earth



**Figure 103:** Satellite image of the San Bernabé district, situated on the western side of the Topo Chico. The outline of San Bernabé and the UATC watershed is also visible. **GIS sources:** Monterrey government, Inegi, Google Earth

## 5.2.4 District San Bernabé context

In order to understand this particular area of the San Bernabé district and its relation to the UATC watershed, the urban context needs to be analysed. It is analysed with GIS and by spatial perspectives from experiences on-site and by Google Maps images.

Theme analyses are selected to make a relevant understanding of the urban area, which are: functions, soil, mobility, green spaces and the waterstructure. Every a particular theme also has its own problematization.

### Density and Population

The area of San Bernabé is 1826 hectares (18.26 square kilometers) in size.
The population for San Bernabé can be calculated with the average population density of the municipality of Monterrey. This number is 3523 residents per square kilometer (Statista, n.d.), so there are approximately (3523 * 18.26) 64,330 people living in the district.

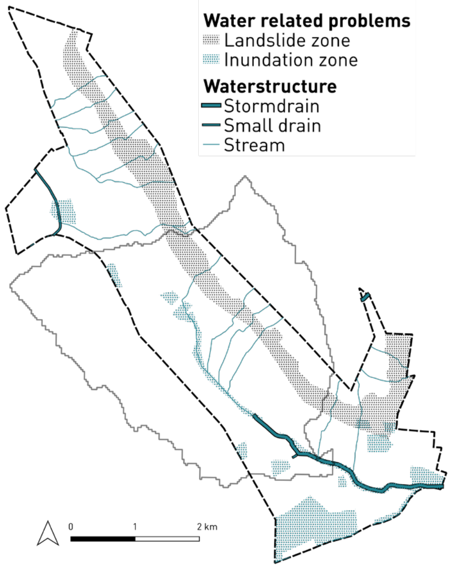



**Figure 104:** Waterstructure in San Bernabé

### Waterstructure

Urbanization caused water related problems in the San Bernabé district because of ignorance of the underlying waterstructure of the watershed (figure 104). Except for the main course of the Arroyo Topo Chico, all the other streams flow through the streets.
In figure 105, the effect of a stream flowing through the small streets is shown. The asphalt can be broken down by the water flowing over.
In figure 106, the storm drain of the Arroyo topo Chico is seen. It consists of a concrete storm drain from the upstream watershed to its outlet in the river Río Pesquería in the north of the city. The storm drain becomes wider while following the course downstream.
In figure 107, it is seen that the watercourses have found their way in the urban fabric. The orange and red represent problematisation in terms of inundation zones (Atlas Riesgos, n.d). This also shows that urbanisation has caused more waterstreams to emerge in reality than INEGI provides, which has to be taken into account while desiging. In figure 108, the current waterstructure for the UATC watershed is shown in a section.

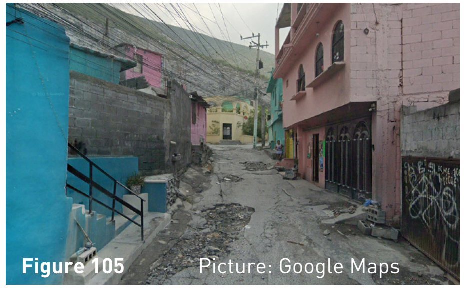


**Figure 105** Picture: Google Maps

**Figure 106** Picture: Google Maps

**Figure 107** Source: Mapa Atlas de Riesgos, n.d.

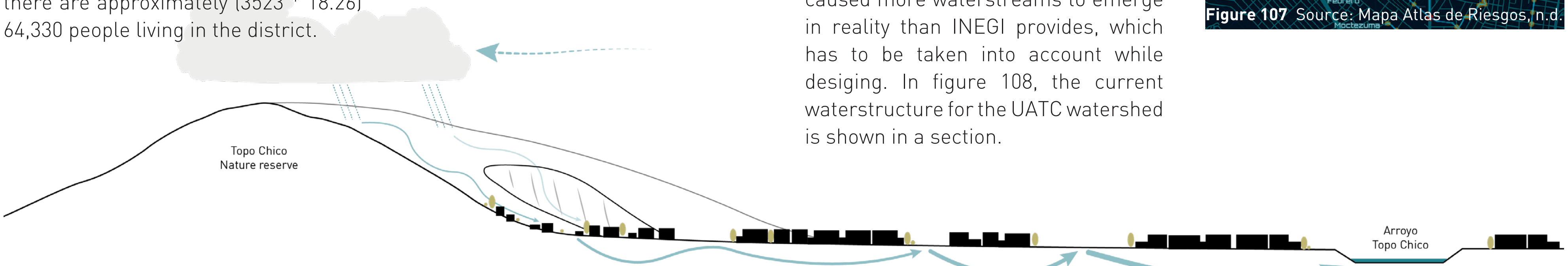



**Figure 108:** Section of the current situation of UATC watershed merged into San bernabé

## Functions

Most of the urban area consists of residential areas (figure 109), which consists mostly of two-story buildings (figure 110). Therefore, the area is widely spread but still dense, according to the current population density. There are multiple facilities available for the residents, such as a community center, which is seen in figure 111.

Informal settlements are also present. These are spread across the area, but are relatively more concentrated along the slopes of the Topo Chico Mountain. These can roughly be identified by the lack of recorded residential data in GIS compared to the images on Google Maps. These buildings are poorly maintained or constructed with relatively simpler materials such as metal plates or lack of wall finish (San Bernabé excursion comment, March 2nd 2024) (figure 112). It is likely that people with the worst living conditions in Monterrey, such as heat stress and little access to water during droughts, live in these informal settlements.

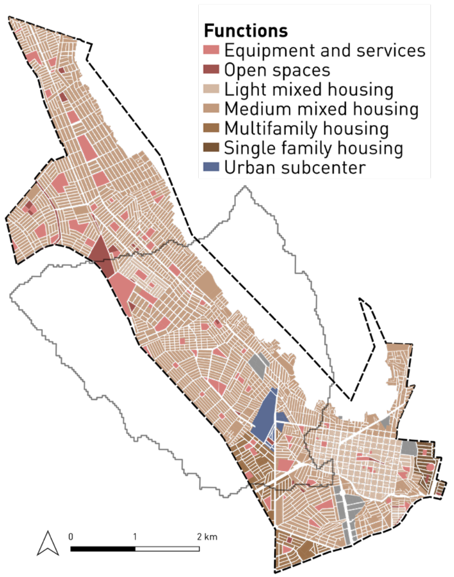



**Figure 109:** San Bernabé functions

Figure 110 Picture: Google Maps

Figure 111 Picture: Google Maps

Figure 112 Picture: Pieter van der Wel

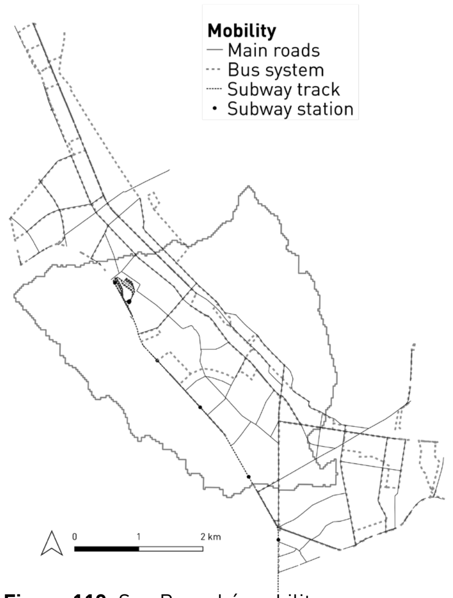



**Figure 113:** San Bernabé mobility

Figure 114 Picture: Google Maps

Figure 115 Picture: Google Maps

## Mobility

The roads are highly focused on cars, as the lanes are wide in relation to the sidewalks. The main roads are shown on the map in figure 113, along with the public transport routes. On the western side of the district, a subway has been constructed to connect people to the southern parts of Monterrey. In figure 114, the structure of the subway is shown with one of the main roads underneath.

Some streets however, are very narrow. As a result, parking is unorganized and happens next to facades, blocking some sidewalks (figure 115).

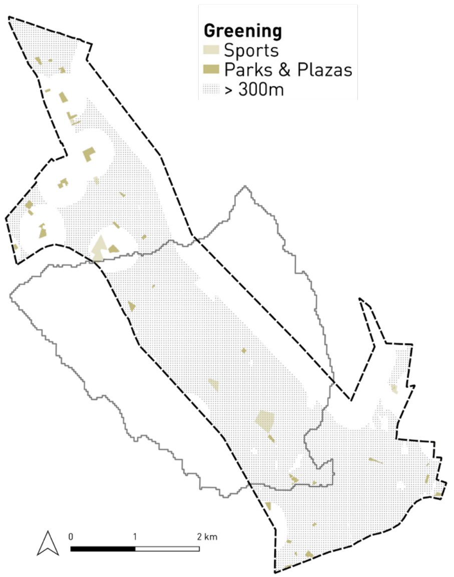



**Figure 116:** Green spaces and 300 meter rule in San Bernabé.

Figure 117 Picture: Google Maps

Figure 118 Picture: Google Maps

## Recreation and greening

The recreational locations in figure 116 are marked as sports facilities, parks, and plazas. Additionally, the area exceeding a distance of 300 meters from these locations is shown, covering 66% of the area.

There are 37 parks and plazas located in the district (figure 117), with five of them exceeding the size of one hectare. Also, there are nine sports facilities present in the district (figure 118).
By performing field calculations in GIS, it becomes clear that the parks and plazas cover 199,161 square meters in the district. This means that the green area per resident (199,161 / 64,330) is approximately 3.1 square meters of green space per resident. This number is less than the average of 3.9 square meters for the metropolitan area and falls short of the recommended 9.0 square meters (WHO). Therefore, it can be concluded that the area needs more green space to improve living conditions for residents.

The nature reserve of the Topo Chico Mountain has not been taken into account as a recreational area. Although this nature reserve preserves an ecological area, it is hardly accessible from the district due to a lack of entrance possibilities, quarries, or informal settlements along the slope. These types of land use block accessibility to the slope. According to Google Maps, there are also no hiking routes located on this side of the mountain.

## Soil

The soil underneath the district of San Bernabé consists of Leptosol, Rendzina, and Phaeozem (figure 119). The humus-rich Phaeozem soil follows the contour of the main course of the Arroyo Topo Chico.
There are also quarries located on the southwest side of the Topo Chico Mountain. In these quarries, urbanization has occurred, consisting mostly of informal settlements (figure 120).

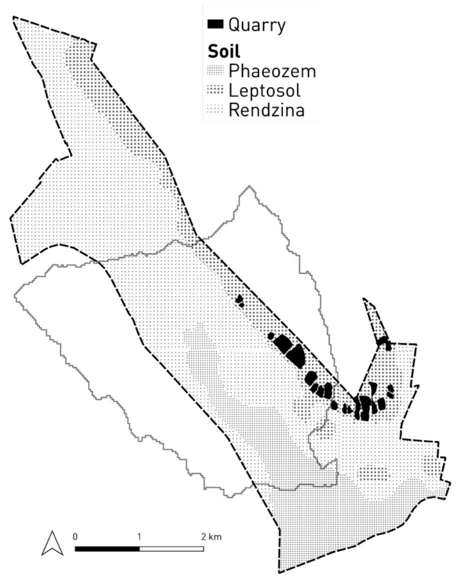



**Figure 119:** San Bernabé soil structure and quarry locations

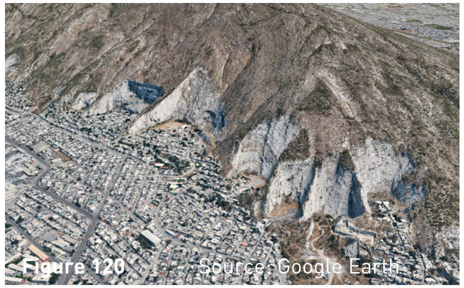


Figure 120 Source: Google Earth

# 5.3 Urban Watershed Design

This new map shows the new design for the southern part of San Bernabé district. The baselayer for the design is the Upstream Topo Chico Watershed. This watershed is used to make ecological and recreational connections via transformed streams flowing through the urban area. This results into an ecological mosaic and a recreational grid which applies to the 300 meter rule.

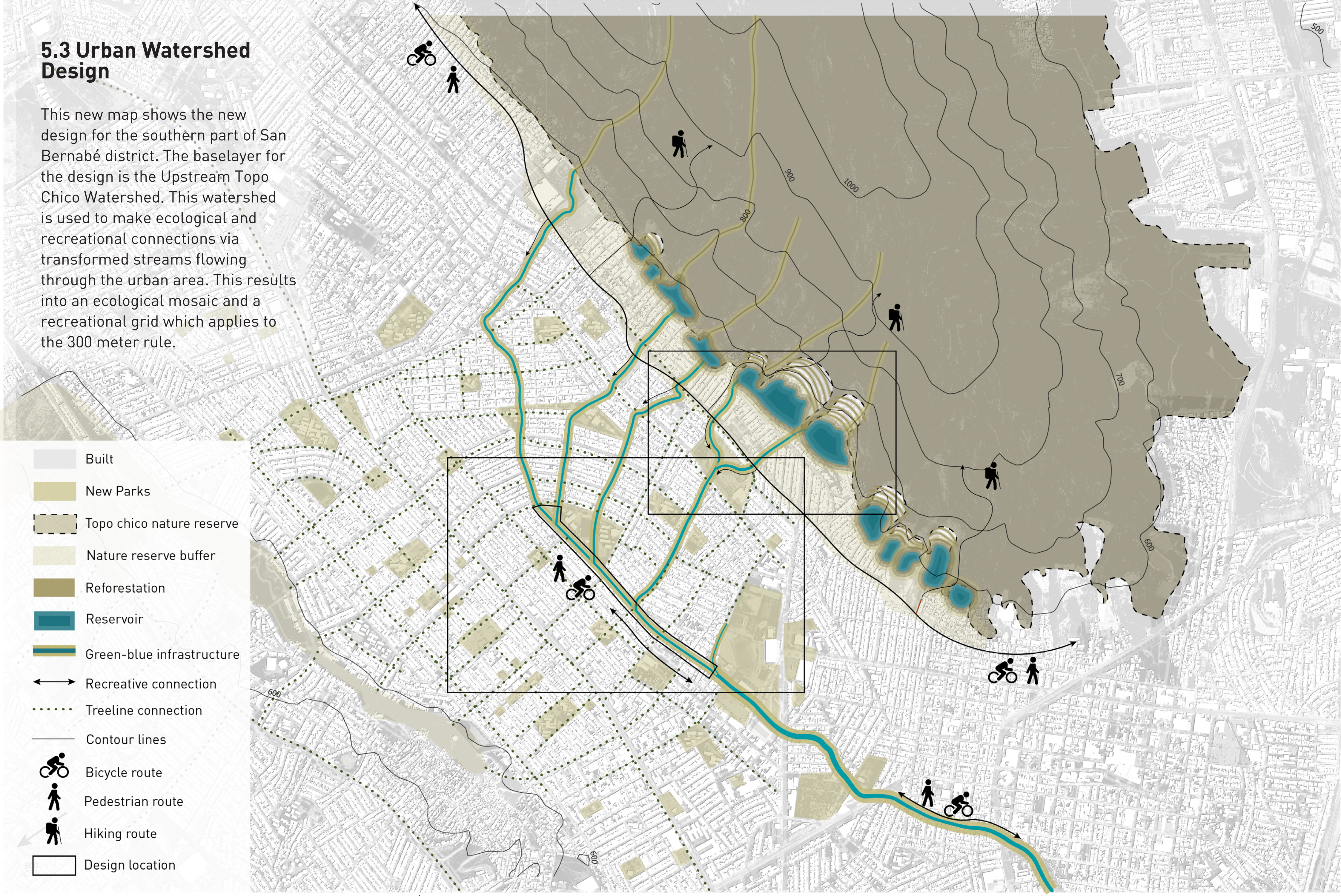



**Figure 121:** The spatial design of southern San Bernabé on city scale

### 5.3.1 Characteristics

**Topo Chico nature reserve**
The Topo Chico Mountain will be accessible on its western side, facing San Bernabé. This provides more opportunities for residents to enter the nature reserve for recreational purposes such as hiking and enjoying nature. The nature reserve is ecologically connected via the streams and a buffer of new forests following the foothills of the mountain. This forest vegetation aims to create a gradient between the ecological environments of the city and the mountain to encourage the migration of species and, therefore, enhance biodiversity.

**Parks**
Furthermore, parks are being made larger and ecologically stronger. The new linear parks along the streams, as well as new tree lines alongside the roads, will connect these new parks both recreationally and ecologically.

**Ecological Grid**
This design of linear parks, tree lines, small and large patches of parks, plazas, and nature reserves creates a new ecological mosaic or recreational grid within the area of San Bernabé. In this way, the 300-meter rule applies to all residents, and the quality of the ecological mosaic is enhanced by the increase in biodiversity.

**Prioritize pedestrians and cyclists**
In the design interventions, pedestrians are prioritezed and become more important than cars. There are car-free streets within the linear parks, new bicycle roads, and new hiking connections. This aims to create quality public spaces in the new design by making them safe, comfortable, and preserving cooler microclimates by removing asphalt.

**Design locations**
Design location 1 focuses on restoring old quarries located downhill on the slope of the Topo Chico Mountain. This area can serve as a water storage and collection site to provide the streams with water consistently and residents with additional tap water.

Design location 2 involves creating a linear park along the main course of the UATC, stretching from the northwest to the southeast.

**Section**
In figure 122, a section is shown stretching from the Topo Chico mountain to the urbanized area downhill. The streams are expanding as they collect more stormwater downstream. These stream patterns create both recreational and ecological connections between the nature reserve and the urban environment.

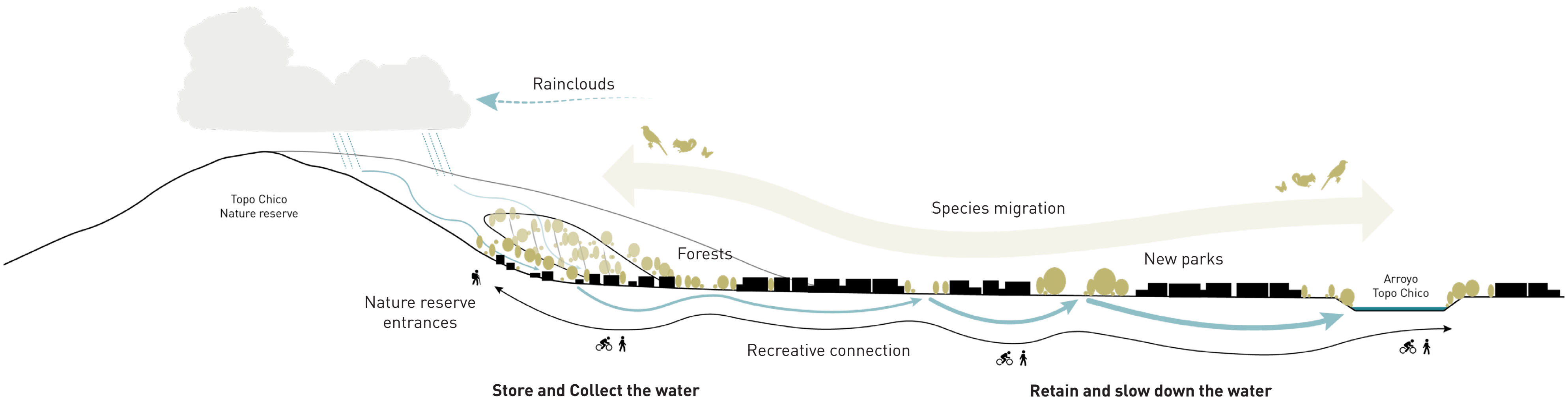



**Figure 122:** Section of the new spatial deisgn in the southern part of San Bernabé, making use of the UATC watershed

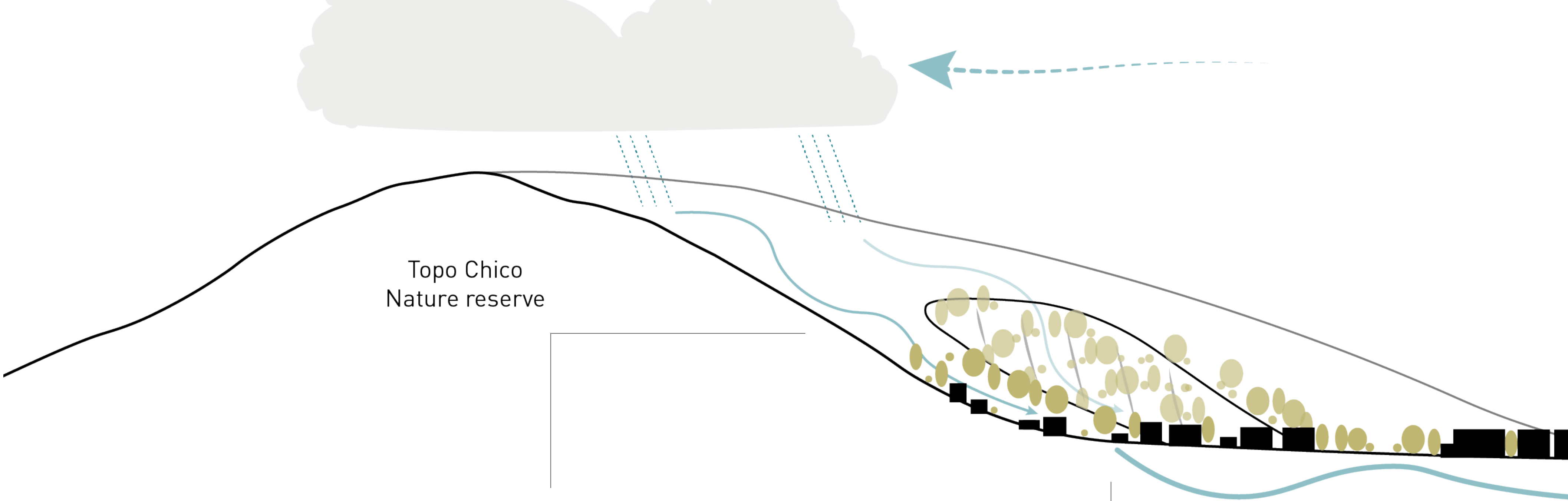
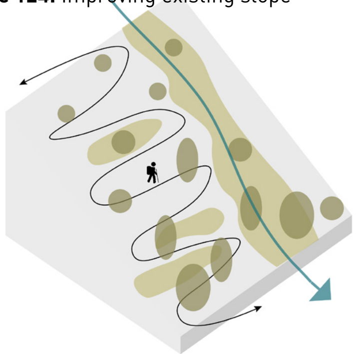



**Figure 123:** Section of the new spatial design provided with the new green and blue infrastructure principles

## 5.4 Green and Blue Infrastructure Principles

The streams flowing from the mountains into the urban environment follow a consistent pattern. These streams from the UATC watershed influence the spatial design structure. Therefore, new design principles are developed based on the stream pattern. This pattern is composed of the following tiles: slope, reservoir, narrow street, wide street, and storm drain (figure 123). Each tile has its own unique transformation principle(s).

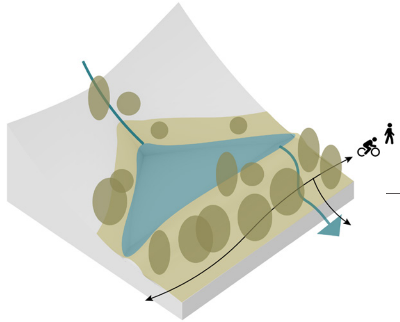
**Figure 124:** Improving existing slope



**Slope: Improving the nature reserve**

The slope of the Topo Chico mountain is part of the nature reserve Cerro del Topo Chico, which needs to be maintained. Therefore, vegetation can be planted upstream. This has advantages for cooling down the slope for encouraging downwinds, and preserving the fauna living there. Additionally, newly placed hiking routes provide recreational opportunities (figure 124).

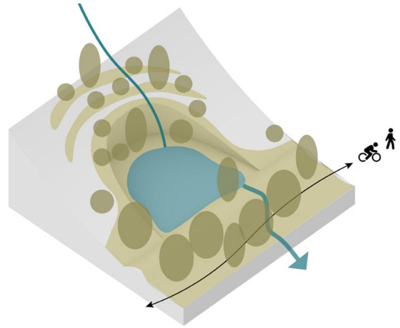
**Figure 125:** Foothill reservoir



**Reservoir: Foothill reservoir**

Downhill, the stream flows into a reservoir where water can be stored and collected by constructing dams. To ensure the ecological strength of this reservoir, the slope of the dam can be made very shallow and covered with vegetation. Additionally, forests surround the water, creating an ecological buffer between the nature reserve and the urban environment (figure 125).

**Figure 126:** Quarry reservoir



**Reservoir: Quarry reservoir**

In cases where a stream enters a quarry, the quarry can be repurposed as a new reservoir. A dam can be built between the foothills surrounding the old quarry. To reduce the steepness of the cliffs, terraces will be constructed to maintain the original slope. A forest surrounding this reservoir provides a buffer zone between the nature reserve and the urban environment

**Figure 127:** Stream in small street

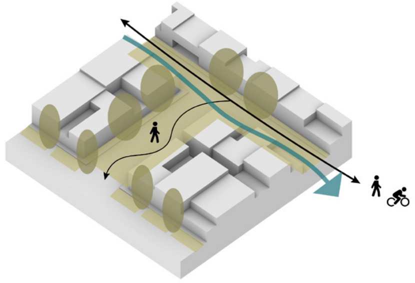


**Figure 128:** Stream in wide street

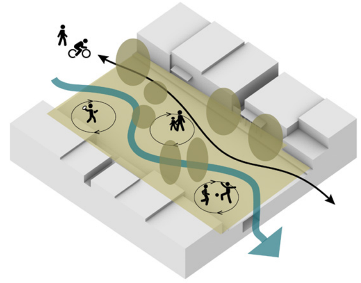
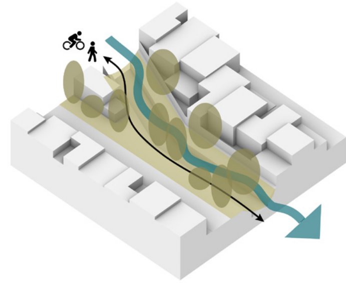


**Figure 129:** Stormdrain transformation




**Narrow street: Green pedestrian streets**
Currently, in the urban environment at the foothills of the mountain, streams follow the streets, causing inundation. In this scenario, the street is removed, and the stream is integrated between the facades provided with weirs to encourage soil infiltration. The banks will be covered with vegetation. These green streets are designated for pedestrians and cyclists (figure 127).

**Wide street: Linear Park**
Streams can also flow into wider streets. In these streets, there are more opportunities for diverse street profile designs compared to narrower streets, benefiting biodiversity and recreation. Therefore, the street is transformed into a linear park. In these interconnected parks, only pedestrians and cyclists are allowed. Residents can cool off under canopies, gather, and enjoy nature in the city (figure 128).

**Storm drain : Daylighting the storm drain**
When the stream enters a concrete storm drain, this channel will be opened up (daylighted) to create a more natural flowing stream. Weirs will be added to slow down the stream. The area along the stream will be filled with vegetation to create habitats. A mixed pedestrian and bicycle lane will follow the course of the stream (figure 129).

**Conclusion**
By implementing these new repeating principles, water is able to flow consistently through the area. Furthermore, the vegetation habitats along the stream extend the characteristics of the nature reserve into the urban environment, ensuring less contaminated and cooler water, which benefits all life forms.

By zooming into the new design locations, the implementation of these green and blue infrastructure principles is demonstrated, clarifying the coherence and the spatial experience.

# 5.5 Plant Catalogue

## 5.5.1 Plant Selection

Green and blue infrastructure cannot be implemented without vegetation. This vegetation will consist of trees, shrubs, and grasses, which are vital for ecosystems to thrive in a city.

To design on a local scale, plants must be carefully selected for inclusion in the design. Seventeen native trees, seven shrubs, and five desert plants have been selected for the new spatial design. These were sourced from Zaragoza's book 'Native Plants in Monterrey'(2009) and the 'List of Plants in Nuevo León' by the state of Nuevo León (2009).

In the following plant catalogue in figure 130 (trees) and 131 (shrubs), the plants are listed by their Latin names, common names in English, and characteristics, as described in Zaragoza's book. The catalogue organizes the plants by their water requirements and foliage, a basic principle for mitigating heat stress. From left to right, the plants have increasing water requirements, and from top to bottom, they are categorized from evergreen to deciduous.

Additionally, the special design characteristics are retrieved from Zaragoza's book and noted, as these characteristics are important for considerations in the new spatial design.

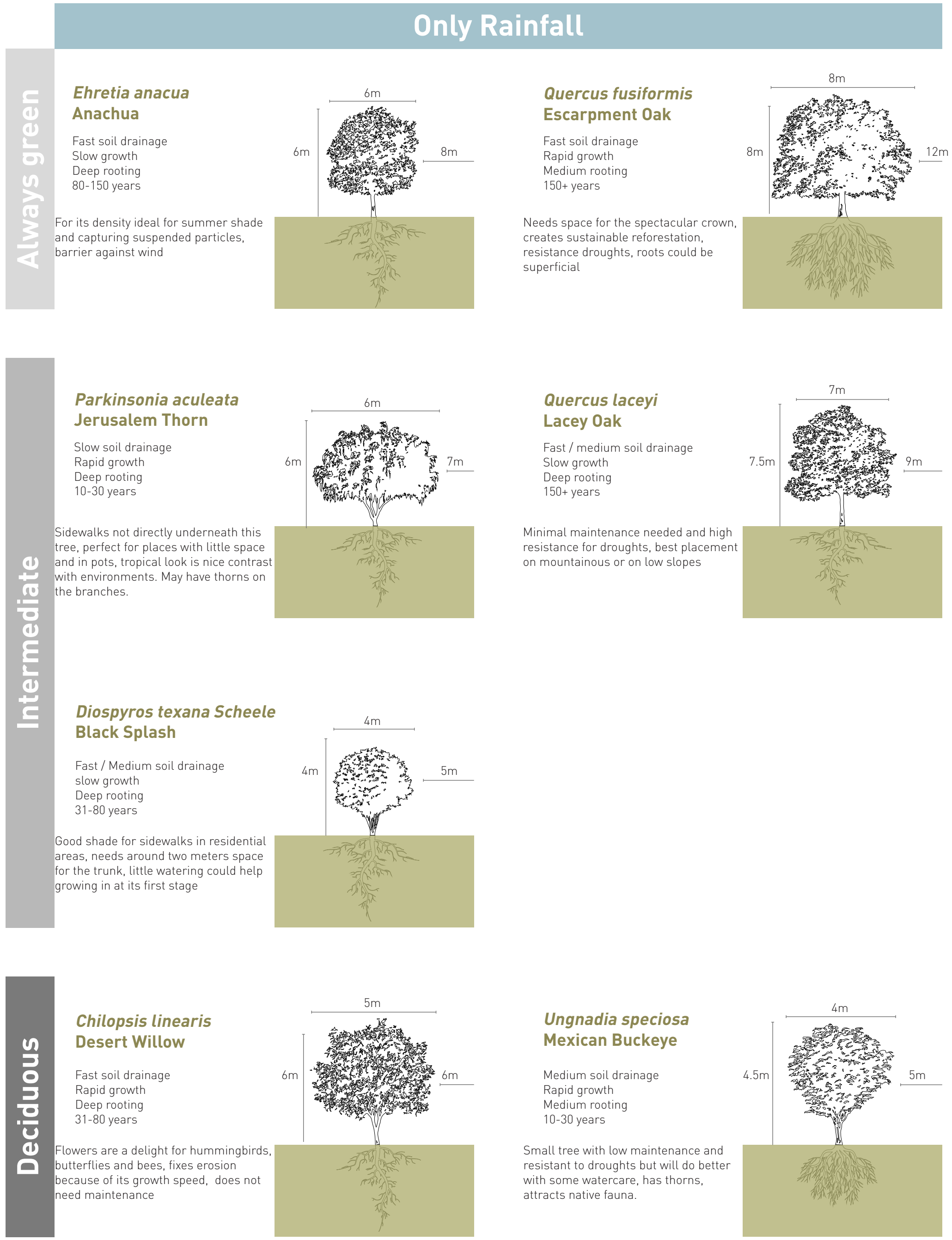


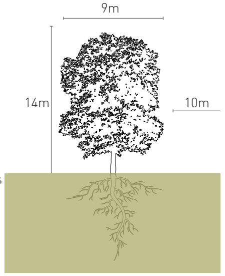

**Figure 130:** Tree Catalogue (Tree visuals retrieved and modified by Texas A&M Forest Service, n.d.)

# Sufficient (per 7-10 days) | Maximum watercare

## Always green

### *Quercus polymorpha*
### Mexican White Oak

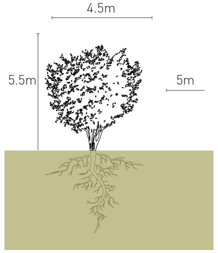
Fast and medium soil drainage
Rapid growth
Deep rooting
150+ years




Good for reforestation, resistant to pests like the other oaks, ideal shade for urban areas, highly recommended for avenues due to deep root and shade

### *Sideroxylon celastrinum*
### Saffron Plum

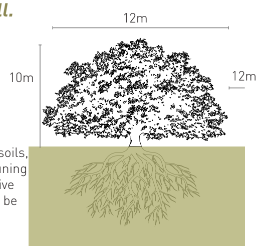
Fast / medium soil drainage
Slow growth
Deep rooting
80-150 years




Small tree with low maintenance and resistant to droughts but will do better with some watercare, has thorns, attracts native fauna

### *Quercus virginiana Mill.*
### Southern Live Oak

Fast and medium soil drainage
Rapid growth
Medium rooting
150+ years

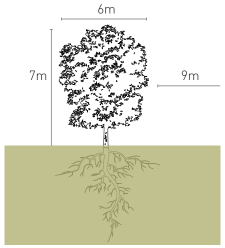



Adapts to dry, humid and saturated soils, also saline and sandy if present, pruning could be considered to avoid excessive growth, attractive for wild life, could be 30 meters wide in the end

## Intermediate

### *Celtis laevigata*
### Sugarberry

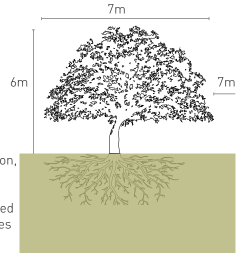
Medium soil drainage
Rapid growth
Deep rooting
31-80 years




Thermal effect on pavement because of dense leaves, without water it can be placed next to streams or stormwater runoffs

### *Prosopis glandulosa*
### Honey Mesquite

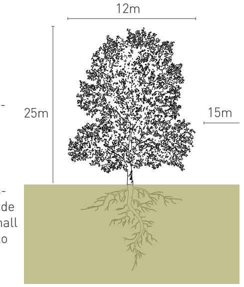
Slow soil drainage
Medium growth
Widerooting
80-150 years




Responds to humidity instead of season, fruit edible for humans, light shadow, takes large space for crown, a few together for best aesthetics, considered as heritage, a soil regenerating species

### *Platanus occidentalis*
### American Planetree

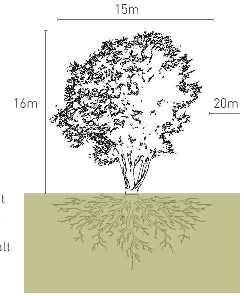
Fast and slow soil drainage
Rapid growth
Deep rooting
150+ years




Has title of reforestation and has aesthetic trunk, can be placed next to wide sidewalks, shadow short term for small houses because of height, resistant to droughts and bad soils, avoid service lines while placing.

### *Salix nigra Marshall*
### Black Willow

Slow soil drainage
Rapid growth
Wide rooting
30-80 years

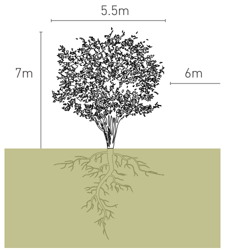



Create aesthetic effects if placed next to other trees, needs a body of water, can be placed near a stream, able to mitigate hot impacts of nearby asphalt surfaces

## Deciduous

### *Cercis canadensis*
### Eastern Redbud

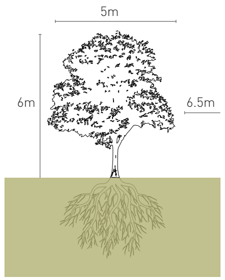
Medium soil drainage
Rapid growth
Deep rooting
10-30 years




Strong aesthetics, resistant to droughts and grows in mountains, can also grow underneath large trees.

### *Sapindus saponaria*
### Wingleaf Soapberry

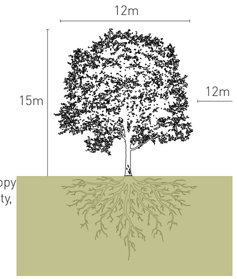
Fast soil drainage
Rapid growth
Medium rooting
10-30 years




Fruits are used for washing clothes, needs special watercare during first years

### *Juglans mollis*
### Mexican Walnut

Medium / slow soil drainage
medium growth
Wide rooting
150+ years




Mitigates summer temperatures, canopy is as wide as tall, needs lots of humidity, Winter allows sun to pass through in front of facades for example

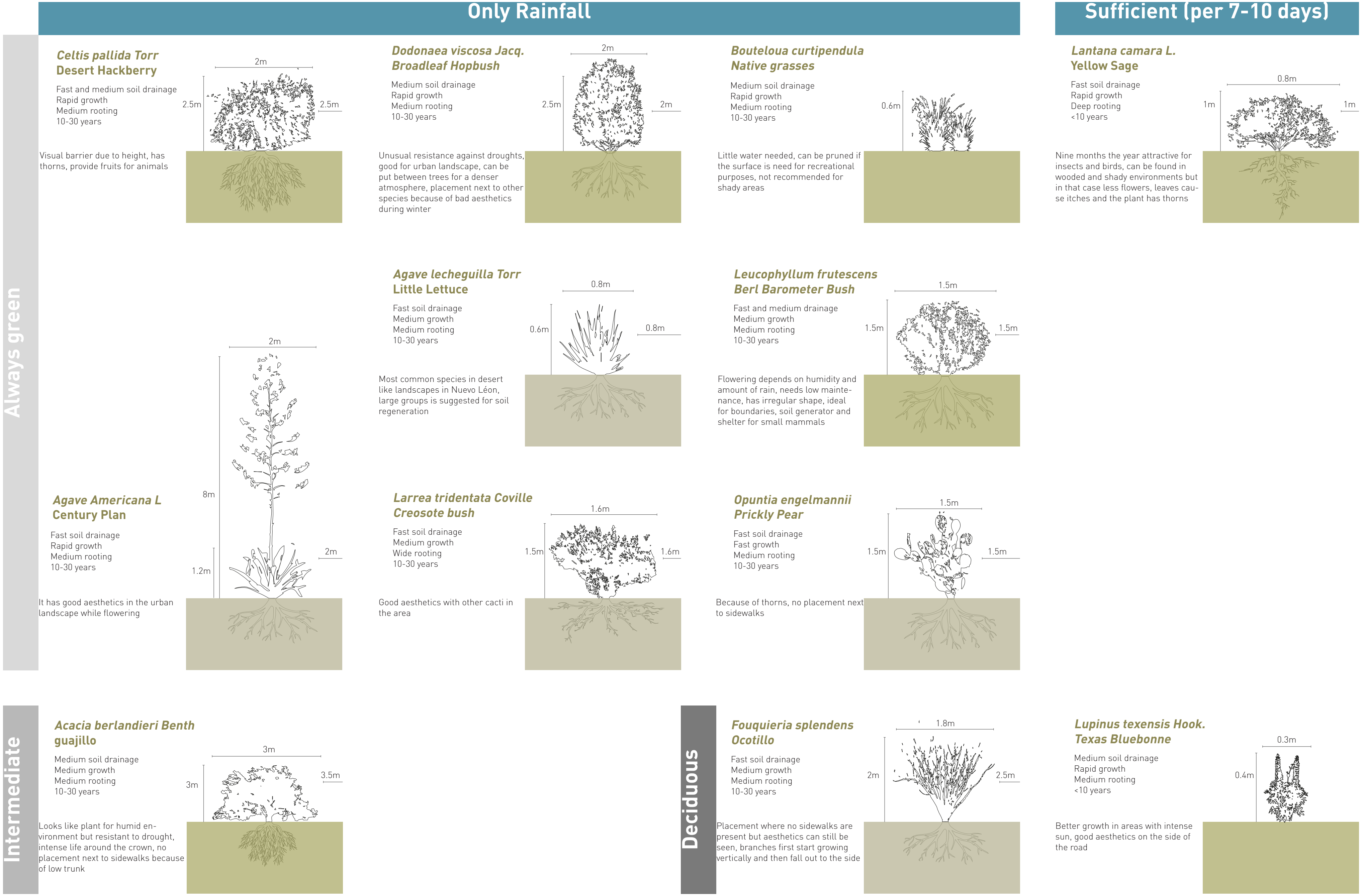



**Figure 131:** Plant Catalogue with shrubs. The shrubs with green soil represents temperatre climates and the brown soil represents more desert climates.

## 5.5.2 Operating with the Plant Catalogue

The selection of certain trees and other plants must be as accurate as possible in the implementation of green and blue infrastructure to achieve mitigation of heat stress and water scarcity.

For this operation, the order of picking trees first and then the shrubs is considered, as trees are significant in mitigating heat stress. This means that the shrubs are selected after the trees are chosen.

To choose the right trees for specific sites, a systematic approach must be taken, involving several steps to ensure the suitability of each tree for its intended location (figure 132).

**Analysing the site**

First, the site must be analyzed to determine the type of tree needed and the site conditions, such as soil, water availability, and land use.

**Plant catalogue**

After analyzing the area, the plant catalogue comes into play. Here, the cooling effect, water requirements, and spatial quality of the trees can be determined.

Trees have different characteristics for mitigating heat stress. The foliage, size and grow speed of the tree are factors that determine the amount of shade and transpiration, contributing to the cooling effect.

For water requirements, the type of tree and its rooting system determine whether it can thrive in areas with limited amounts of water in the soil because of the watertable and soil structure which can differs in drainage. A tree placed right next to a stream has more water availability than a tree located farther away.

While it is possible to water the plants additionally if necessary, sustainable water management goals dictate that this should be minimized.

Spatial quality is essential for creating quality public spaces. This includes considering the aesthetics of the tree and specific characteristics like thorns or the amount of maintenance needed.

**Evaluation**

At last, an evaluation is needed after designating a tree or certain trees to a space. For instance, the trees which are placed in a certain area has to be diverse, in order to enhance biodiversity. Furthermore, trees could cover other plants too much which need relatively more sunlight. The outcome of the evaluation determines whether the tree or group of trees can be established for that place or if other plants have to be considered.

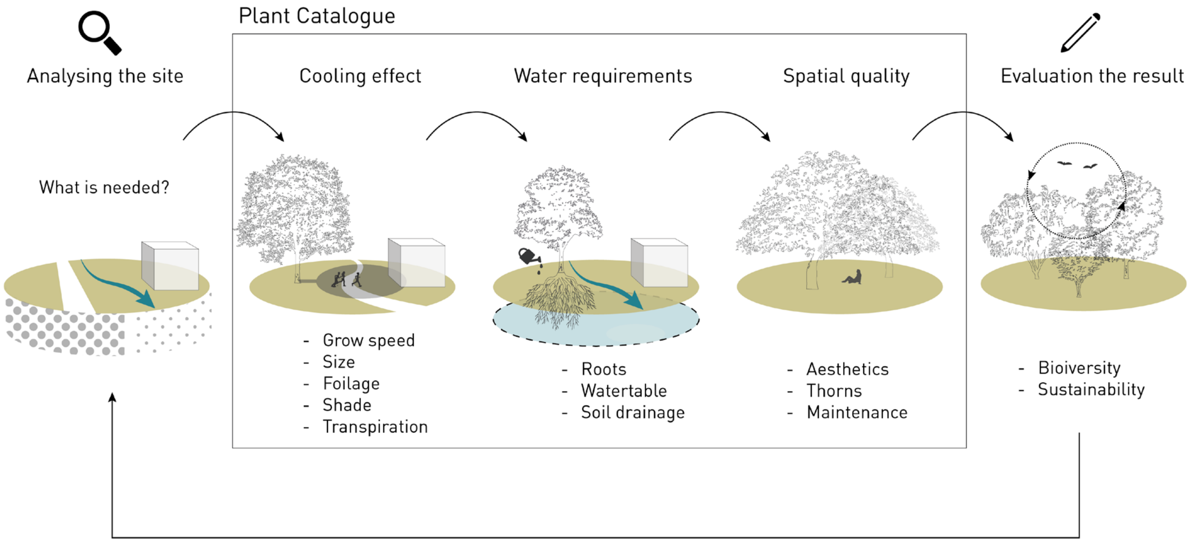



**Figure 132:** Operation with the plant catalogue


**Figure 133:** Context map of design location 1
**GIS sources:** Monterrey government, Openstreetmap

Figure 134 Picture: Google Maps

Figure 135 Picture: Google Maps

Figure 136 Picture: Google Maps

Figure 137 Picture: Google Maps

## 5.6 Design Location 1

### 5.6.1 context

The context of the first design location is depicted in the GIS map in figure 133. The area contains informal settlements situated in one small and two larger quarries along the slope of the Topo Chico mountain (figure 134). Here, residential neighborhoods have illegaly expanded onto the slope of the mountain. These areas are at risk of landslides, particularly triggered after heavy rainfall (Kalsnes & Kapobianco, 2022).

Water streams from the slope follow the streets downhill to the lower area of the UATC (figure 135). However, due to asphalt paving and buildings, the natural stream beds no longer exist. Consequently, streets flood during heavy rainfall due to the lack of infiltration into the ground. This creats hazardous conditions between the buildings.

The soil structure in the area primarily consists of Leptosol, which is rocky soil with a top layer of organic material. This organic layer contains a maximum thickness of 25 centimeters above the bedrock, containing more than 40 percent calcium carbonate in this layer (Leptosols, n.d.).

On the map in figure 129, a white spot is highlighted. According to Monterrey's GIS data, this area is designated as a transformation area, although Google Earth displays it as an industrial area. In a future scenario, this industrial area could potentially be replaced with new residential development. Additionally, within this part of the residential area, there small park and a school (figures 136 and 137).

### 5.6.2 Hydrological system Design and calculation

In the quarries located on the foothills of the Topo Chico mountain, new reservoirs are proposed. For this upstream design location, such a proposed reservoir is shown in figure 138 on the next page. This reservoir serves to preserve quality water directly flowing from the nature reserve. It functions as a water buffer between the slope and the urban area to ensure a constant flow of water through the urbanized area, addressing differences in weather events throughout the year. Rainy conditions can lead to inundation, while dry periods can result in water scarcity. The reservoir will provide the possibility of maintaining a safe and constant flow of water through the urban area and may also serve as a potential source for tap water extraction in the future.

In figure 138, the watershed on the slope uphill of the newly proposed reservoir is shown (retrieved from the geodatabase of INEGI, n.d.). The precipitation that falls into this watershed will eventually flow into the reservoir. This includes runoff from the slope and water that infiltrates into the soil. Groundwater also moves to the lowest point and may eventually be discharged above ground at a lower

### 5.6.3 Calculating extreme event

Designing with hydrologic infrastructure must be based on the hydrology of the site. Therefore, it is crucial to understand the potential drainage capacity during extreme events (commented by R. Fonseca from Tecnológico de Monterrey Water Center, May 11th, 2024). Utilizing data from INEGI, calculations can be performed to measure extreme events and design civil structures accordingly. Figure 138 illustrates the uphill watershed and is included in these calculations.

#### Waterflow Q

The following formula is retrieved from INEGI to calculate the waterflow in an extreme event:

**Q = C * I * A**

**Q**: The flow of the water in cubic meter per second ($m^3/s$)

**C**: the water runoff coefficient

**I**: Intensity in meters per second (m/s)

**A**: surface of the basin in $m^3$

**Surface basin**
The surface area of the basin, retrieved from SIATL, is 290,000 square meters.

**Runoff Coefficient**
This number, known as the runoff coefficient, lies between 0 and 1 and represents the proportion of water that flows down the slope instead of infiltrating into the soil. It is highly dependent on the slope gradient and the soil structure. In this case, the soil structure is Leptosol, and the average slope gradient is 39% (INEGI). The runoff coefficient used is 0.36, which has been approved by Tecnológico de Monterrey Water Center and is determined by the rocky and mostly pasture land in the watershed.

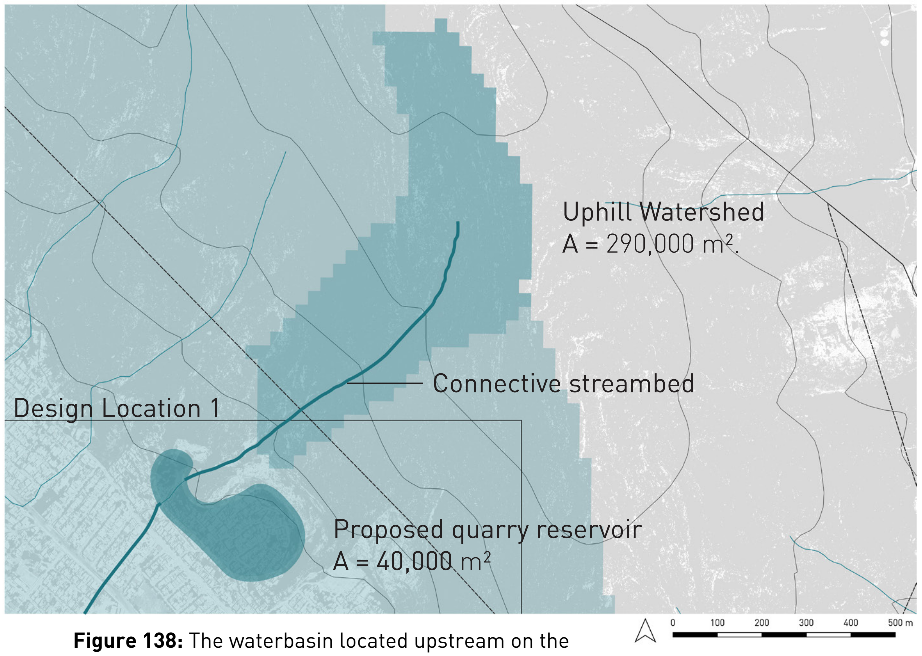



**Figure 138:** The waterbasin located upstream on the slope of the Topo Chico mountain and the proposed reservoir on the foothills located in a quarry

**Intensity**
The intensity is the amount of rainfall with a certain return period. For civil structures in Mexico, a return period of 20 years is used (commented by R. Fonseca from Tecnológico de Monterrey Water Center, May 11th, 2024). Thus, the intensity of rain is the amount of precipitation that falls every 20 years. This number is retrieved from another study by the Water Center conducted on the same slope of the Topo Chico mountain. This number is 0.000142363 m/s.

**Calculation**
The flow of the water can be calculated following the formula:

$Q = C * I * A = 0.36 * 0.000142363 * 290{,}000 = 14{,}86\ m^3/s$

This means that almost 15 cubic meters of water flows into the reservoir per second during intensive rainfall. Therefore, it is necessary to build a dam to hold the force of the water (commented by R. Fonseca from Tecnológico de Monterrey Water Center, May 11th, 2024).

**Water volume during the extreme event**
To calculate the water volume during the event, the time span has to be included. The rain intensity has a duration of 10 minutes or 600 seconds. This means that (14.86 * 600) 8916 cubic meters of water flows down into the reservoir during this extreme event of 10 minutes.

## 5.6.4 Reservoir characteristics

**Infiltration**
Water still infiltrates into the soil due to gravity, but since the soil consists of Leptosol underneath the new proposed reservoir, it contains a bedrock layer. This bedrock layer retains all the water in the reservoir for a longer period, so infiltration is not significantly taken into account.

**Evaporation**
According to the climate information of page 23, in this area there is an annual evapotranspiration between 500 and 600 millimeters. This means that, with the amount of 590 millimeters of precipitation, the amount of water is approximately balanced. Theoretically, it means that a volume of water remains about the same without infiltration in this area. The evaporation in the reservoir throughout the year can also be assumed as 590 millimeters per year.
In the future it is possible that there will be more evaporation than precipitation due to climate change. The annual precipitation will decline and when the temperature rises, the amount of evaporation is lower.

**Surplus**
The annual balance of precipitation and evaporation results into a constant watertable for this design. But the reservoirs which will be placed along the slope will be filled up with water by the runoff from the uphill watershed.

**Area**
The placement of the reservoir is in the area where the excavation of the quarry has started. In this case, the steep sides of the quarry can work as a dam. It will take the place of a smaller and bigger quarry. Determining the area can be done by Google Earth studies. According to the preferenced place of the new reservoir, the surface area is measured to approximately 40,000

square meters or 4 hectares.

**Depth**

The reservoir will exists of gentle slopes but will have a depth of a minimum of 5 meters in the middle of the lake to preserve water quality (Wetzel, 2001). That means that the average depth for the new reservoir will be at least 5 meters.

## 5.6.5 Reservoir input and outlet

**Annual input: Surplus**

The water that flows as a surplus into the basin per time unit can be calculated.

In one year, there is 590 millimeters of rain. The uphill watershed has a surface area of 290,000 square meter. That means that an amount of (0.59*290,000) 171,100 cubic meters of water will eventually flow into the reservoir in one year. In this case, the runoff coefficient is not taken into account because it is assumed that all the water in the uphill watershed eventually flows into the reservoir.

The amount of rain that falls in the surface area of the new reservoir in one year is not added to the volume because it is also evaporated in one year.

In order to calculate the watertable rise in one year without infiltration, the volume surplus of water is divided by the area of the new reservoir. This results into an annual watertable rise of (171,000 / 40,000) 4.28 meters, without infiltration on the slope and on the bottom.

**Annual outlet: Water discharge and water extraction**

The annual outlet of water is the discharge further downstream in the UATC watershed and the tapwater extraction.

The annual discharge by the sluice and tapwater extraction can never be more than the annual surplus, because then the reservoir runs short. This means that there should be a certain balance between the discharge and the tapwater extraction.

For the discharge through the sluice, a constant flow is necessary. This sluice can be manually controlled to determine the amount of water flowing out of the reservoir and causing the watertable to fall.

For tapwater extraction, an experiment of watertable fall of one meter can be assumed to never pass the minimum watertable level of 5 meters. This is a total of 40.000 cubic meters of tapwater extraction per year.

Since the annual surplus is 171,100 cubic meters per year, the annual discharge is (171,000 - 40,000) 131,000 cubic meters per year. The discharge per second through the stream down the reservoir will be 0.0042 $m^3/s$ or 4.2 l/s. This discharge is an average, because in dry periods, less water will flow in the reservoir and in wet periods, more water will flow in the reservoir.

**Starting position Reservoir**

The reservoir has to be filled up in the beginning to preserve a volume of water. This period has no discharge to the downstream part of the stream.

The reservoir can be filled up with a maximum of 4.28 meters per year without infiltration. This means with a minimum depth of 5 meters and no infiltration, two years must pass to fill up the reservoir for the first time.

At the end of this moment, the watertable is theoretically 8.56 meters high. After this moment, the water in the reservoir can be discharged to the Arroyo Topo Chico downstream.

That means that the watertable will start between 8 and 9 meters. The dam can be placed one meter higher than this watertable, which makes the elevation of the top of the dam to the bottom of the reservoir 10 meters In figure 139, the concept of the reservoir is shown with its mechanisms of the inlet, outlet and the watertable´s starting position. This concept design can also be used for a reservoir design which is not placed in a quarry. In that case, the numbers of inlets and outlets will change due to different topographic characteristics and reservoir size.

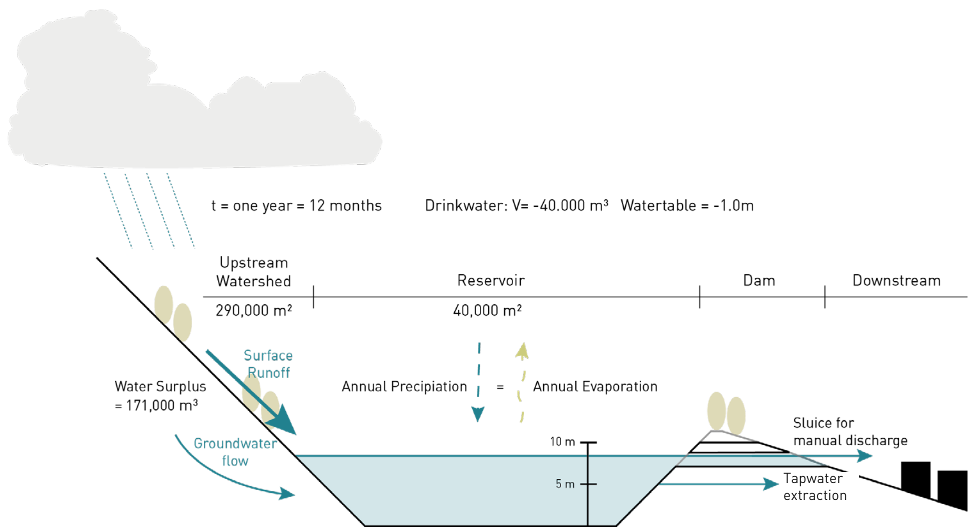



**Figure 139:** Concept reservoir section of the annual inlet and outlet of water. The reservoir serves as a buffer to control the discharge of the water through the urban area and as tapwater extraction.

## 5.6.6 Reservoir calculations during (extreme) periods

**Montly precipiation and evaporation**

Because of variable and extreme weather events, the amount of water in the reservoir will differ. Therefore, it is necessary to determine the amount of precipitation and evaporation for specific periods in one year.

For the extreme events, four periods will be taken into acount: the dry month of July, the wet month September, a drought with 90 days without rain and a hurricane event.

Therefore, the montly numbers for precipitation and evaporation are gathered for further calculations. The tapwater extraction is still present during these situations. In table 1 (Appendix, p. 110), the amount of precipitaion is gathered. In table 2 and 3 (Appendix, p. 110), the mean tempreature and sunny hours per month are gathered which detemines the amount of evaporation per month. During these specific months, precipitation and evaporation of the reservoir is not balanced anymore, whereby the watertable of the reservoir will rise and fall. An extra precipitation surplus is added by the uphill watershed, except during droughts.

The montly mean precipitation can be retrieved from sources such as ClimatesToTravel (n.d.) (figure140). The monthly evaporation can be sketched and determined by the complex factors such as temperature, sunny hours and the mean evaporation of 49 mm (590 / 12) per month. In figure 140, 141 and 142, the amount of evaporation and precipitation is defined in graphs for further calculations and assumptions.

**Dry month: July**

July is the month with most amount of evaporation relatively to the least amount of precipitation. It has a mean temperature of 29.3 degrees Celcius with 250 sunny hours and 45 millimeters of rain (ClimatesToTravel, n.d.).

There is appoximately 80 millimeter of evaporation throughout this month according to the sketched evaporation graph. In figure 143, the mechanics of the reservoir is shown in July. There is a watertable rise of 21 centimeters which can provide a discharge of 3.3 liters per second in order to keep the watertable at the same position.

Since July is the dryest month of the year and still provides a rising watertable, it is assumed that every other month contains a surplus of water.

**Wet month: September**

September is the wettest month with a mean precipitation amount of 150 millimeters (ClimatesToTravel, n.d.) and an estimated evaporation of 60 millimeters. This results into a watertable rise of 1.10 meter which can provide a discharge of 16.9 liters per second to keep the watertable at the same position (figure144).

**Drought: 90 days without rain**

A next severe drought like in 2022 is liklely to happen in the future due to climate change. A dry period of 90 days can be taken into account as an extreme event. It will take the summer months of June, July and August. In figure 145, the mechanisms are shown and it is seen that in this period there is no surplus of water from the slope. To keep the water flowing downstream to provide vegetation from water and mitigate heat stress, a discharge of 5.0 liters is considered. In this case, the watertable will fall 1.45 meters in total. It is likely that the wetter months of September and October can fill up the reservoir in its normal position after the drought.

**Hurricane: Extreme rainfall**

A hurricane provides an extra surplus of water because this is not considered into the mean weather events. The hurricane of Alex in 2010 is used for the calculations. This hurricane created 800 millimeters of rain in 48 hours. The amount of evaporation and extraction during this humid and short time period is not signficant. In order to prevent overflow and prevent dangerously high amounts of water discharge downstream, the reservoir will be flushed away, a week before the hurricane starts. This can be done by a lower positioned sluice. In figure 146, it is seen that a hurricane comparible to Alex creates a watertable rise of 6.6 meters in total. Before the hurricane,

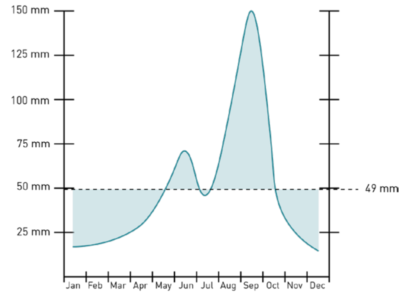



**Figure 140:** Precipitation amounts every month, with the montly mean precipitation of 49 mm (590 mm / 12). Drawn by table 1.

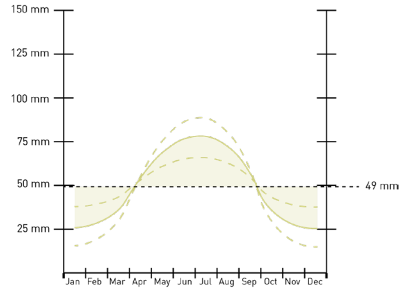



**Figure 141:** Evaporation amounts every month, determined and sketched by by table 2 and 3. During summer, the amount of evaporation is higher than other times of the year by higher temperature and more sunny hours, This results into a parabol. During wintertimes, it is assumed that evaporation is never 0. The parabol sketched in such a way that the symmetry axis is the montly mean of 49 mm. The top of the parabol could differ with 25 mm.

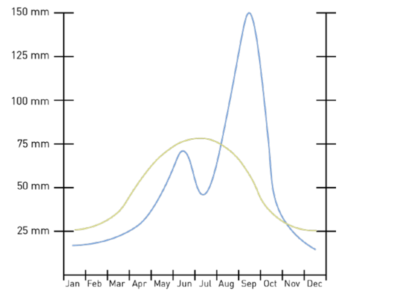



**Figure 142:** Amount of precipitation and evaporation in one graph. During August, September and October, the amount of precipitation is higher than the evaporation.

## Dry month: July

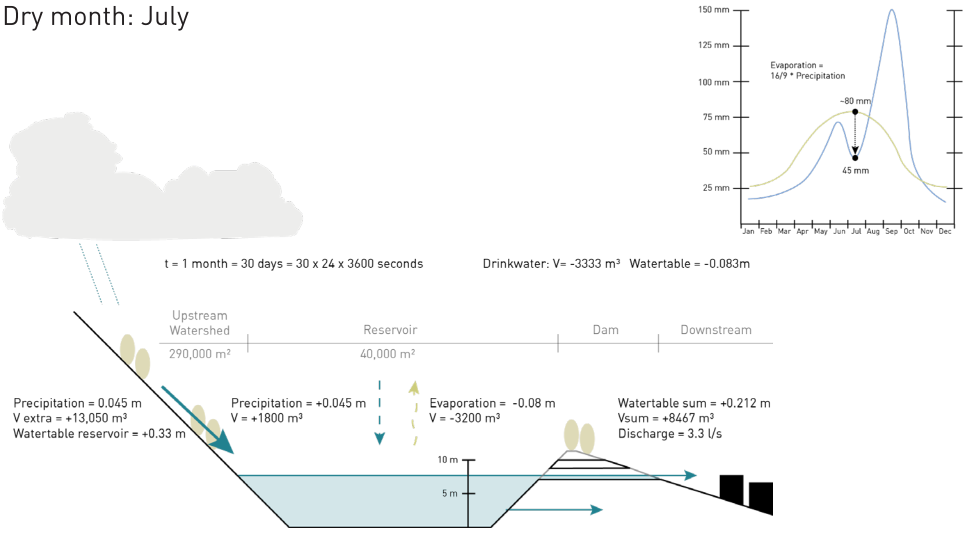



**Figure 143:** Reservoir section during July, with the lowest average watertable. The amount of evaporation is the highest in relation to the precipitation.

## Drought: 90 days without rain

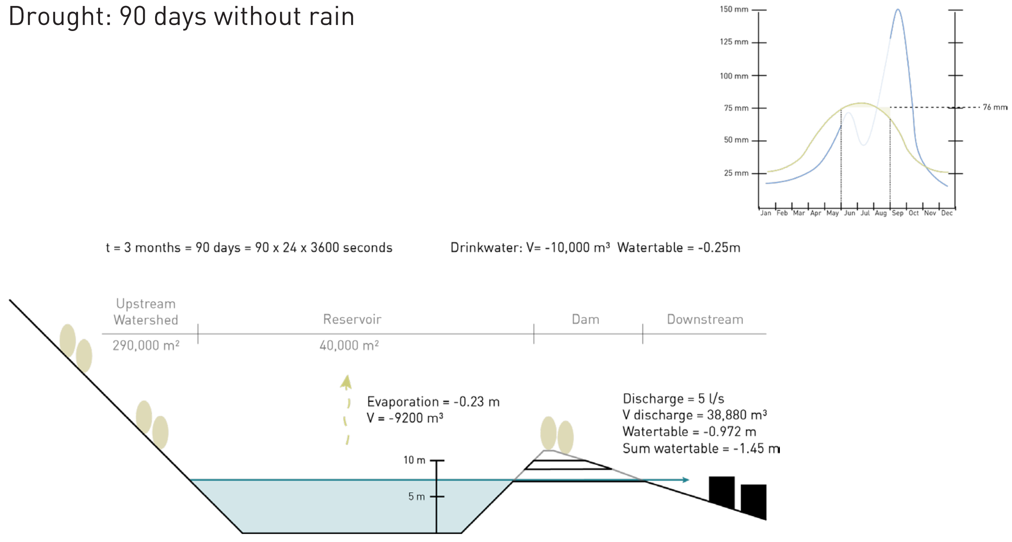



**Figure 145:** Reservoir section during a servere drought of 90 days in the summer months of June, July and August. There is no pricipitation and approximately 230 mm of evaporation ( 3 * 76 mm ).

## Wet month: September

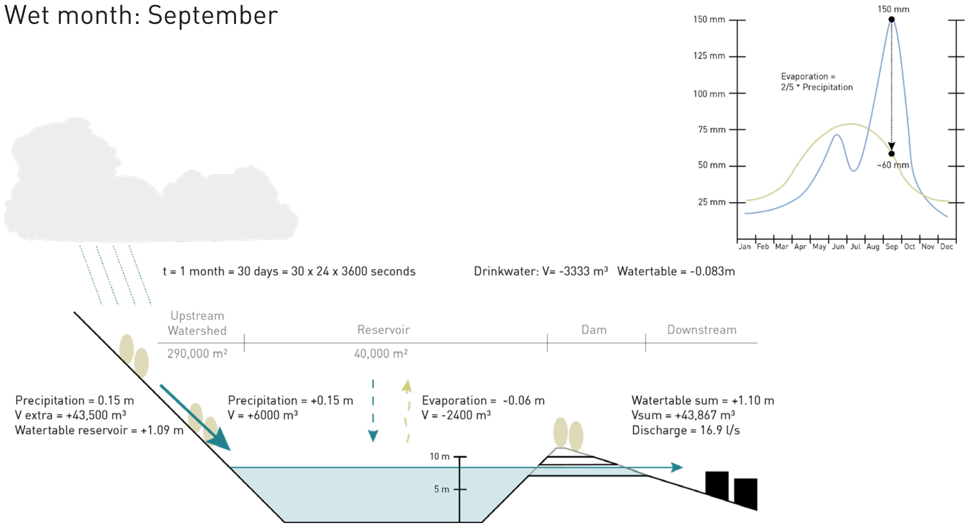



**Figure 144:** Reservoir section during September, with the highest average watertable. High precipitation and high evaporation occurs.

## Hurricane: Extreme rainfall

the watertable will fall to between 0-5 meters, so it can be filled up again between 8-9 meters in the end. Due to uncertainties, a flexible discharge with a maximum watertable fall of 3 meters is still possible. This leads to a maximum discharge of 694 liters per second.

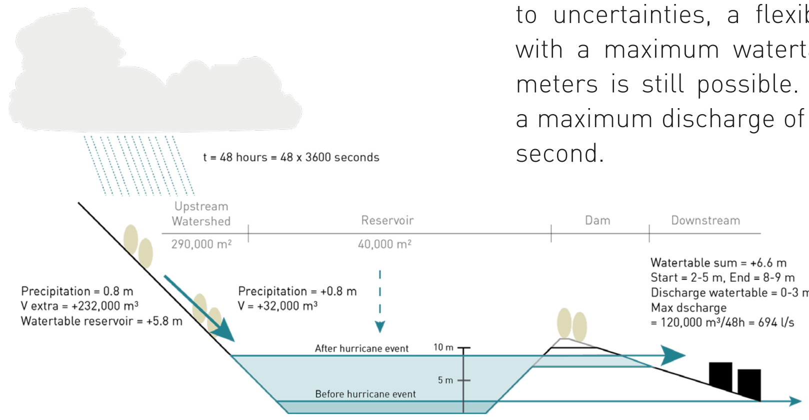



**Figure 146:** Reservoir section during a hurricane. There is an extreme amount of 800 millimeters of rain in 48 hours and significantly no evaporation during this period.

# 5.6.7 Location 1 Design: Quarry reservoir

The quarry reservoir design has two new reservoirs situated in three different quarries. The reservoir in the north is constructed based on previous calculations, while the reservoir in the south is planned for a later phase.
These reservoirs serve to connect urban ecology with the ecology of the nature reserve, while also facilitating a new recreational connection between the urban area and the mountain.
Furthermore, a large urban development area downstream offers the new sustainable housing for the people currently living in the quarries.

Figure 148: Example visuals of the new urban development area, provided with green roofs and white facades (Sources: Inhabitat, n.d. & Archiru, n.d.).




**Figure 147:** Spatial design location 1

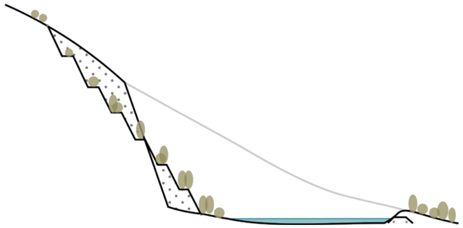


**Figure 149:** Section of the terraces. The limestone of the upper part of the clif is used for the down part and for the construction of the dam (inspired by R. Roggema, Tecnológico de Monterrey).

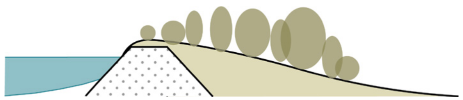


**Figure 150:** Secton of the Dam. The dam will be made of concrete. The ground covering the dam is made of limestone and organic material.

### Reservoir design
The reservoirs are the buffers for providing the streams with water throughout the year. They also protect the urban environment from floodings. They consist of a maximum depth of 10 meters and a minimum depth of 5 meters. The water is blocked by the steep slopes of the quarry and a dam facing the urban area. On the side of the urban area the dam is hidden underneath a gentle slope between 5 and 10 percent gradient (figure 150). This dam is made of extra excavated limestone which are the leftovers from making the reservoir deeper or making the terraces on the slope. On the dam, dirt and vegetation is placed in order to maintain a biodiverse area. On the southern reservoir, solar panels are placed. This has multiple advantages such as a new sustainable power source and it has a significant effect on keeping the reservoir from evaporating (Margolin, 2023). This decline of evaporation can provide more water during droughts or more tapwater extraction per month.

### The terraces
The terraces create a new gradient between the landscape downhill and on the slope (figure 149). The terraces will make sure that the steep slope of the old quarry is removed, whereby the risks of landslides will decline. Also, the gradient between the ecology of the nature reserve and the new forests on the foothills will be enhanced. These terraces will be constructed by extra excavation. The new limestone from the  mountain can be used for new infrastrcuture and a dam for the reservoir. The trees have to be planted manually and consists mostly of oaks since they are good in rooting through rocky soils. The rooting of the trees will enhance the stability of the rock, so that the risks of landslides reduce, especially during heavy rainfalls.

### The forest
The forests consist of oak forests and other type of trees which grow on the rocky Leptosols, which are present in this location. The trees growing here do not have to be watered and will be diverse. At the beginning, the trees are planted manually to give a boost for the ecological environment.

### Wind slopes
The foots of the mountain, which are created by excavating the quarries, will be used as wind slopes. Down these foots, the use of trees is reduced in order to create wind corridors in the direction of the city. Preferably, the corridors continue between the facades through the urban fabric. In that case, the streets directed to the slope, are able to cool off by the wind.

### New urban development area
In the new urban development area on the old industrial site, new residential appartment blocks and houses are built (figure 148). The people from the old informal settlements, which were located in the old quarries, can live here. In this area, two sidestreams of the Arroyo Topo Chico come together and can function as a waterpark between the new buildings. This waterpark can work best during the wettest month of September, or after intense rainfalls when the sluice gates are opened more. The buildings will also consist of green roofs for insulation and cool materials in order to reduce the heat stress as much as possible.

### Connection downstream
Following the sidestreams of the Arroyo Topo Chico downhill, the street where they flow are now turned into a much greener street with treelines and more ground covered vegetation.
The streets, which are allocated for the more natural streams, are determined by the GIS sources of Riesgos and SIATL, to make sure that the streams are following its preferred and original course as much as possible.
These streets along the streams are allocated to pedestrians, where cars can only cross them. These green streets along the streams are stretched to the linear park in the second design.

### Tapwater Extraction
The normal amount of tapwater use in Monterrey is on average 160-170 liters per day. But the World Health Organisation (WHO) recommends the use of 100 liters per day in order to mitigate water scarcity (Chacón, 2022). This is 36.5 m2 cubic meters per year per person.
In the tapwater extraction experiment, an annual amount of 40,000 cubic meters water is available. That means that the annual amount of residents that can be provided with water is (40.000 / 36.5) 1095.
That means that with the density of San Bernabé of 3523 residents per square kilometer, 0.31 square kilometer or 1.7 % of San Bernabé can be provided with tapwater.
To conclude, this reservoir of 4 hectares and its uphill watershed of 29 hectares can provide 1.7% of San Bernabé with water if the watertable of the reservoir is allowed to fall one meter per year for extraction.



**Figure 151:** Context map of design location 2
**GIS sources:** Monterrey government, Openstreetmap


Figure 152 Picture: Pieter van der Wel


Figure 153 Picture: Google Maps


Figure 154 Picture: Google Maps


Figure 155 Picture: Pieter van der Wel

## 5.7 Design Location 2

### 5.7.1 Context

The second design location's context is shown in the GIS map in figure 151. Here there is a wide street called Lic. Luis Echeverría Álvarez (Álvarez street), which is shown in figure 152. This street is around 25 meters in width with a road designated to cars with a width between 20 to 25 meters. The asphalt road is relatively wide because the street is build on top of the Arroyo Topo Chico storm drain (San Bernabé excursion comment, March 2nd 2024).
There is a high change of inundation during rainfall. Therefore, the houses are build 0.3 to 0.1 meter above the street profile to prevent them from flooding. There are also bridges crossing the street in order to bring people to the other side of the street during floods (San Bernabé excursion comment, March 2nd 2024). Currently, drains have been made in the road to bring the water on the street into the storm drain underneath.

In the context of the Álvarez street, more public facilities are present than in location 1. There is a primary school (figure 153) and a high school. There are multiple sport facilities and different kind of parks and plazas present in the area (figure 154). In the southwest, there is a metroline which goes into direction of the city center of Monterrey.

At the end of the Álvarez street in the southeast, it changes abruptly into a concrete storm drain (figure 155). This is the Arroyo Topo Chico flowing downstream to the Río Pesquería in the north of the MAM.

The soil structure in the area consists mostly of Phaeozem, which is a more humus rich soil layers and more organic material. In their natural state, they are covered with grasses and deciduous forest vegetation (Phaeozem, n.d.).

# 5.7.2 Location 2 Design: Linear Park

The Álvarez street is transformed into a linear park stretching from northwest to southeast following the course of the Arroyo Topo Chico. The park works as a connector between different functions in San Bernabé for the residents. Along this park the sidearms of the Arroyo Topo Chico enter where the main stream gets filled up with water. In this map, the new ecological mosaic or recreative grid is also clear consisting of the streams, green streets and new and bigger parks.


**Figure 156:** Spatial design location 2

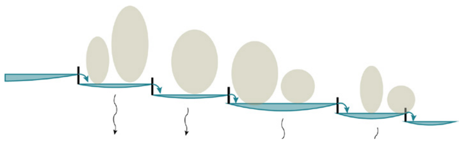


**Figure 157:** Section facing the facades. Weirs are palced in order to slow down the water and let the water infiltrate into the humus rich soil.

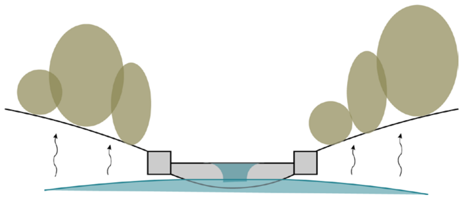


**Figure 158:** Section facing upstream. The saturated soil creates the opportunity for roots to take up te water.

## Park

In the new design, the Álvarez street is transformed into a new linear park. The park stretches from the church in the northwest to end of the street in the southeast. Hereby, pedestrian friendly connections are made between different kind of public functions. Also, ecological connections are made with different kind of trees, shrubs and grasses gathered from the plant catalogue. This way, biodiversity is strongly enhanced.

In this park, the storm drain underneath the old road is exposed to the atmosphere and transformed in a new stream. This stream will always flow with water controlled by the reservoirs upstream. Weirs are placed in the stream in order to retain the water (figure 157). As a result, water infiltrates better into the soil ready to be taken up by the roots from trees and other plants (figure 158).

Next to the new stream, there is space to walk, cycle and gather in order to enhance the social activities and therefore the qualty if the public space. In times of heatwaves, people can sit underneath the canopies of the tree to find shade or next to the stream to experience the cooling effects of water.

## Car free

The park will be car free. The cars can park on new build and organised parkinglots that consist of permeable pavement. These are located on the perpendicular and parrallel roads along the park. There are different crossings for cars over the park and the stream, but on the juctions, pedestrians and cyclist have priority in crossing.

## Grid

Surrounding the linear park, improved and enlarged existing parks are connected with each other with other green pedestrian roads and treelines, creating a new grid. This grid will make sure that the patches of green in the city are ecological connected awith the new corridors made of natural streams, green streets and tree lines.

**Figure 159** Picture: Google Maps

**Figure 160** Picture: Pieter van der Wel

**Figure 161** Picture: Google Maps

**Figure 162** Picture: Google Maps

## 5.8 Detailed Design

**Detailed park design**

A detailed design is necessary to show the quality on a local scale. Materialisation, experience and quality of public space will be clear with detailing. That includes the types of vegetation on specific placement. The detailed design applies for the linear park along the Arroyo Topo Chico. That means that the green and blue infrastructure principle of the wide street in figure 129 on page 69 will be amplified.

The detailed design consists of sections and a map. The sections show the differences in park types on different segments of the linear park. The map shows the coherence of these different sections together.

### 5.8.1 Current situation Álvarez street

**Drain and high-rised sidewalk**

The Álvarez street, which has been build on the storm drain, is lower in comparison to the sidewalk. This sidewalk is around 0.3 to 1 meters high and has been built in order to protect the houses from flooded streets (figure 159). The picture of figure 160 and drains in figure 161, hints the place of the location of the storm drain underneath the road.

**Water crossing bridge**

The bridges have been made in order to cross the road safely if the streets are flooded with water. These bridges can be reused for pedestrian crossings over the stream (figure 162).

**Facades**

The facades are facing southwest and northeast. The first facades have a higher prioirity for shade because they are facing the afternoon sun, which is the hottest.

**Current Street profile**

The current situation of the street profile is seen in the section in figure 163, facing the northwest (upstream). This example of the current situation shows the road which has a width of 23 meters. The sidewalks are between one and two meters wide. Under the right side, a storm drain is located.

The water that flows through the street takes the space between the sidewalks and the space in the storm drain. This together is surface area of approximately 20 square meters. So in the new section design, the same area can be used in order to create a safe environment during floods.

**New intervention**

The most important intervention is about putting out all asphalt and concrete and implementing pavement only where needed. New sidewalks on both sides with a width of three meters will make better connections for pedestrians and for cyclists there will be a lane of two meters in width. On these lanes and in front of the southern facades, the most shadow and thus tree canopy is needed. For the new design interventions, variants can be made by the stream having different positions in the new linear park.

### 5.8.2 Section Design

**Daylighting the storm drain**

In the new section design in figure 164, the storm drain located underneath the road, is 'daylighted' and so exposed to

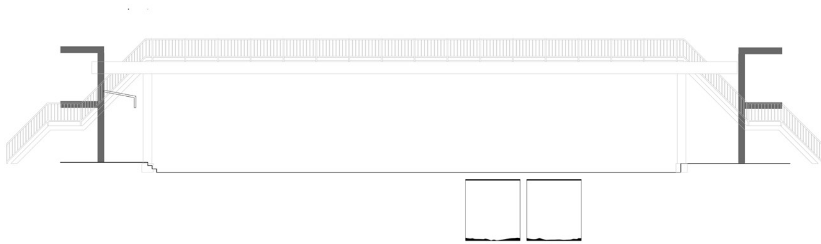
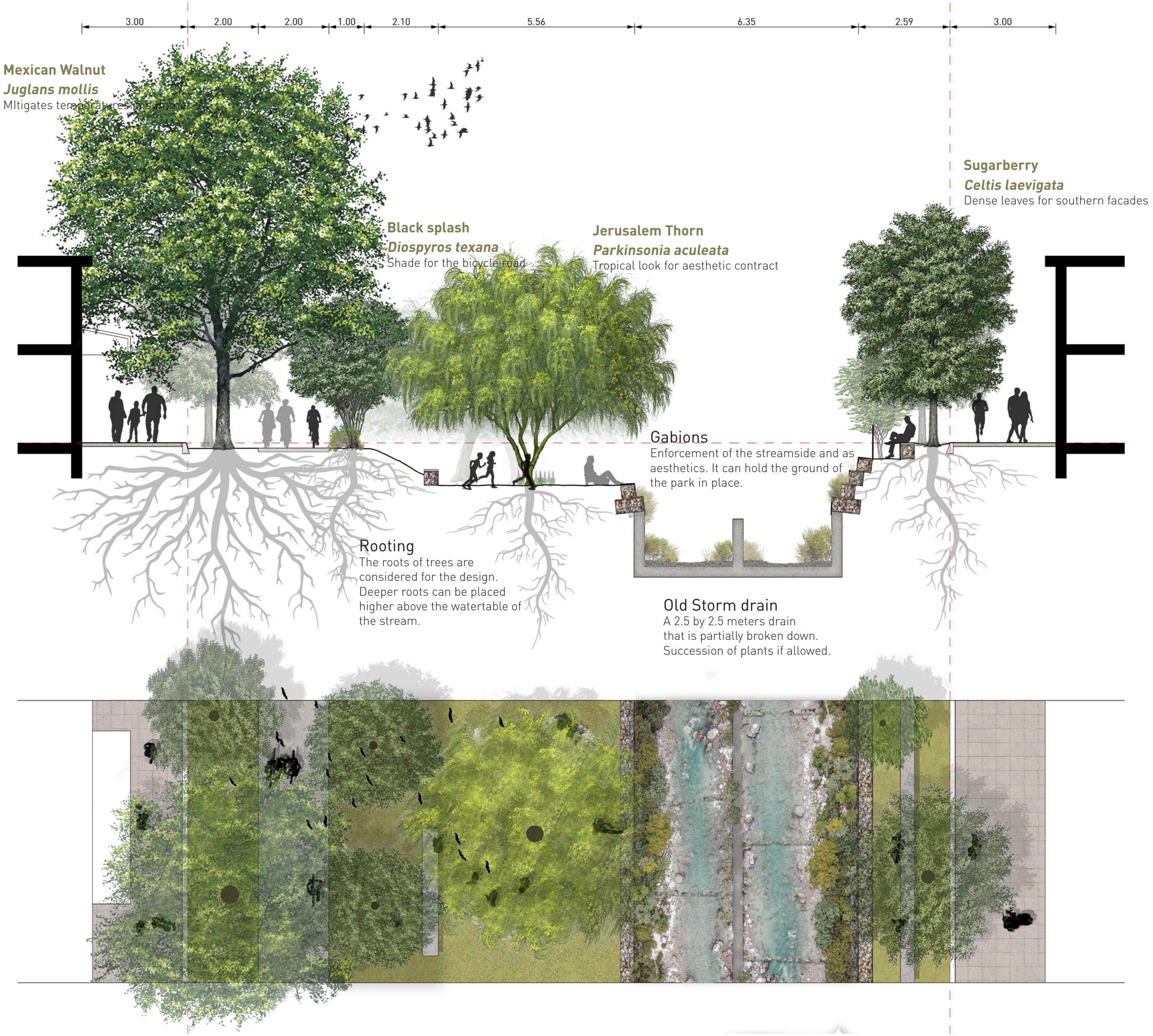


**Figure 163:** Street profile of the current situation facing the northwest (upstream). The underground storm drain is located on the right side of the street.

the atmosphere. By this intervention, minimal changes are used to create a green connector.
In this variant, the storm drain is still in use to let the water flow through the park. It is allowed for shrubs to grow in the storm drain.
Two sidewalks with a width of three meters are used at every side of the road. Furthermore a bicycle road of two meters in width is placed on the southern side of the stream.

**Vegetation**
In this section, the facades on the right receives the most amount of sunlight. A Sugarberry, for example, is always green and can block the sunlgiht throughout the year by placing it in front of the facade. With its deep rooting, it can be placed on the highest spots of the street profile without extra water requirements.

**Materialisation and recycling**
The asphalt of the old road can be used for other infrastructure in the city of Monterrey. The concrete, which is taken out of the old storm drain, is used to make new gabions. These gabions can hold the force of the water and can also serve as benches with a concrete slap on top as the seating. These benches are inspired by the students from P.D. Pacheco-Vásquez, Tecnológico de Monterrey.



## 5.8.3 Section Design variants

**Stream on the left: Tribune**

In the section design in figure 165, a variant of the stream on the left side of the linear park is shown. Here people can gather, meet and sit along the stream. On the other side, there is still felxible space for other activites. Stairs can be used to walk to the lower side of the streambed. Next to the stream a willow can be places because of the existence of flowing water.

**Stream on the left: Wide park**

In the section design in figure 166, the stream, together with the bicycle road is placed to the left side as much as possible to provide a wide flexible space of the right side. In this case, groups of mezquites can be placed in order to create easthetic and half shaded environments. The trees also function for soil regeneration and the draw of native birds. Benches can differ in placement over this area.

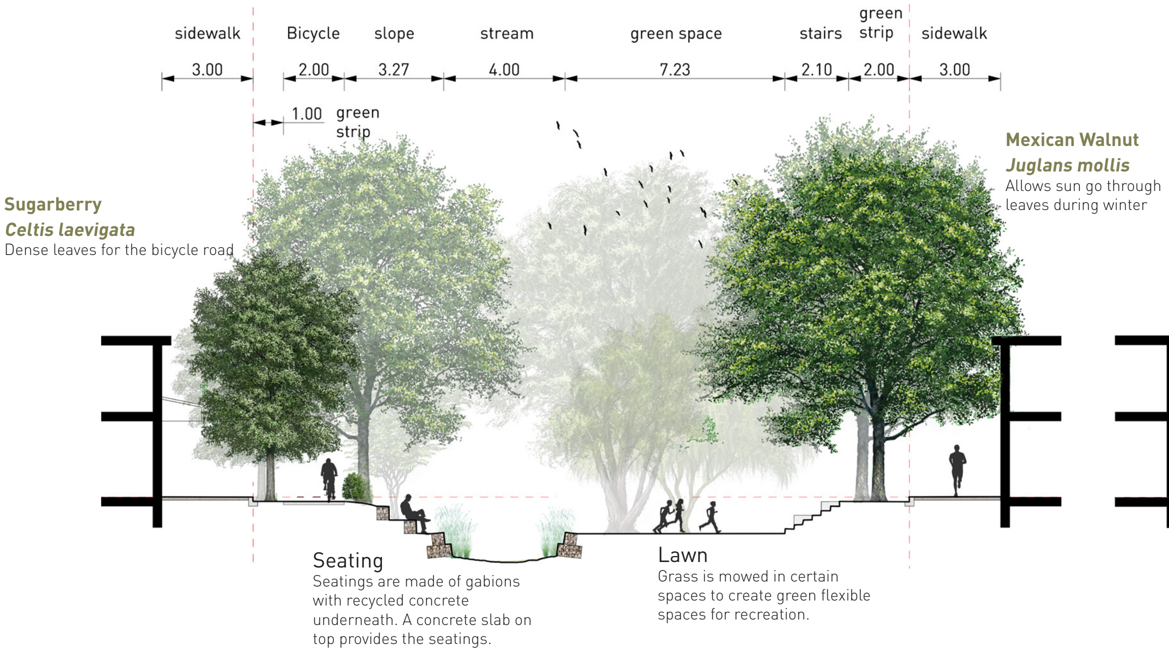



**Figure 165:** Section design of the Álvarez street turned into a flexibal space with a tribune and stream located on the left side.

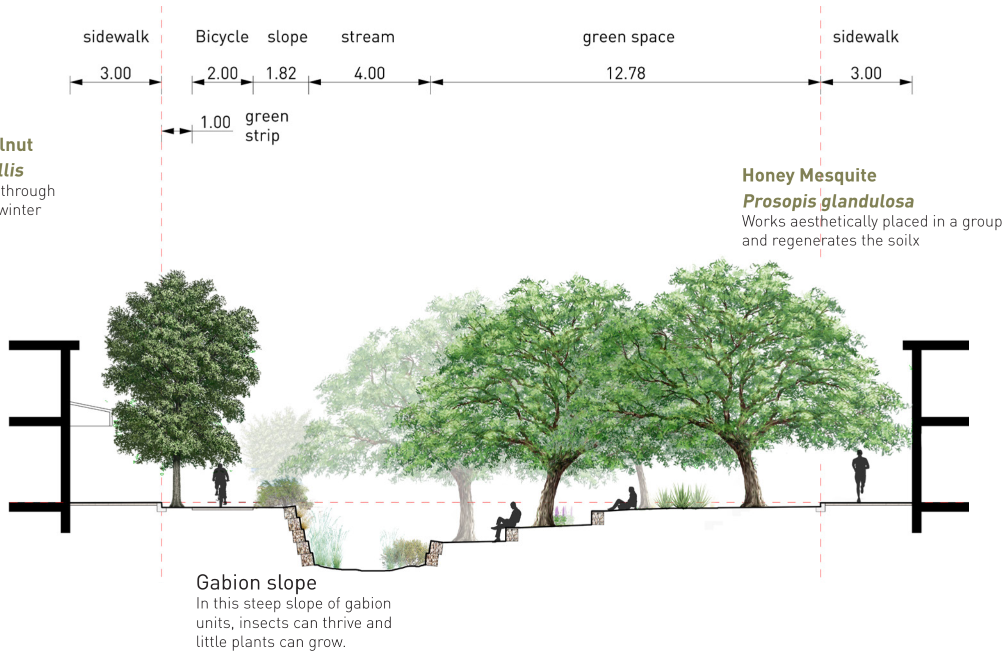



**Figure 166:** Section design of the Álvarez street transformed into a wide linear park with the stream located on the left side.

**Stream in the middle: Natural**

In the section design in figure 167, the stream is located in the middle of linear park. In this case the stream can be as natural as possible on both sides. In this case, people are not able to enter to the stream which gives the possibility for animal species to thrive between the plants.

**Stream in the middle: Garden**

In this section design in figure 168, the stream is again placed in the middle and enforced with gabions along its side to make a easthetic view over the stream. In this garden approach, more maintenance can be done and flowered bushes and natural grasses can be placed.

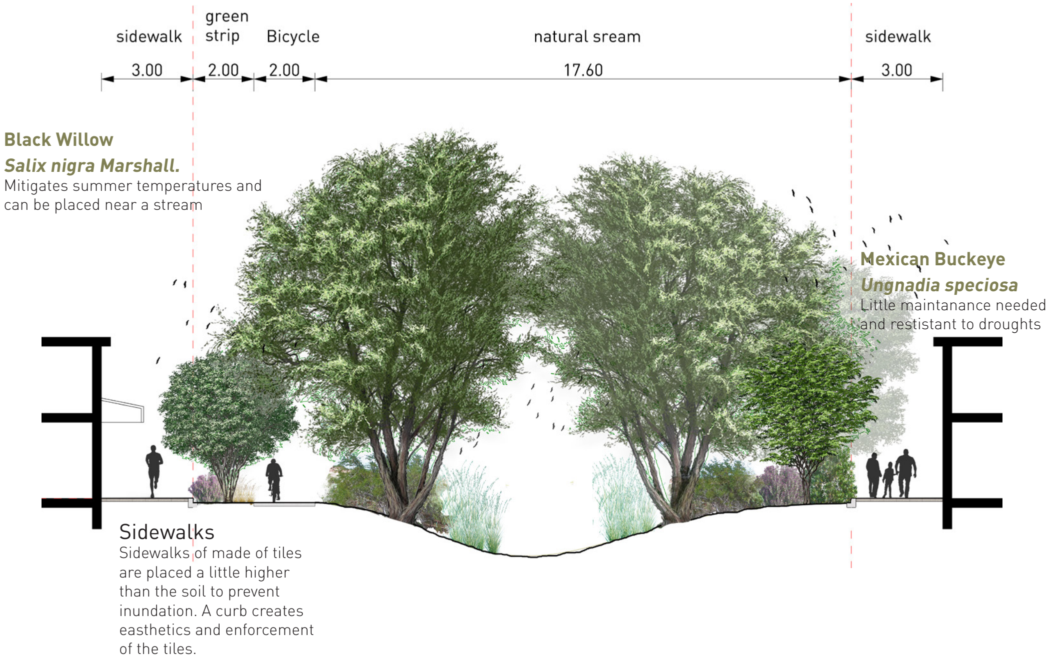



**Figure 167:** Section design of the Álvarez street transformed into a natural stream

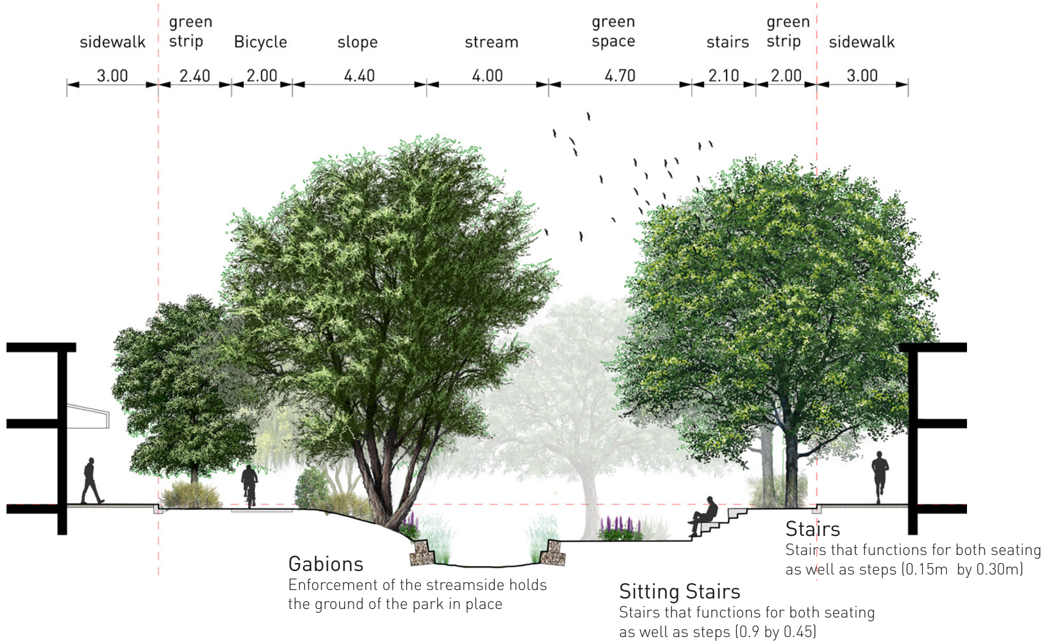



**Figure 168:** Sectiond design of the Álvarez street transformed into a garden

## 5.8.4 Section Design phasing

The sections which are shown on the previous pages, show an ideal situation after a minimum of 25 years. This is because the trees have grown into their adult state. In this case, they can provide most if their ability to mitigate heat stress and ability to uptake water for their roots on their own. But in order to design with time, different stages are proposed to work with. Those are 10 years, 25 years and 50 years into the future.

**10 years**

In then years, The linear park is in its young state. Trees are young but storm drain is already daylighted in order to transform the asphalt and concrete into a natural area, which helps mitigating the heat stress levels significantly (figure 169).

**25 years**

After 25 years, trees get into the adult state and start to look like the ideal situation. It is possible that the canopy has not covered most of the street profile yet (figure 170).

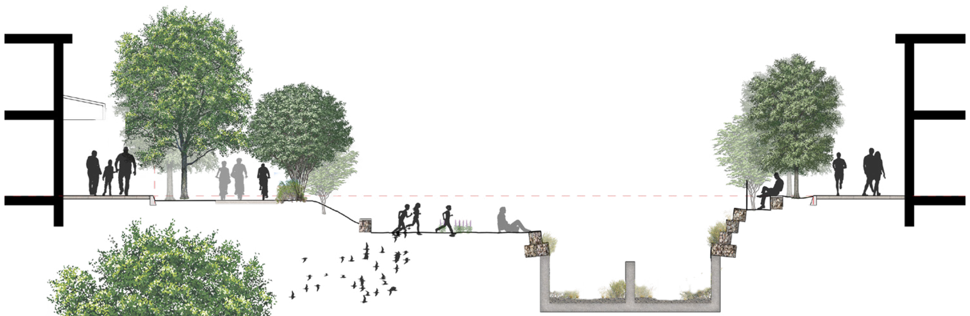
**50 years**

In the year 2074,  years trees are fully grown. It is likely that the trees have covered the whole street with canopy.

It is possible that shrubs and grasses have passed a few generations, but are planted again if necessary.

In this year, it is assumed that more heat waves and longer droughts are possible due to climate change. But due to the adaptation with these types of green and blue infrastructure, heat stress is mitigated and water is accessible for flora, fauna and the residents (figure 171).

**Figure 169:** Section design of the daylighted storm drain in the first ten years



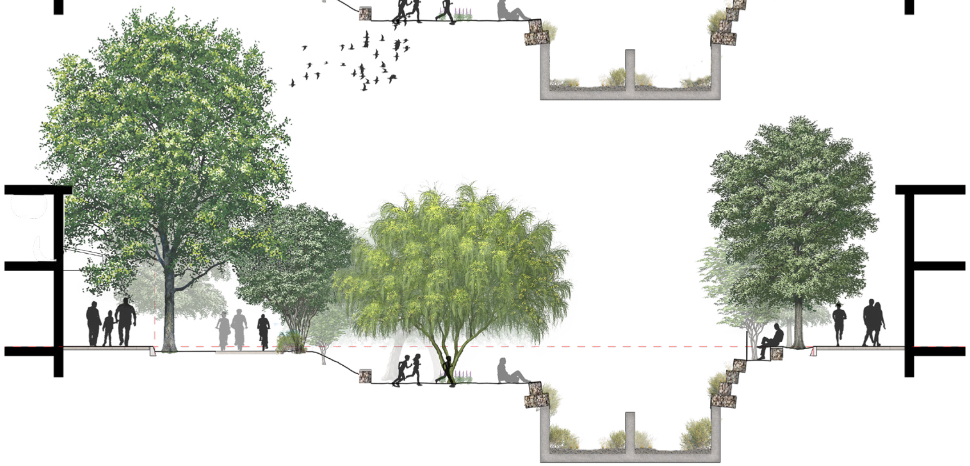


**Figure 170:** Section design of the daylighted storm drain after 25 years

**Figure 171:** Section design of the daylighted storm drain after 50 years

## 5.8.5 Detailed Map

This detailed plan shows the situation in and around the linear park on the southern part. This place in particular shows the old place from the Álvarez street continuing into the old storm drain. The new park is car free. The parkinglots are more ordened and new parkingspaces are made in the sidestreets around the linear park. These parkinglots are permeable, so water can infiltrate into the soil of the parkinglots.
Also, different kind of tree species are shown in the map.
In this map, the different placements between the sections is also shown. It shows the spatial shift between the sections.


**Figure 172:** Detailed map of the southern location of the linear park

## 5.8.6 Function Map

This function map shows the impact on the facilities in and around the Linear park.
Functions such as bars, little shops and supermarkets can stay. It is recommended for an auto repairshop to move to a vacancy place nearby its current location where cars are able to access.

Parkinglots are more organized than before. They are repeated with a tree in between stretching a pattern of 6 meters in lenght and 2 meters in width. These parkingstrips are placed along the most southern facades of the building blocks. The numbers in this map show the amount of parkingspaces available on that strip. For this area the parking number is estimated for 0.9 cars per household.

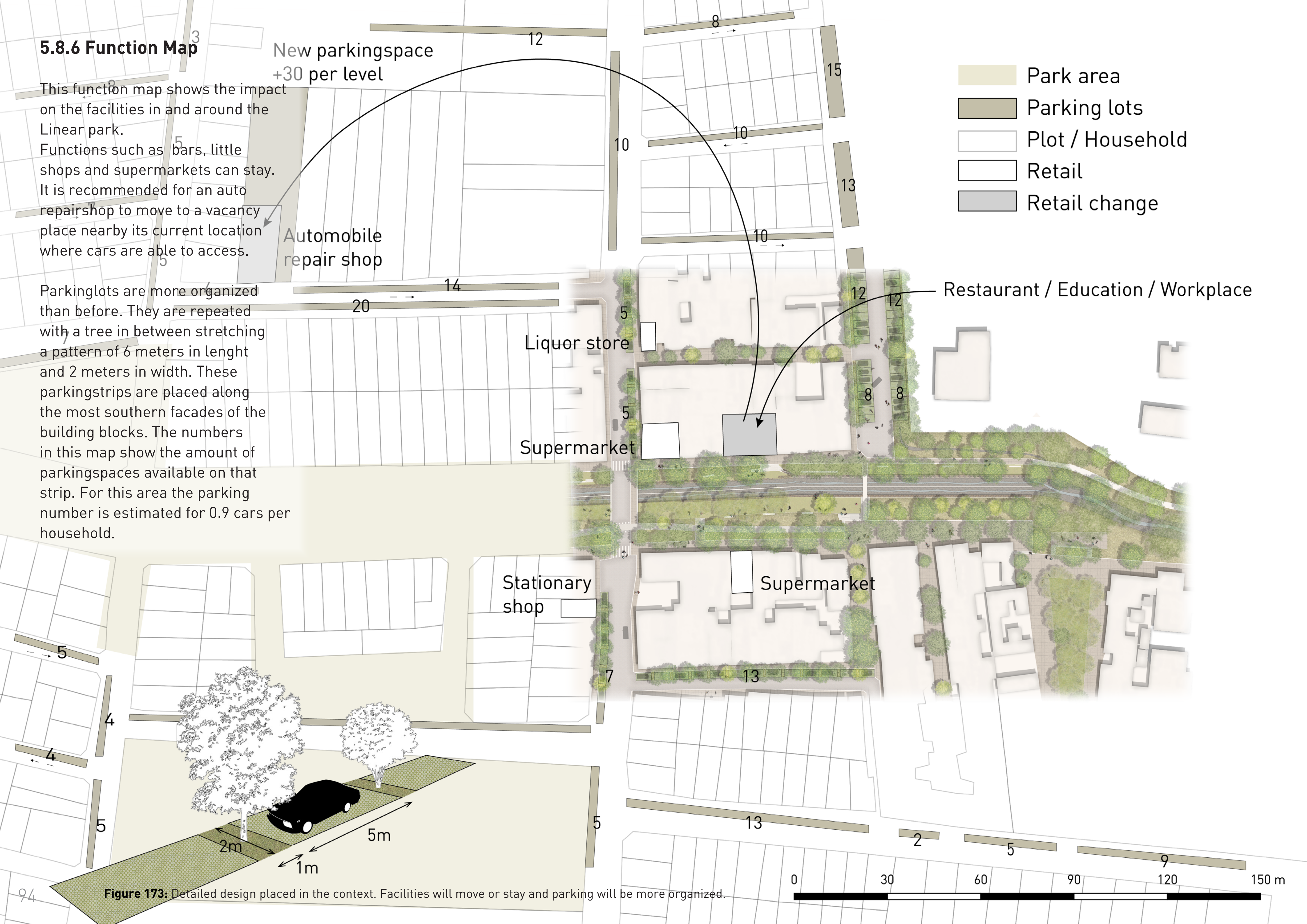



**Figure 173:** Detailed design placed in the context. Facilities will move or stay and parking will be more organized.

## 5.9 Phasing

In the following three maps of location 1 and 2 combined, shows the spatial design phases over 10 years, 25 years, and 50 years. Because the interaction between the upstream reservoir and the downstream linear park is highly interconnected, the phasing program is applied to both design locations simultaneously.


**Figure 174:** Phase of both location designs after ten years

### 5.9.1 First phase: 10 years

This map shows the phasing program over 10 years. The calculated reservoir is constructed, and the first part of the linear park is developed on the southern part of Álvarez Street. Residents of the informal settlements, who used to live in the area of the new reservoir, can already move to the new sustainable dwellings in the new designated urban design area.

The linear park currently only consists of the storm drain variant due to the potential for hurricanes and the implementation of only one reservoir in the UATC watershed. Consequently, the water discharge can still be very high, requiring the old storm drain to remain functional. However, the side parts of the storm drain downstream can be removed.

**Figure 175:** Phase of both location designs after 25 years

## 5.9.2 Second phase: 25 years

This map shows the situation in 25 years. By this time, all the upstream reservoirs are constructed to control the water flow both upstream and downstream. Consequently, the linear park can be completed with other variants of the section design. The other variants do not need a deeper storm drain to discharge the water.
The water table of the stream in the new section variants is higher in elevation than the water table in the old section. This results in a aesthetic waterfall being placed in the middle of the park where the two variants meet.

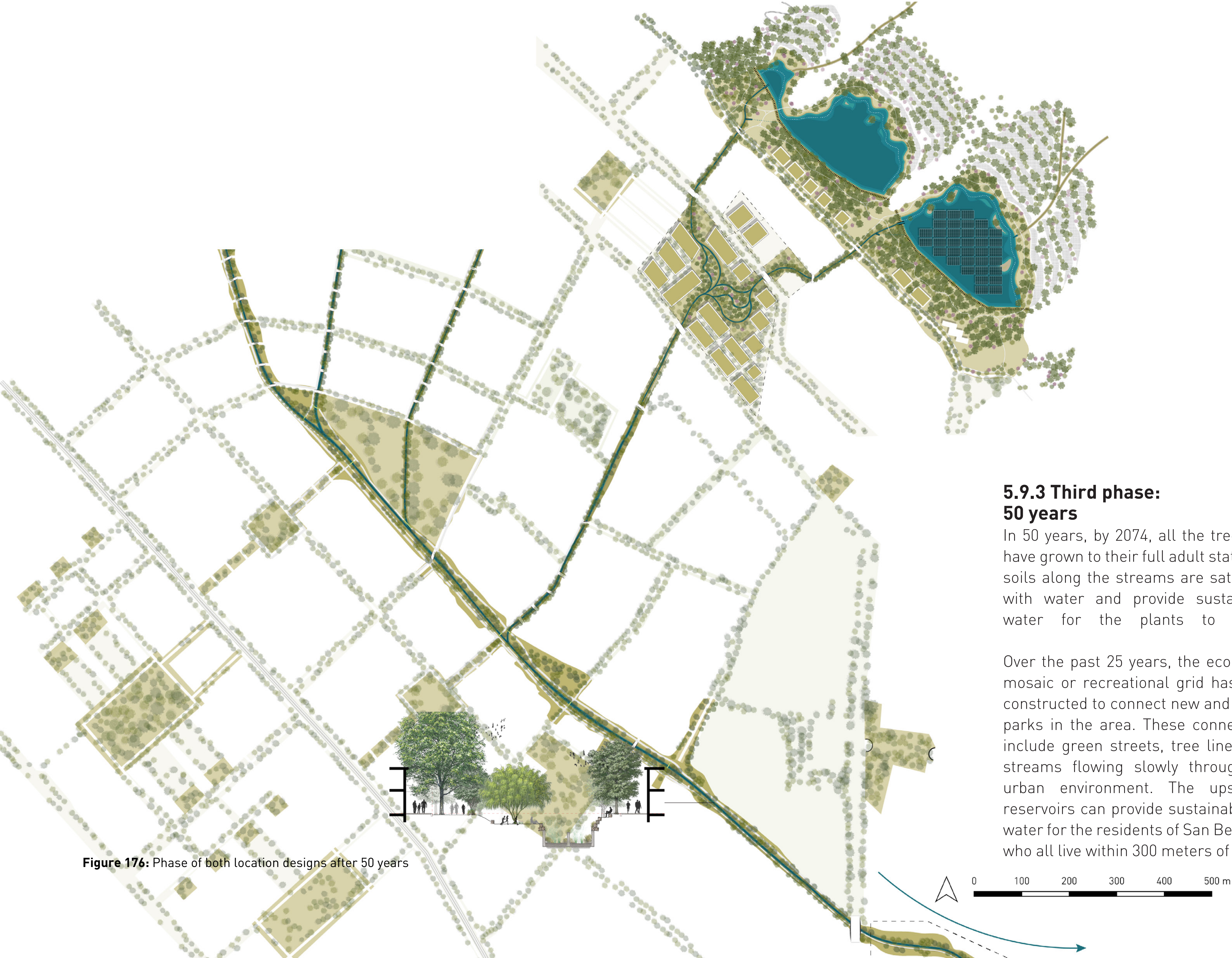



Figure 176: Phase of both location designs after 50 years

## 5.9.3 Third phase: 50 years

In 50 years, by 2074, all the trees will have grown to their full adult state. The soils along the streams are saturated with water and provide sustainable water for the plants to thrive.

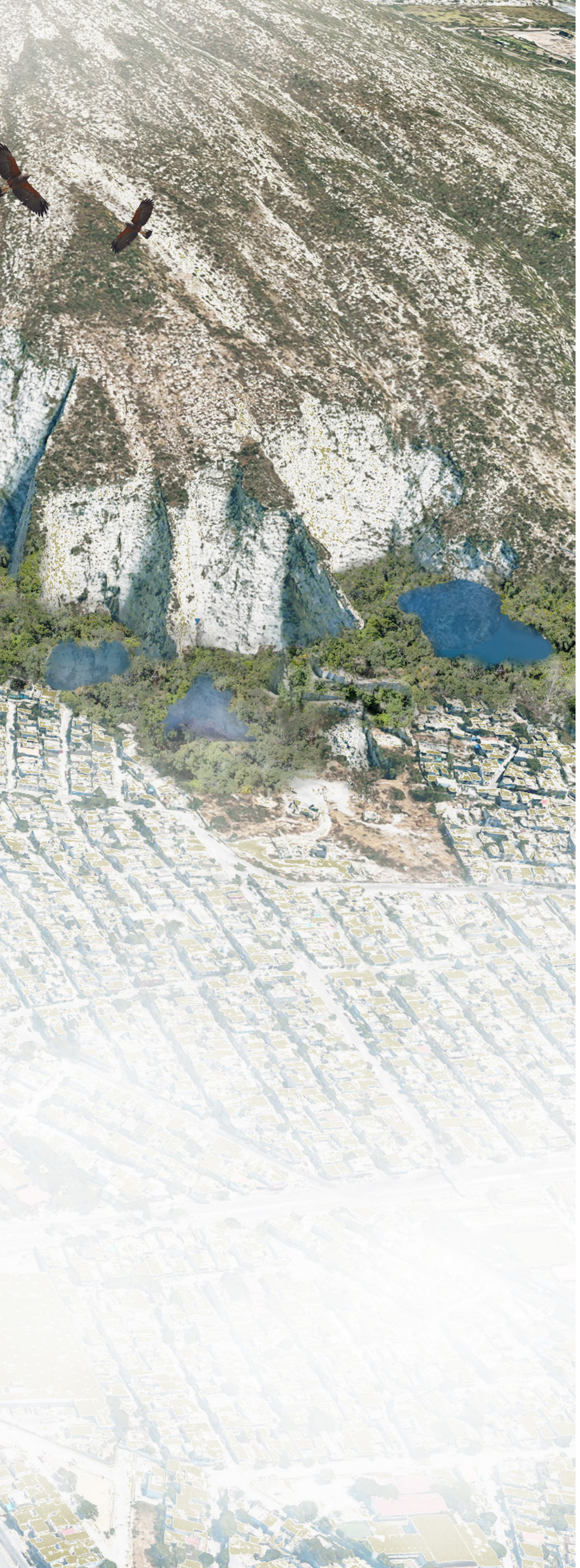
Over the past 25 years, the ecological mosaic or recreational grid has been constructed to connect new and larger parks in the area. These connections include green streets, tree lines, and streams flowing slowly through the urban environment. The upstream reservoirs can provide sustainable tap water for the residents of San Bernabé, who all live within 300 meters of parks.

## 5.10 Walkthrough Impressions

### 5.10.1 Birdeye

In this bird's-eye view, the watershed is seen from a southern perspective in the direction of the Topo Chico mountain. The discharge of water downstream is dependent on the water control in the reservoirs upstream. The following eye-level impressions show the future experience after the design


**Figure 177:** Birdeye view of the design in the southtern part of San Bernabé



## 5.10.2 Quarry Reservoir

**Figure 178:** Impression of the quarry reservoir design

## 5.10.3 Green street

**Figure 179:** Impression of a green street design

## 5.10.4 Lineair Park

**Figure 180:** Impression of the linear park design

## 5.10.2 Arroyo Topo Chico

**Figure 181:** Impression of the daylighted storm drain design on the Arroyo Topo Chico

# 6 Conclusions and Discussions

## 6.1 Conclusion

The research question for this thesis is: **“What spatial strategy can be used to implement green and blue infrastructure in order to tackle droughts and heat stress in the metropolitan area of Monterrey?”** This question is divided into sub-questions that are addressed throughout the research and design project. The answers to these sub-questions contribute to answering the main research question.

Starting with the research for design phase, the first subquestion will be answered: "**What are the (natural) systems of the landscape in and around the Metropolitan area?"**
The first step is to analyze the metropolitan area to map the issues of drought and heat stress in Monterrey. To guide this research into possible design principles, an integrated approach is proposed that begins with analyzing the area's natural systems, including terrain, water structures, soil, vegetation, and ecosystems. Subsequently, landscape and ecological design principles are developed which supports the upcoming design principles for mitigating droughts and heat stress.

New design principles will be made from analysing the systems of heat stress and droughts in the MAM.
The following subquestion will be answered: **"What are the design principles translated from the analysis?"**
The causes and solutions of heat stress are examined and documented. The hydrological cycle is analyzed and mapped to identify the unsustainable defects in the system.
These documentation and system flaws leads to other sustainable solutions and new design principles. For mitigating heat stress, existing solutions, based on literature are used. To make a sustainable hydrological design, the storage and retention of water is considered.
The new design principles are made with the perspective in mitigating heat stress and tackle drought with its foundation in landscape and ecology and nature based solutions.

The resulted design principles have their own spatial characteristics which have their ability to change the metropolitan system. The following subquestion is: '**How are the design principles implemented in the metropolitan area leading to the new metropolitan vision?"**
Firstly, the design principles of restoring the ecology and waterstructure are the main principles and the basis for a greener metropolitan area. Generally, they create the overarching approach of a greener and sustainable metropolitan area.
Some design principles, such as nature based solutions for buildings and collecting water in new watertanks can theoretically be implemented everywhere. Nevertheless, most design principles are only suitable for certain places in the MAM. The use of wind slopes can only be executed at slopes and the use of wind corridors only in dominant wind directed streets.
For the selection of other design principles such as transforming landuse, the 300 meter rule is tested on the metropolitan scale of Monterrey. Hereby, design principles of mitigating heat stress are tested in Monterrey by using processing tools in GIS. The result shows the possible outcomes of a greener MAM with a grid with bigger and more parks and nature reserves, connected by accessible rivers, streams and green streets with treelines. This new map eventually leads to the first metropolitan vision concept.

In this vision concept, the system changes of the hydrological cycle are added. That means, emphasizing the implementation of new reservoirs on the foothills of the mountains, and showing the retention water by natural streams and rivers.

In this vision, it is explained that every citizen has equal access to water and lives closer than 300 meter from a green space.

For using a spatial strategy on a certain location in the metropolitan vision. A design location has to be chosen. The following subquestion is: "**What strategy is used for designating the design location?"**
The design area will focus on a critical residential area in Monterrey. This critical area is chosen based on the level of poverty and heat stress compared to the rest of the metropolitan area. Because poor residents have the least access to tap water during droughts and relatively less cooling options during heatwaves, which impacts their quality of life the most.
The designated location for the new spatial design is the district of San Bernabé. This district faces issues related to water structures, such as the concrete cased Arroyo Topo Chico and it contains landslide risks and inundation zones. Furthermore, 66% of the area does not apply the 300 meter rule and nowadays there is only 3.1 square meters of green space per resident present.

Implementing the design principles as green and blue infrastructure in San Bernabé, needs a strategy. So the last subquestion is: "**What strategies are**

**used to implement green and blue infrastructure into a spatial design?"**
The strategy to implement green and blue infrastructure in district San Bernabé involves using the underlying watershed as the design foundation. By leveraging this watershed, both water storage and retention are considered to provide sustainable water management accessiblity for the people and the environment. Therefore, two design locations are made for storage and retention.

Six new green and blue infrastructure principles are made by the new design for San Bernabé to further amplify and elaborate in the location designs and spatial designs.

Three principles are made upstream. First, on slope, where the water starts running of, the area will be accessibile and preserved for enhancing the ecology on the mountain Topo Chico.
Downhill, water storage and collection will occur, where quality water is both used for a continuous discharge and extraction. A dam can be constructed to retain this water, suitable for high-intensity rainfalls, and the resulting lake can supply tap water to a significant number of people.
In the case of a quarry, present in the design area, the new reservoir is constructed in this place and terraces are excavated to prevent landslides and create an ecological gradient to the mountains. The excavation provides extra material for new infrastructure or the new dam, holding the reservoir in its place.

Downstream, three principles are made based on the water flowing in different urban environments. Water flowing through a small street will transform into a green street. Water flowing through a big street will transofrm into a linear park and the storm drains will be daylighted by removing the concrete, whereby vegetation will be implemented.

A plant catalogue will guide the practical implementation of vegetation in the design at the local scale. This ensures carefully selected vegetation that supports water retention, temperature regulation, architecture, and biodiversity.

It is crucial to analyse the urban context as interventions in the urban fabric lead to other changes.
For instance, for implementing the new reservoirs, the residents of informal settlements will move to another location which will be more sustainable with improved dwellings consisting of insulation, green roofs and more green space.
The new linear park along the Álvarez street, requires more orderly parking spots around the park to ensure parking spaces for current residents, given the city's car dependency. Additionally, pedestrian-friendly, green streets connected to parks along main streams creates safe and comfortable pathways to other city functions such as schools, churches, and sports facilities.

The new design offers a redesigned grid of green spaces and connections, ensuring an increase in the amount of green space per resident and every resident lives within 300 meters of a green space. Moreover, with the presence of reservoirs, there are also possibilities to tap water for residents during severe droughts in the future.

This design creates the beginning of a new metropolitan area that can cope with the increasing environmental impacts in the future.

## 6.2 Discussion

### 6.2.1 Used approaches

I utilized three main approaches to make my design effective: the Patches and Corridors from Forman (2006) approach and the use hydrological system of the watershed as a baselayer for the design. Also the 300 meter rule is used to measure the amount of green area which is present and can be transformed for greening the city.

The ecological approach aims to create a stronger ecological environment. This approach can go together with the approach of the 300 meter rule. Therefore, objections of an ecological mosaic or recreational grid is made to visualize a greener metropolitan area.
However, integrating this 300 meter rule approach into an urban area which is as dense as San Bernabé is very complex due to the lack of existing green spaces. Using this approach for every place in the area, buildings may be demolished in the ideal situation. This could be done with the informal settlements, because there are build off the regulations of the government. Nevertheles, every type of demolishment makes controversy among the concerned stakeholders.

## 6.2.2 Further research

Due to time limits and the possibility to make accurately research, further research is possible on different aspects.

**Hydrological system**

Using the hydrologic system as an approach, will bring more civil engineering into the design, such as making dams and making more precise space for the water.

This is because of safety measures during intense rainfalls, but also implementing this in the urban fabric is also very complex due to the dense urban environment. Especially if the course of the streams are currently using the same infrastructure as the cars.

Also, an ingtegrated topographic rsearch is possible to calculate flow rates through the UATC watershed.

**Urban Design**

To make this design applicable, more urban design research is recommended. There could be more factors and stakeholders in the urban field that can be analysed for implementing the green and blue infrastructure principles.

Furthermore, in the new sustainable urban development field, where the residents of the informal settlements are offered moving to, can be designed by urbanists.

**Reservoir design**

The reservoir design can be researched into further detail. Leptosol is present underneath the reservoir but it is possible that infiltration could happen due to the long time perspective.

To empty the reservoir, water can go into pipelines for other purposes like flowing in other storage tanks for irrigation or storing tapwater. Therefore, other options could be considered than only discharge the water downstream.

**Calculations**

The monthly evaporation rates in Monterrey will be different, if they are carefully measured instead of determined by the used approach.

Additionally, in reality, both the amount of evaporation and precipitation vary throughout the year due to weather events, especially in Monterrey, given its location between different climatic zones.

Furthermore, weather conditions are expected to become more extreme in the future due to climate change. Higher precipitation levels and less evaporation may result in more evaporation than precipitation throughout the year, potentially leading to water shortages.

However, the reservoir can handle longer periods of drought and extreme rainfall, as it functions as a buffer to regulate the water table and discharge downstream

**Tapwater extraction**

During dry periods, it is likely that residents need mroe tapwater. In that cade it could be considered to extract more tapwater from the reservoir than usual.

**Soil infiltration**

Trees take up a siginificant amount of water. If groundwater extraction is considered over a longer term, it could be researched wether it is possible to 'share' the groundwatater with the new growing trees in the area.

Also, even if the discharge from the reservoir is calculated accurately, the water does infiltrate into the soil along its streambed, which means that it can take a long time in the for the water to flow on the way.

## 6.2.3 Bigger perspective

Hydrate Monterrey means the imperative to hydrate the people of Monterrey. It is about giving the poeple in Monterrey an opportunity to provide them of thermal comfortable places and give them improved access to water.

In the MAM, there are more places which are similar with the circumstances of the design location. So, the strategies can be copied to nearby urban areas.

There could also be places in the world which has the same environmental problems the metropolitan area of Monterrey is facing. These areas can use the same strategy as Monterrey. A landscape based strategy in order to make a spatial design which tackles the same environmental problems as in Monterrey like droughts and heatstress. These areas can be located in semi-arid environments where water is scarce and heat stress is and will become more present in the future. Certain locations for potential strategy use are Mexico-City (Mexico), Los-Angelos (United States)or Santiago (Chile).

# 7 Reflection

### 7.1 Approach results

The approach of creating an ecological mosaic establishes conditions for species to migrate from green patches to other areas. This thesis primarily creates conditions for species currently inhabiting the ecological environment of the MAM. It has not specifically researched which animal species actually migrate. However, the ecological mosaic creates conditions where native species can thrive.

The approach of using the 300-meter rule for green spaces has helped me understand which design principles mitigate heat stress by implementing more green spaces. Mapping this also shows where it is possible to choose certain design locations. It can also be used to assess whether the approaches have worked after the design implementation.

My approach of utilizing the underlying landscape to implement green and blue infrastructure has been successful in spatial design. The streams present in the area determine the locations for the implementation of new (linear) parks in the urban fabric.
It also works due to fortunate circumstances. The reservoirs are located in places where informal settlements are present. These types of housing developments are easier to replace than typical housing. Additionally, the width and relatively quiet Álvarez street have provided the opportunity to implement a linear park, making it feasible to efficiently claim an urban area that complies with the 300-meter rule.

### 7.2 What could be better

The time for the thesis is limited, which affects the amount of research for design and the level of detail and quality of the spatial design itself. More analysis could be conducted on several aspects.

**Urban design**

First, the design is based on the existing urban landscape of its specific location, making it unique to that area. For other locations, the created strategies can be implemented, but a new system must be established as the foundation of the spatial design. This thesis reflects on both the research and design.

**Hydrological system**

Designing with hydrological systems requires calculations. More aspects could be calculated. Only one watershed is considered in this thesis. Therefore, a comprehensive topographic study needs to be conducted.

**Feedback**

I have used feedback from mentors to improve the project and its quality, particularly regarding the explanation of systems, the relevance and quality of maps, pictures, and symbols, presentation techniques, and the significance of my design implementation. I also learned from scaling down from a metropolitan scale to a smaller scale.

### 7.3 Learning

From my work, I learned that landscape architecture in an urban environment involves multiple aspects, including various types of streetscapes and limited opportunities to alter public spaces. I learned that landscape architecture intersects with many fields in the built environment and collaborates with them, such as urban design and civil engineering. Civil engineering is relevant because it involves working with water and holding it at its place.

### 7.4 Landscape Architecture and Urban Ecology

The relationship between this topic and landscape architecture is the approach of using the landscape to implement green and blue infrastructure. The underlying watershed is considered in the design process. In landscape architecture, it is crucial to utilize the landscape to improve the surrounding area.

The lab is Urban Ecology or Urban Ecology Design. The relation of this topic to urban ecology is its ability to enhance the ecological environment in Monterrey. Monterrey struggles with isolated nature reserves and a lack of green areas with vegetation. By creating new vegetative connections, ecology will be enhanced because more conditions are established for species to thrive in the city. Additionally, landscape design principles are used to enhance the ecology, leading to urban ecology design implementations.
Improving the landscape and ecology through a spatial strategy, my thesis will address the themes of droughts and heat stress, introducing new components to urban ecology design.

### 7.5 Changing approach within the field of Landscape Architecture

In the field of landscape architecture, it is important to pick up approaches that promote climate resilience, enhance biodiversity, and improve the quality of life for people, especially in cities. Civil engineering can be included if needed. To provide spaces with quality architecture, the underlying layers and systems should be analyzed. The focus is more on systemic solutions rather than the spatial quality itself.

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# 9 Appendix

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | **Sep** | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15 | 15 | 20 | 30 | 50 | 70 | 45 | 80 | **150** | 75 | 25 | 15 | 590 |
| % | 2.5 | 2.5 | 3.4 | 5.1 | 8.5 | 11.9 | 7.6 | 13.6 | **25** | 12.7 | 4.2 | 2.5 | 100 |

**Table 1:** Mean precipitation per month and the monthly percentage. Retrieved and modified from ClimatesToTravel (n.d.).

| | Jan | Feb | Mar | Apr | May | **Jun** | **Jul** | **Aug** | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 15.6 | 18.2 | 21.4 | 24.6 | 27.1 | **29.1** | **29.3** | **29.4** | 26.8 | 23.5 | 19.1 | 15.8 | 23.3 |
| +/- | -7.7 | -5.1 | -1.9 | +1.3 | +3.8 | **+5.8** | **+6.0** | **+6.1** | +3.5 | +0.2 | -4.1 | -7.5 | 0 |

**Table 2:** Mean temperature per month and the amount of higher or lower degrees celcius per month compared to the yearly average. Retrieved and modified from ClimatesToTravel (n.d.).

| | Jan | Feb | Mar | Apr | May | Jun | **Jul** | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 140 | 155 | 195 | 195 | 190 | 205 | **250** | 240 | 200 | 170 | 165 | 135 | 2240 |
| % | 6.3 | 6.9 | 8.7 | 8.7 | 8.5 | 9.1 | **11.1** | 10.7 | 8.9 | 7.6 | 7.4 | 6.0 | 100 |

**Table 3:** Amount of Sunny hours per month and the monthly percentage per year. Retrieved and modified from ClimatesToTravel (n.d.).