WATERING THE SEMIARID

DESIGNING A WETNESS RETENTION LANDSCAPE IN JAGUARIBARA, BRAZIL

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Typical creek at Caatinga in dry (left) and rainy season (right).

Source: Available at professorcaninderocha.blogspot.com Accessed in December, 2019.

Preface

I was born and raised on the coast, listening to the impressive stories told by my mother and her family, who came from a remote village in the Brazilian semiarid. Stories of when they lacked not only water, but everything that vanishes from the land when the water evaporates and the rain does not come.

What fascinated me most about these stories was the perception of a people, lacking education and resources, but immensely rich in practical knowledge and resilience. A people that has historically been forgotten by public policies and that should be heard; not only as social compensation, but because I believe that their wisdom can bring great contributions to studies on climate change, when combined with scientific knowledge.

Thereby, I hope to contribute to the dissemination of this knowledge, designing a wetness retention landscape by hearing their voices.

Dog and raft on dry bed of the Jaguaribe river, Ceará, Brazil.
Source: tribunadoceara.com.br.
Accessed in December, 2019.

On the left: Rangeland in Jaguaribara city,
Ceará state, Brazil.
Source: Google Street View (2020).

ABSTRACT

Since the earliest records, the Brazilian semiarid, in the northeast of the country, has suffered from water scarcity and recurrent droughts. To mitigate the effects of high variability and low availability of water in the region, governments have been investing, since the 1960s, in the construction of dams to stop the loss of water to the ocean, and water channels, to quickly distribute the stored water to places of greatest demand. Of the 10 states in the Brazilian seminary, the one with the largest amount of waterworks is ***Ceará***, where the largest reservoir in Latin America is also found, ***Castanhão***, built in the middle third of the ***Jaguaribe river***, whose basin drains 50% of the state's territory . The construction of the Castanhão dam demanded, among other actions, the resettlement of the urban centre of the city ***Jaguaribara***, which had 2/3 of its territory flooded to make way for stored water.

The initial study showed the unsustainability of the regional water system and a series of problems regarding the use and availability of water in Jaguaribara. Such observation aroused the hypothesis that local water management could be improved by combining engineering and nature-base solutions, considering the inhabitants of Jaguaribara and the unique biome of Brazilian semiarid, the ***Caatinga***.

Therefore, the present work adopts the research through design strategy (RTD) and starts from the analysis of the wetness Ceará and Jaguaribara, to propose design strategies that aim to establish a wetness retention landscape in Jaguaribara - also stretching these ideas at a larger scale. As result, the design strategies were evaluated for their effectiveness in terms of creating an autonomous and drought-resilient community, being classified into seven types, according to their specific objectives and areas of implementation.

Keywords: water retention (urban) landscape; holding wetness; drought-resilient community.

CONTENT

Jaguaribe river landscape (downstream) seen from the top of Castanhão dam in January, 2019.

INTRODUCTION

This chapter presents the research subject, which focuses on the water (or wetness) in Brazilian semiarid, susceptible to recurrent droughts, where inhabitants live in conditions of low water availability. It also presents the study region's context and the landscape changes resulting from the works to mitigate the effects of droughts. Furthermore, it explains the research problem in the larger and local scale, followed by research questions and objectives, as well as the relevance for the community.

1. INTRODUCTION

1.1 SUBJECT

“We live in the time of wetness, a wetness that is everywhere before it is water somewhere. Nothing is really dry, only less wet”.

It was with this statement that Dilip da Cunha and Amurada Mathur opened their lecture titled “Designing with wetness”[1]. This mindset is especially interesting when designing in areas with low water availability: instead of only focusing on the absence of water, diving into the waterscape itself.

By seeing the whole world as a gradient of wetness we enlarge our perspective on the landscape as this intrigues us to look for the water when it can not be seen in its fresh state on the surface; when it is moisture in the air or in the soil, when it is absorbed by vegetation or flows underground.

In places under semiarid climate, where rainfall is scarce and poorly distributed, understanding the water flow in the landscape at different points in time can be the first step in exploring this valuable resource in a sustainable manner, with social and ecological responsibility.

In Brazil, the semiarid region covers about 13% of the national territory, in the northeast of the country, reaching 1,262 municipalities and over 28 million people inhabitants. (SUDENE, 2018)
There, climatic and geomorphological conditions led to the formation of a unique biome in the world: the ***caatinga***, where fauna and flora adapted perfectly to physical conditions of the land. (Brasil, 2017) (image 1.1)

The inhabitants also had to adapt to overcome water scarcity. First, indigenous peoples, natives of the region, were the first to develop vernacular solutions for storing water, even though they lived essentially as nomads. Subsequently, the first Europeans who occupied the region adapted

(1) Lecture given at Faculty of Architecture and the Built Environment, Berlage Room, Delft University of Technology, on December the 2nd, 2019.

Image 1.1: Caatinga landscape in dry months (left) and during rainy season. (bellow)

Source: Associação Caatinga (2018). Available at facebook.com/associacaocaatinga. Accessed in December, 2019.

the indigenous solutions while importing many others; applying the technological knowledge they had in combination with the resources found in the landscape in order to improve their living conditions.

Over the years, with the social and economic growth of the country, other solutions have been developed, culminating in a wide range of buildings and apparatuses that make up the wide water system network of north-eastern Brazil.

In general, this water system consists of major engineering works, which, similar to what happens in other parts of the world, aim to store and transport an enormous volume of water as a way to distribute this resource in space (to other locations with higher water demand) and over time (to be used all year round, not just during the rainy season and even in years of drought).

However, these solutions are not site specific; they do not dialogue with the landscape they transform; they are alien to the richness of the caatinga biome and the socio-economic particularities of each location.

With the worsening of extreme conditions due to climate change, the trend is to further extend this current water system, repeating the same imported solutions. Or perhaps it is time to encourage a paradigm shift.

Therefore, this work arises from the combination of these two ideas: the critical attitude towards the water system adopted in the Brazilian semiarid combined with the desire to look at its land(water) scape from a different perspective. One that considers the caatinga's gradient of wetness and the use of water by the inhabitants, following their economic and socio-cultural needs.

The fascination behind this work is also to explore local solutions as opposed to the tendency of past decades in transporting water over long distances; to propose nature-based solutions that have low construction and maintenance costs, as well as low energy consumption.

Finally, the idea is to seek answers in the landscape to mitigate the effects of living with low and inconstant water availability in such a way that it can contribute to improving the quality of life in the region. **To watering the semiarid by holding the wetness, considering the inhabitants and the biome.**

1.2 CONTEXT

Semiarid and drought

Semiarid regions can be found in every continent. They are generally defined as regions where rainfall does not meet vegetation growth needs throughout the year. That is, the aridity index (precipitation / potential evapotranspiration) does not exceed 0.5 percent. (Semiarid Platform, 2019)

In Brazil, the semiarid climate covers about 13% of the territory and is considered a climate exception, being located at the same latitude of tropical forests, such as Amazon. (Brazil, 2017) (image 1.3)

Semiarid conditions can be found in 10 of the 26 Brazilian states, being 9 of them in the north-eastern region of the country, where the study area (Ceará state) is located. The choice was made for reasons that will be clarified later in this chapter. (image 1.2)

Image 1.2: Territorial limits of the country, coverage of semiarid climate and location of Ceará, where the study area is located.
Source: SIMACaatinga (2019) Available at lapismet.com.br/SIMACaatinga/rain_ht.php. Accessed in December 2019.

The potential evapotranspiration in Ceará is slightly higher than twice the rainfall rates, culminating in aridity index of 0.2 in the driest areas and 0.47 in average. The high potential evapotranspiration is due to the intense solar radiation of around 6.250 Wh/m² a day. (Caitano et al, 2019) (images 1.4-5)

The climatic effects are accentuated due to the concentration of more than 97% of the annual precipitation in just four months of the year (usually from mid-January to mid-May), while the territory is exposed to intense insolation and high temperatures in the rest of the year. (Caitano et al 2019) (image 1.6)

In addition, the region suffers periodic droughts. The average frequency is 9 years of drought per century, with at least one per decade. However, these events are not recent phenomena. Since 1500, Europeans' arrival date in the territory, 117 years were considered dry by travellers, clergy and residents. These records show that, although climate change tends to worsen the effects of droughts, they are essentially they are natural phenomena that, as far as is known, have always occurred in the region. (SIMACaatinga, 2019) (image 1.7)

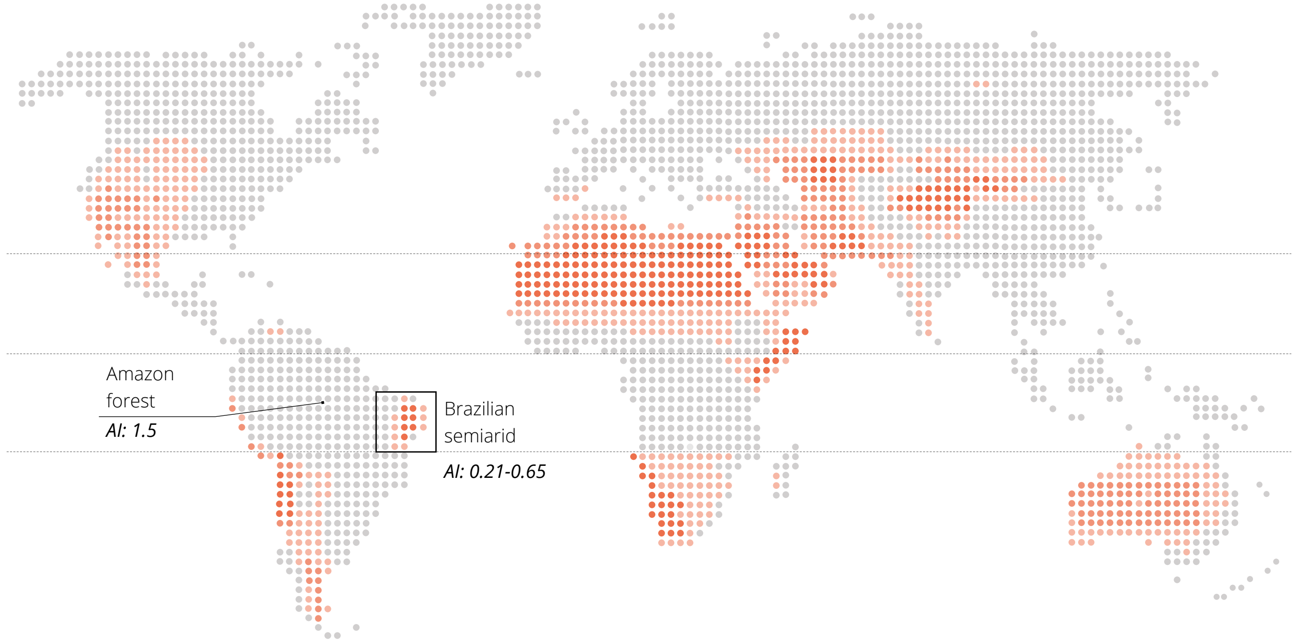


Image 1.3: Location of Brazilian semiarid in relation to other semiarid and arid climates in the world.
Source: Created from informations Available at data.knmi.nl. Accessed in December, 2019.

CLIMATE	ARIDITY INDEX (AI)
Hyper-arid	< 0.03
Arid	0.03 - 0.2
Semiarid	0.21 - 0.5
Sub-humid dry	0.51 - 0.65
Sub-humid moist	> 0.65

Image 1.4: Table with Aridity Index classification per climate.
Source: Adapted from Caitano et al (2019).

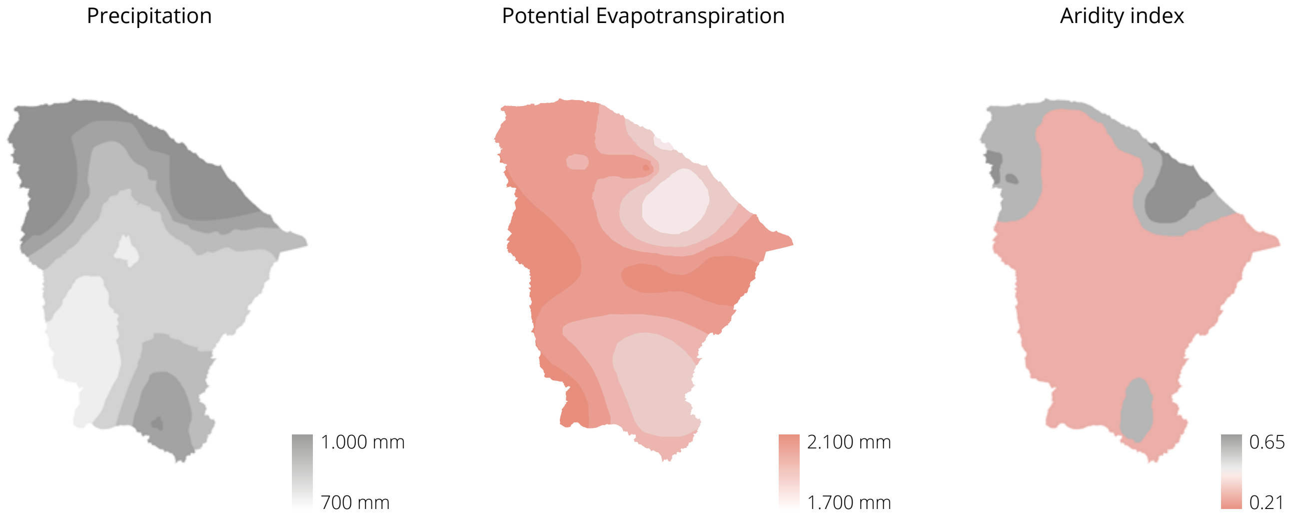
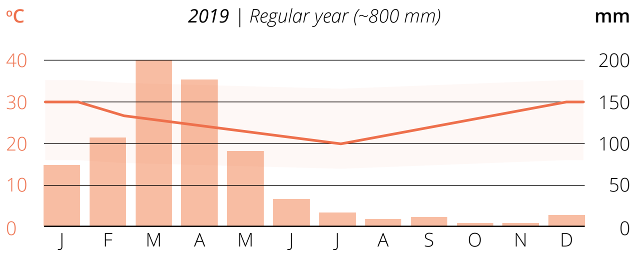


Image 1.5: Maps with average rainfall and potential evapotranspiration in Ceará, as well as estimated aridity index in the state over a 30-year period (1976 - 2009).
Source: Adapted from Caitano et al (2019).

Droughts in north-eastern Brazil are the result of the action of winds in the air masses responsible for the formation of rains. The rains in this region are due to the meeting of air masses of both hemispheres in the equatorial zone, causing showers and thunderstorms in the first months of the year. However, sometimes winds move part of the masses further north of the Ecuador. When this happens, the Brazilian northeast is dominated by the South Antlantic anti-clone, culminating in a considerable reduction in rainfall (in general, the rainfall index falls by half). (Perote, 2006) (image 1.6-8)



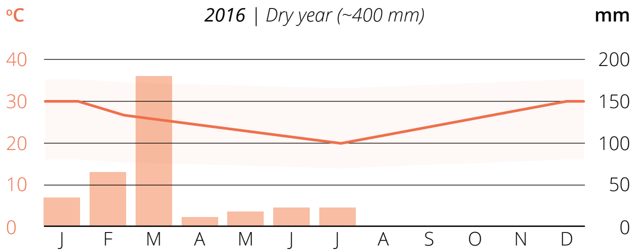


Image 1.6: Rainfall (bars) and temperature (line) in Jaguaribara - Ceará in a regular year (2019, top) and in a dry year (2016, bottom).

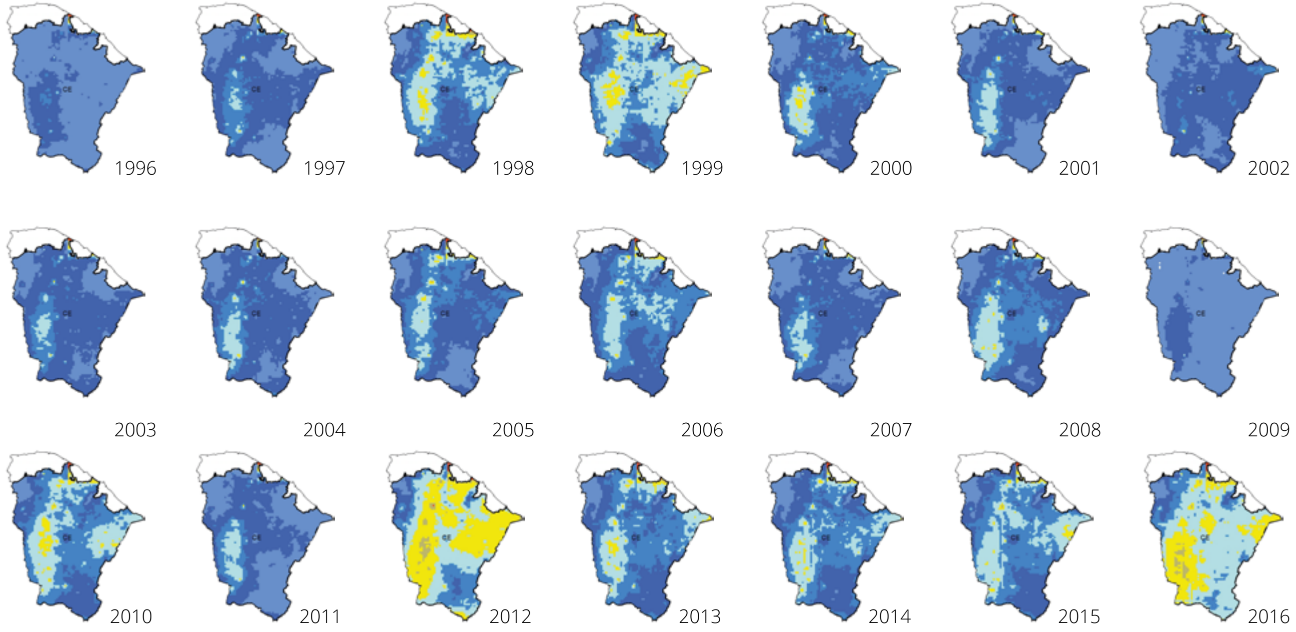
Source: Adapted from FUNCEME (2019).

Image 1.7: Rainfall in regions under semiarid climate in Ceará during years 1996-2016.

Source: Adapted from SIMACaatinga (2019) Available at lapismet.com.br/SIMACaatinga/rain_ht.php Accessed in December 2019

Image 1.8: Jaguaribe river in a regular year (top) and in a dry year, before perennialization (bottom) .

Source: Pablo Soares (2013) and Manuel Porto (2012) Available at www.panoramio.com/photo/92641150. Accessed in December 2019



Water works in Ceará

Throughout modern history, much has been discussed about how to mitigate the effects of drought and ensure the water supply throughout the year in Brazilian semiarid. However, public actions in a regional level did not actually begin to be implemented until the late 1950s.

In general lines, the solution in region scale comprises a system of dams, reservoirs and kilometers of water channels that connect river basins, crosses state borders and distribute water to various locations.

Of the 10 states under the semiarid climate in Brazil, the one with the largest amount of waterworks is **Ceará.** It is also the state with most of the water channels (4,360 km in the main system) and the one with the largest reservoir in Latin America, the **Castanhão**, with storage capacity of 6.7 billion m³. This information explains why Ceará was chosen as the study region on the larger scale in this work. (HIDRO.CE (2020)

In Ceará, the regional water system started with the construction of the **Orós** dam, in 1961. Built in the Jaguaribe river, the largest in the state, it aimed to improve the water supply in the countryside, boosting the development of the agricultural industry. Then, this system was expanded from the 1980's onwards to meet the growing demand for water in the metropolitan region of **Fortaleza**, the state capital. (images 1.9-10)

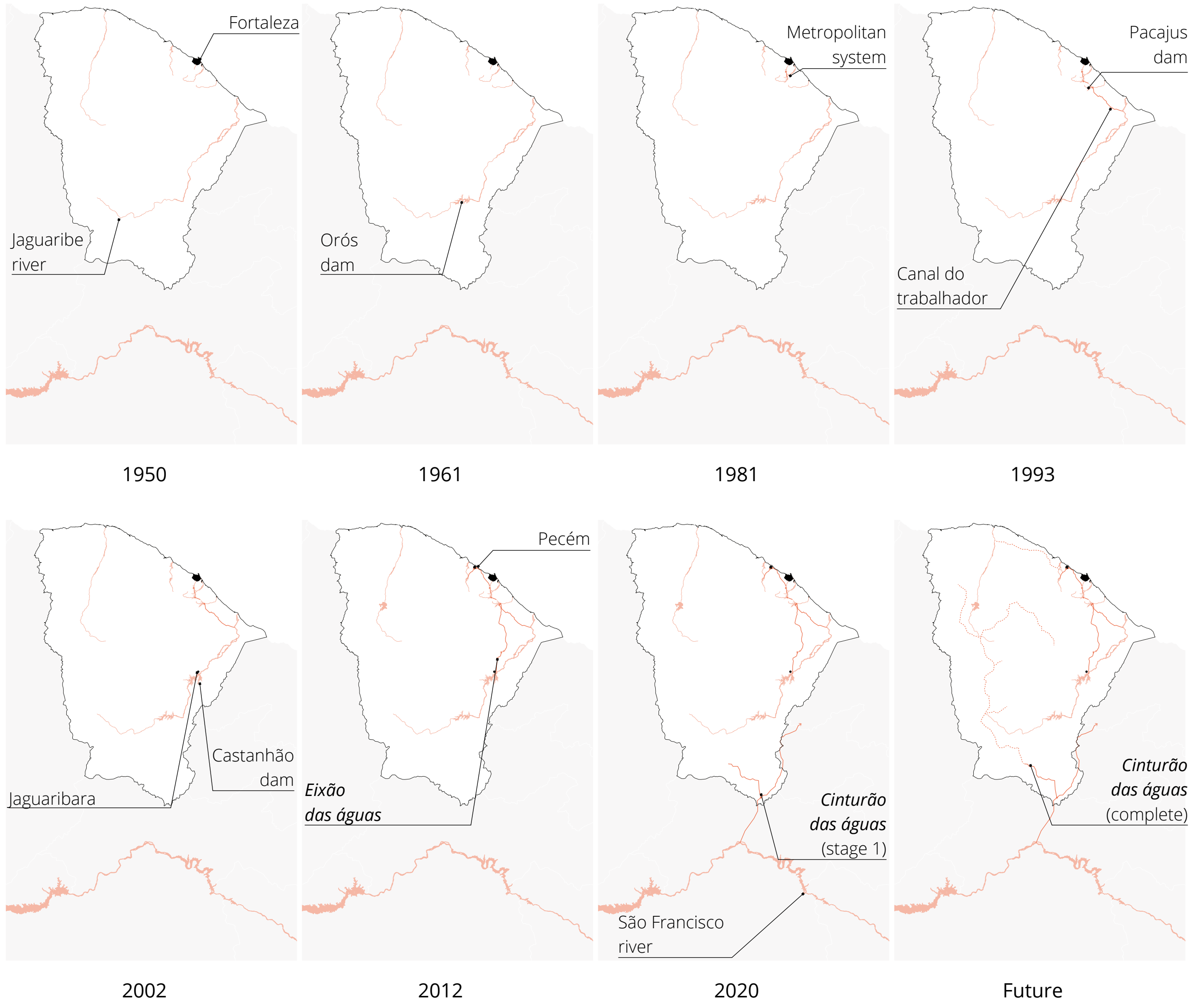
Until the 80's, the water needs of the capital was fulfilled only by local sources. The increase in demand was due to the development of industries on the outskirts of the city from the 70's. Thus, the internal system was connected to three dams just outside the city (Gavião, Riachão and Pacoti), creating the so-called **metropolitan system**.

However, 10 years after that, Fortaleza's water supply was already at imminent risk of collapse. As a result, in an emergency action of 90 days, the 102 km of water channel that constituted the **Canal do Trabalhor** ("worker channel") was concluded. It was made to capture water from the Jaguaribe river at 30 km from its mouth, transporting it to the Pacajus reservoir, that was connected to the metropolitan system.

Understanding the actions carried out until this point would not be able to meet the water demand for a long time, two years later, the construction of a new dam in Jaguaribe river begin. The **Castanhão**, as the Padre Cícero dam is popularly known, took

Image 1.9: Succession of maps showing the evolution of the regional water system in Ceará over the years.

Source: Adapted from sysfile.verdesmares.com.br/data/public/a3f44af877/canais.html. Accessed in December, 2019.



7 years to be build and cost about 30 million Euros. (image 1.12) (HIDRO.CE, 2020) (image 1.11)

In order to redirect the water from Castanhão to Fortaleza, it was necessary to build a 256 km long concrete channel. The ***Eixão das Águas*** (literally "large water axis") was finished in 2012 and is divided into five sections. The last one extends the metropolitan system to the city **Pecém**, 45 km from Fortaleza, where a new industrial port complex was emerging. (image 1.12)

During the last major drought, between 2012 and 2016, the water infrastructure built so far could be tested in a situation of extreme water scarcity. After identifying the most vulnerable areas, and in view of the still increasing water demand, a new plan was developed to expand the state's water storage capacity. (SRH, 2018)

Image 1.10: Three elements from the regional water system in Ceará: Orós dam (top), Pacajus (middle) and Canal do Trabalhador (bottom).
Source: portal.cogerh.com.br. Accessed in April, 2020.

Among other strategies, such as the construction of new dams, a bold new system was proposed, based on an ancient aspiration of Brazilian's monarchy times.

This new system begins with the transposition of waters of the **São Francisco river**, which runs south of the state. To spread this water throughout the central area of the state (that showed greater vulnerability to water scarcity), it was designed a system of water channels called ***Cinturão das Águas* - CAC** ("great water belt").

The first phase of the CAC, whose work began 5 years ago, is being concluded in June 2020. The CAC is planned to be constructed in six stages and it is not yet known when it will be fully completed. (image 1.13)

Image 1.11: Castanhão dam (top)
Source: portal.cogerh.com.br. Accessed in December, 2019.

Image 1.12: Water channels of *Eixão das Águas* (middle)
Source: portal.cogerh.com.br. Accessed in December, 2019.

Image 1.13: Pumping station and water channels from *Cinturão das Águas* (bottom)
Source: portal.cogerh.com.br. Accessed in December, 2019.

The flooded city

The area chosen for the construction of the Castanhão was where there was a gorge on the Jaguaribe river, which facilitates the installation of a dam. Despite being considered the ideal geographical area, the process was marked by many controversies.

First, a large number of engineers were against the designed dam, arguing that it was oversized. The government agency responsible for the project (DNOCS[1]) wanted to make the most of the water storage potential due to the geographical feature, building a 60 meter high barrier. However, some technicians doubted that the river water flow would be enough to ever fill the reservoir, which would not justify the 30 million Euros invested in the work. Other professionals were against it because the storage of a lot of water in the same place implies costs to transport water to other regions. In addition, the environmental impacts for the river ecology were also widely questioned. (PEROTE, 2006)

Furthermore, it would be the first time that a water work would lead to the resettlement of so many inhabitants in Ceará. To complete the work, it was necessary to remove all occupations up to the 100 quota, which includes about 15 thousand families distributed in 18 settlements.

They were distributed in four municipalities affected by Castanhão: Jaguaretama, Jaguaribe, Jaguaribara and Alto Santo - the latter being the city where the barrier would be built. However, of all these municipalities, the most affected was Jaguaribara, which would have flooded 3/4 of its surface area. In addition, while the regions of the other municipalities to be affected were rural areas, Jaguaribara would have its urban centre submerged. (images 1.14)

In general, the resettlement process was participatory. Jaguaribara residents were able to choose their next home between three new rural communities - ***Mandacaru*** (irrigated farming), ***Curupati irrigação*** (irrigated agriculture), ***Curupati peixe*** (fishing farming community) - and the urban centre, whose location was chosen by voting among six possible options. The chosen area was the residents' preference for being on a higher topographic level, which implies better ventilation.

Despite this, many inhabitants resisted the removal, creating community associations. After

(1) Departamento Nacional de Obras Contra as Secas (National Department of Works Against Drought, free translation)

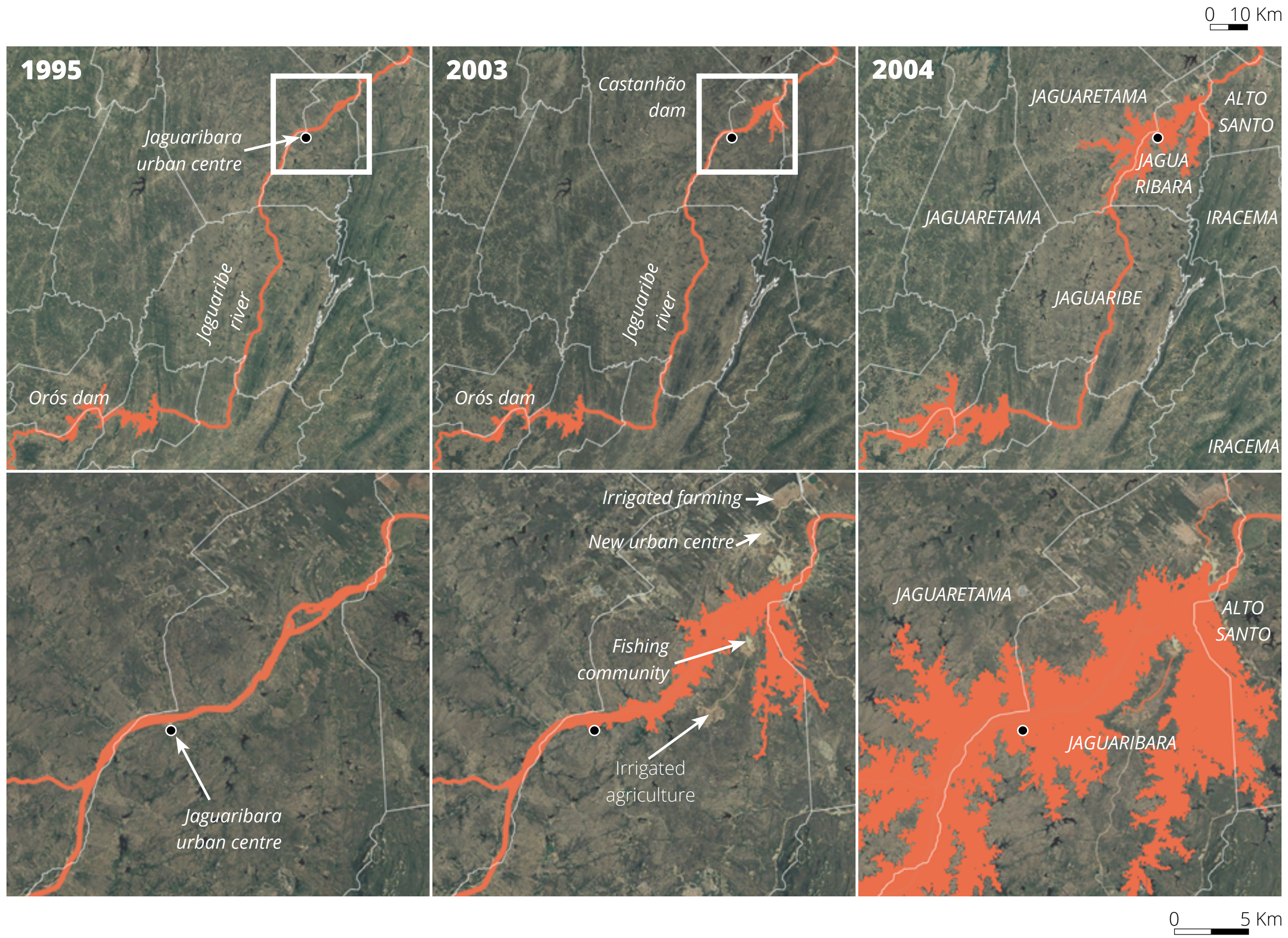


Image 1.14: Satellite images of the Jaguaribe river before and after Castanhão.

the inauguration of the new urban centre in 2001 and the end of dam's construction in 2002, a lot of families still remained on the site. However, in 2004, after a rainy season with rainfall five times higher than the historical average, the reservoir quickly filled up and they had to leave the site, putting an end to community resistance.

Eighteen years have passed and the Castanhão reservoir has only filled twice, in 2004 and in 2009. In the last 10 years, the storage volume has varied between a 73.57% (in 2012) and 2.09% (in 2018), the percentage considered dead volume is 4.5%. (HIDRO.CE, 2020)

Jaguaribara's inhabitants are still adapting to the new conditions. Economic activities, that previously revolved around the Jaguaribe river and its plains, can no longer be practiced in the same way in the new locations. Thus, the inhabitants have been learning new techniques of agriculture, farming and fishing. Adaptation, however, has proved to be complicated by several factors and economic flows are still unstable. In addition, the affective memory related to the old city and the proximity to the river remains. With the reduction of the volume of water stored by the reservoir, the ruins of the old flooded city emerge, bringing to the surface a feeling of nostalgia (CEARÁ, 2019). (images 1.15-20)

Image 1.15: Inhabitants of the old urban centre of Jaguaribara, choosing the new location (left).

Source: IMOPEC (1990) In Leite (2010)

Image 1.16: Dam under construction (right).

Source: DNOCS (2002)


Image 1.17: Aerial photograph of the submerged city (left) and the new city (right).

Source: Seinfra (2001)


Image 1.18: Residential street in the old location in 1983 (left) and in the new in 2001 (right).

Source: IBGE (2019)

Image 1.19: Residents in the old urban centre (left).

Source: Beth Guabiraba in Frota Júnior (2017).

Image 1.20: Photograph in the same place before/after flooding.

Source: Extracted from CEARÁ (2019)

1.3 PROBLEM

An unsustainable water system

As previously mentioned, the regional water system in the state of Ceará is essentially based on the storage of surface water, through the construction of dams in rivers and tributaries. This strategy aims to harvest rainwater to distribute it spatially to other areas of Ceará's territory, through channels and water mains, in order to mitigate the effects of water shortage in dry periods. Since rivers in Ceará are not particularly voluminous, the most important water works are concentrated in the hydro-graphic basin of the largest river, Jaguaribe. (images 1.21-22)

Thus, of the entire water storage capacity in Ceará, 73% is concentrated in reservoirs along the Jaguaribe river basin - which, due to its size and diversity, is divided into five sub-basins. Castanhão dam alone has 37% of the state's water storage capacity. Therefore, a large amount of water is stored in only one region, which leads to the construction of water channels to distribute this water to other regions, such as *Eixão das Águas*, which brings water from Castanhão to the metropolitan region of Fortaleza. (images 1.21-22)

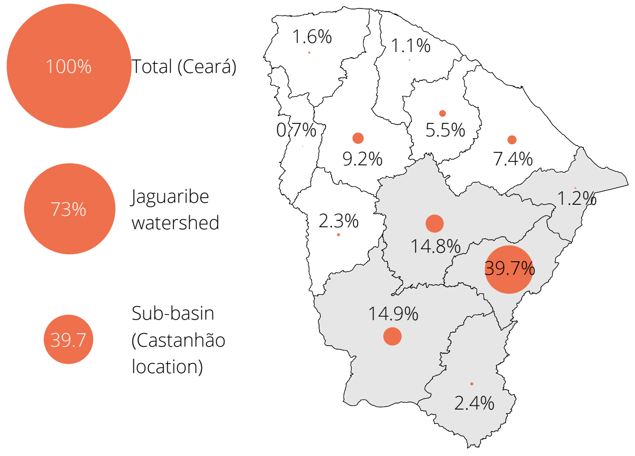
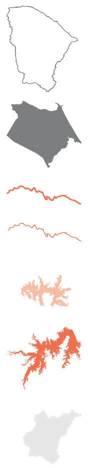
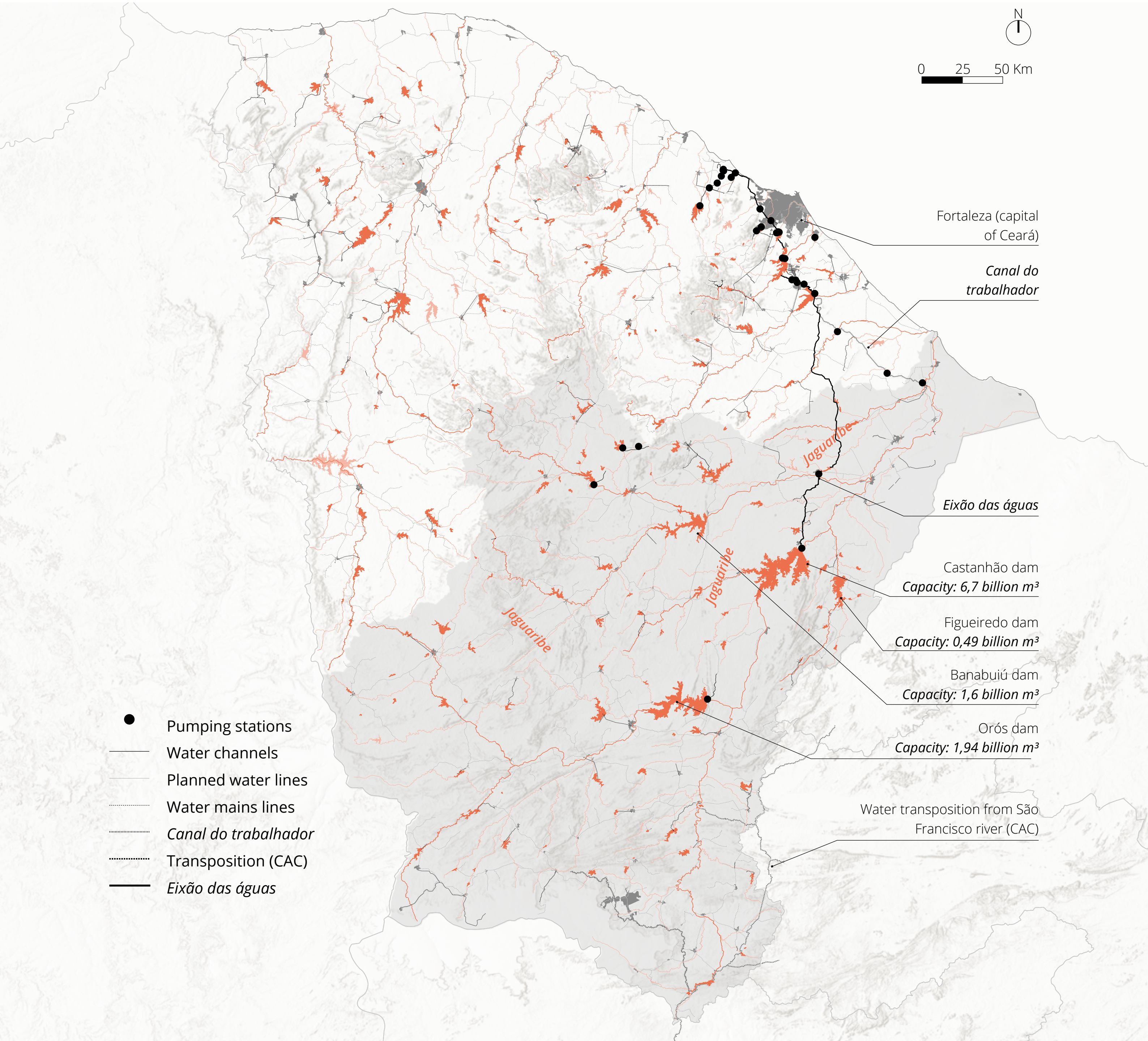


Image 1.21: Water storage capacity of Ceará's watersheds

Image 1.22: Ceará's regional water system: river, dams, water lines and pumping stations. Highlighting Jaguaribe river watershed and the state's capital, Fortaleza. (right)





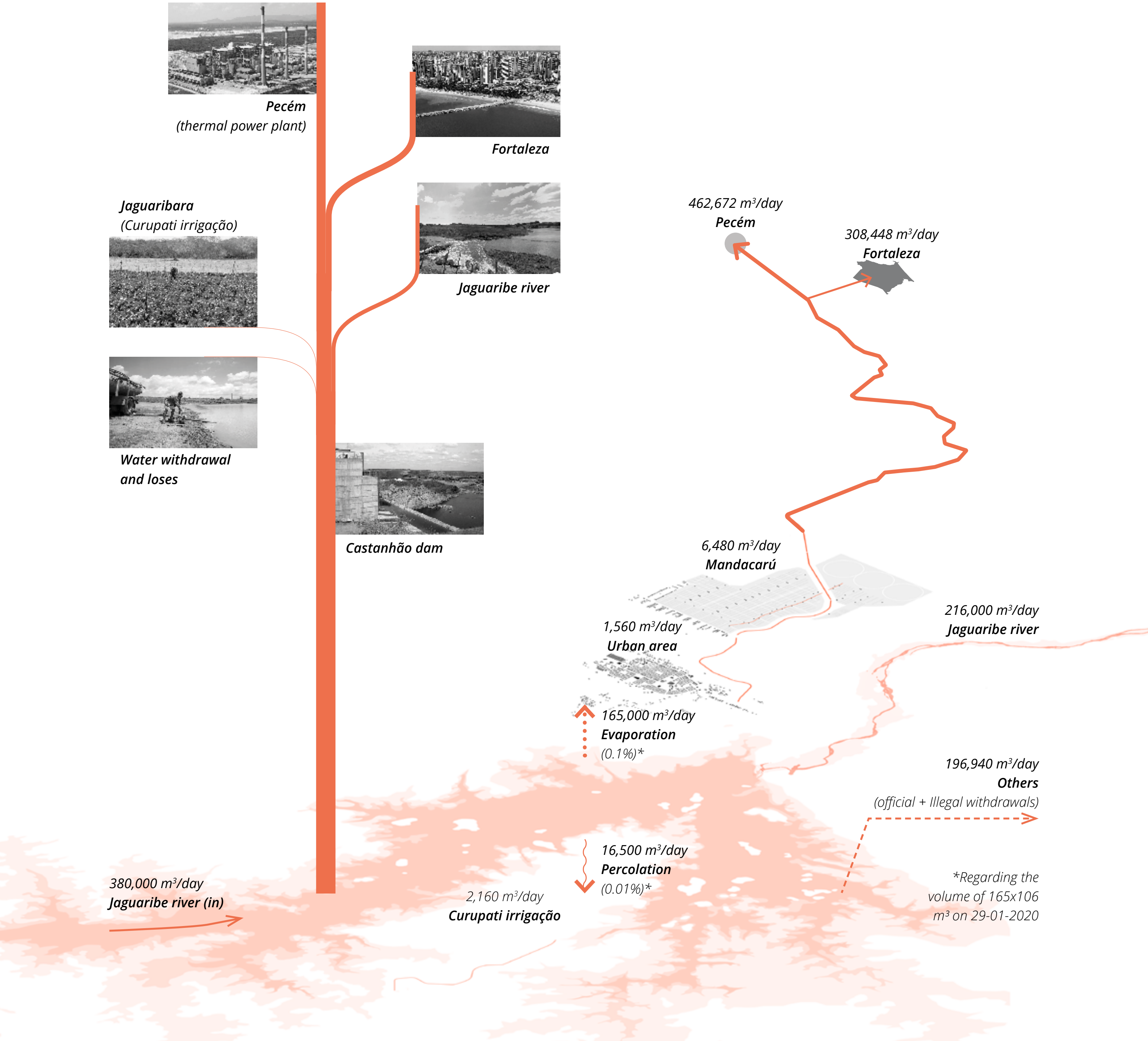


Image 1.23: Castanhão's water distribution.

These long concrete channels, have some disadvantages. Firstly, they become barriers to the passage of fauna, causing impacts on the ecosystem of the Caatinga biome. In order to overcome height differences along the route, reducing the need for water pumping stations, the channels are sometimes dug or raised from the actual level by a few meters. This means that land animals are unable to cross them.

In addition, the channels have high construction and maintenance costs. The construction of *Eixão das Águas*, for example, cost a total of 210 million Euros. Furthermore, as the channels are made of concrete, they require that there is always water, at risk of cracking due to strong sunlight and heat. However, in a region under semiarid climate, ensure that this water is often complicated. (ANA, 2020) For instance, the *Canal do Trabalhor*, which was built on an urgent basis, became obsolete after the construction of the *Eixão das Águas*. Thus, in order to avoid very high maintenance costs and fearing that all investment would be lost, the state government gave up using the canal for private farms.

The distribution of the water stored in Castanhão is also controversial. Every day, Castanhão loses 1 million m³ of water. While 21% of this quantity is directed to the Jaguaribe river, 77% goes on the *Eixão das Águas* to the metropolitan region of Fortaleza and only 1% supplies Jaguaribara. In addition, most of the waters that flow through the *Eixão das Águas* are intended for only one industry; a Thermal power plant located in the city of Pecém. Each of its 6 boilers consumes 800 litres of water per second to generate energy from steam, around 44,000 GW/day altogether. (image 1.23) (ANDRADE, 2019[1])

This all shows that there is a question of poor water distribution due to the influence of private companies and that the state favours economic development to the detriment of ecological, social and cultural issues. In other words, the regional water system in Ceará is out of balance when it comes to sustainable development.

Finally, we know that this water system was already tested during the last drought (2012-2016) and that it showed vulnerabilities, especially in the central area of the state. This is because, although most of Ceará's water is stored in the semiarid region, much of it is redirected to the coast (whose climate is sub-humid) in order to meet industrial development.

(1) Verbal information: interview given by Fernando Pimentel de Andrade, supervisor of the Castanhão dam, on a field visit on January 28, 2019.

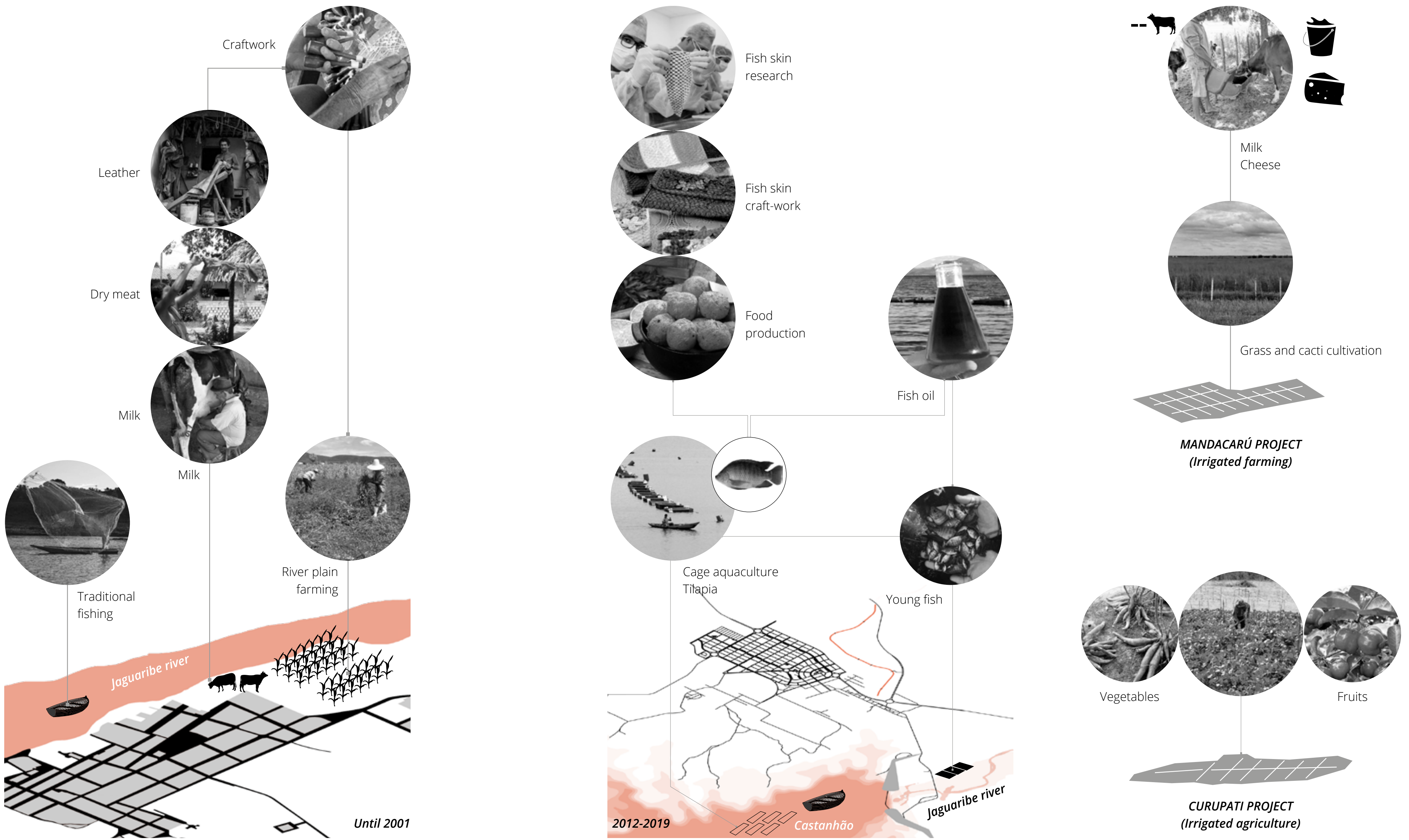


Image 1.24: Former productive flow of Jaguaribara before (left) and after Castanhão (right), 2012-2019.

Water instability, unstable livelihood

Although it allows a better management of the river waters and its perennialization, dams generate some disadvantages. In addition to altering the river bed, they contribute to the siltation and salinization of the soil. In addition, as many cities in the semiarid are formed on the banks of rivers, the construction of reservoirs often leads to resettlements. (CAMPOS; STUDART, 2008)

In the case of Jaguaribara, which had a large part of its population resettled for the construction of the Castanhão dam, the impacts caused by this change were not only in the social and emotional sphere, but also economically. (PEROTE, 2006)

Before the resettlement, the city's economy basically revolved around the Jaguaribe river. The inhabitants practiced agriculture on the river plains and traditional net fishing. Some had cattle in small number that grazed in areas of riparian vegetation, while women washed their family's clothes directly in the river. (image 1.24) (PEROTE, 2006)

In the new location, further away from the river, the city would have to adapt. Besides that, the construction of the Castanhão was followed by the prohibition of some of these traditional practices, aiming to protect the riparian forest, since many regions along the river were under threat of desertification. (ANDRADE, 2019[1])

As a compensation measure, the government developed irrigated areas for agriculture (*Curupati irrigação*) and farming (*Mandacaru*), in addition to an aquaculture program in the waters stored by the dam (*Curupati peixe*). The latter represented the majority of public investments. (image 1.24)

Excavated tanks were installed close to the dam, where breeding of tilapia fish was taken place. The young fish were then delivered to the local farmers who cultivated them inside the reservoir until they were the right size for sale. Given the high volume of fish production, the region's economy developed rapidly in the early years and many other economic practices were derived from it; for instance, fish food products, fish skin craftworks, or even selling fish skin to research centers. The guts of tilapia were also used; they were returned excavated tanks installation, which produced oil from these remains. (ANDRADE, 2019[1])

However, despite the initial success of the aquaculture system, some setbacks put an early end to it. As there was low water renewal, there was an accumulation of organic matter due to the ration given to the fish in the cages. This led to eutrophication, with a significant reduction in the concentration of oxygen in the water. In addition, the water pressure variation, a consequence of water flow management, had great impact on fish health. These two problems not only led to a high level of mortality of fish in cages, but also of life in the river itself. Thus, in March 2019, the aquaculture activity in Castanhão was officially suspended. Nowadays, in the excavated fish tanks, tilapia fish are still being produced, but they are released in the Jaguaribe river to compensate for the ecological damage caused by the dam. (ANDRADE, 2019[1]) (image 1.25)

Both systems of irrigated farming/agriculture (*Curupati* irrigação and *Mandacaru*) still work today, but they encounter some barriers so that they can develop as planned. In the case of *Curupati*, although the production is going well, farmers find it difficult to deliver the goods to the market, since the access road is unpaved and they lack of proper transport. In *Mandacarú*, the 130 families that invested in the system with the help of the government were to receive the cattle breeding stock, which did not happen so far. Thus, only a

(1) Verbal information: interview given by Fernando Pimentel de Andrade, supervisor of the Castanhão dam, on a field visit on January 28, 2019.

few producers were able to buy cattle, even if in small quantities, to continue producing milk. The rest has just gone on with planting grass (which should be used to feed livestock) to be sold to other private farms in the region. (NETO, 2019[2])

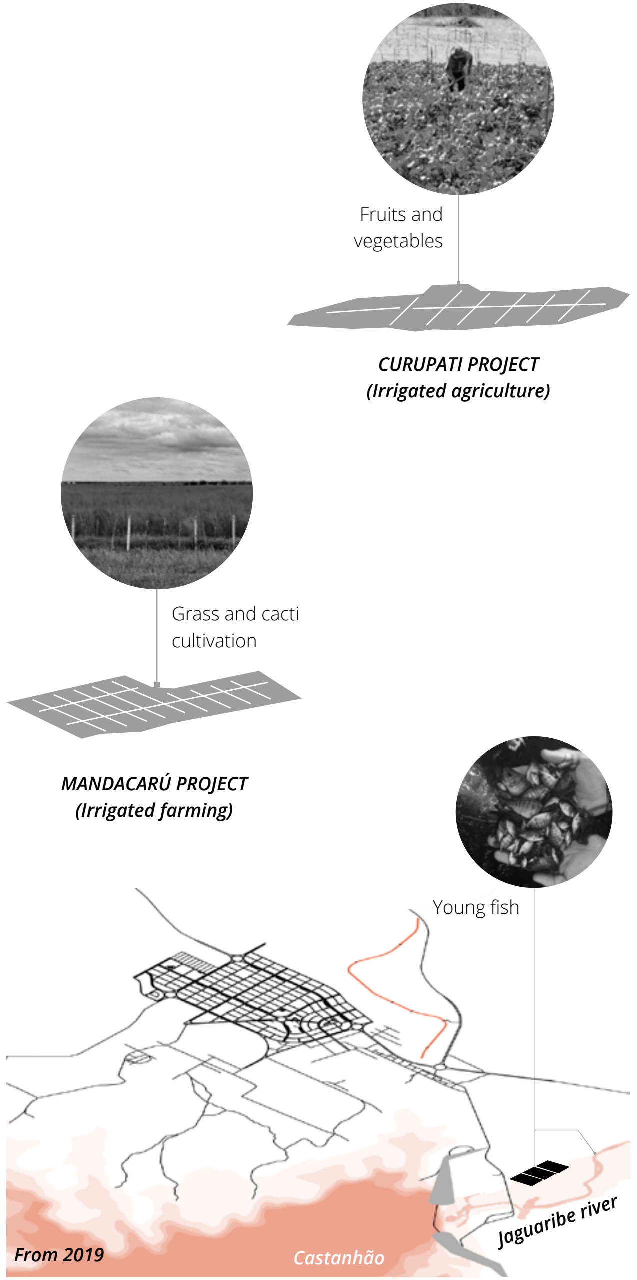
However, both *Curupati* and *Mandacarú* face the same problem related to water supply. With the reduction in the volume of water stored by Castanhão, the supply of water destined to both systems has also reduced over time. (NETO, 2019[2])

In general lines, former small-scale subsistence activities have been replaced by large-scale correspondents, which were to boost the region's economy. However, traditional practices, despite eroding riparian forest, had the advantage of consuming little amount of water, unlike current practices.

Therefore, the producers are not only dependent on the water supply from Castanhão, but also from systems of high water consumption level amid the semiarid region. In other words, Jaguaribara lost economic sustainability and its production autonomy as the relationship with water and the river changes.

(2) Verbal information: interview given by José Martins G. Neto "Netinho" (politician and farmer's son), on a field visit on January 29, 2019.

Image 1.25: Jaguaribara's current productive flow.



Problem statement

The current water system is unsustainable.

It reflects an undemocratic water supply, privileges economic development on a regional scale (Ceará), while generating environmental, social and economic impacts on a local scale (for instance, in Jaguaribara).

In addition, despite the fact that Ceará is the state with the largest amount of dams and water works in the Brazilian semiarid region, it has not yet become resilient to situations of water scarcity. Still, it continues to follow solutions that waste water with evaporation (since water is stored on the surface in a region with high potential evaporation) and are expensive to transport (which raises the final cost of water for the consumer).

Finally, at the local scale, production practices go against the semiarid context and rely on high water consumption to achieve the production need that corresponds to the financial investment for implementation and maintenance.

Hypothesis

The water system can be improved by holding wetness in the landscape.

By making the most of the water available at the region - avoiding waste and evaporation and decentralizing water storage - it would be possible to maintain economic activities in the local scale without having to rely on the displacement of water over long distances.

Therefore, it would be necessary to combine engineering and nature-based solutions, considering inhabitants and the Caatinga biome.

1.4 QUESTION AND OBJECTIVES

Given what was previously discussed, the following questions arise:

How to improve the water management in Jaguaribara, considering the relationship between inhabitants and landscape?

- How can the redesign of the water flow, by retaining wetness, benefit the local community?
- How can an integrative approach of engineering, landscape and social aspects reshape the territory?

Thus, the main objective of this work is **to develop design strategies regarding the water flow to be applied in Jaguaribara**.

Among the specific objectives are:

- Redesign the water flow in a systemic manner, using local sources and reducing the need for water transport;
- Work on the access to water as a tool to encourage conscious use of water and strengthen the sense of community.

1.5 RELEVANCE

The relevance of this research lies in different scales: within the semiarid context (especially in an underdeveloped country, such as Brazil), in the professional field and the global scientific community.

Considering the context of the semiarid climate, it is important to note first that semiarid regions can be found on every continent. Each has its particularity, history, culture, modes of production and biome. However, the issue of low water availability unites these regions around the same issue.

Therefore, studying ways to design with wetness, and later deriving principles from a case study, provides design inputs for water solutions different regions of the world.

In addition, systems based on dams and waterways have been used worldwide throughout the history of mankind. Thus, studies on the humanization, naturalization and optimization of this kind of system can benefit communities in several other contexts.

Within the professional context, it is important to emphasize that practices guided by democratic concepts are relatively new in the field of landscape architecture. Thus, design exercises that seek to reflect the democratization of landscape is of great relevance to inspire professionals in the field to be agents of landscape transformation around the world.

Finally, for the scientific community on a global scale, the research theme reflects a major concern of our times regarding the future. Low water availability is a growing concern in more and more places around the world and has attracted professionals from different areas.

Due to climate change, what was previously only a concern of arid climate regions has become a reality in places where previously the availability of freshwater was not a concern. Therefore, it is necessary to change the mindset as to how we think the flow of water on the landscape scale before we are all out of water.

On the left: Three children draw water from a well dug in the ground (called "cacimba") while a fourth waits in a wagon. Children will only leave the place when the barrel is full of water.

Source: Available at domtotal.com. Accessed in December, 2019.

THEORETICAL FRAMEWORK

Essentially, the methodology is supported by the tripod: problem, theory and method. The first of these components was presented in the previous chapter. In the following pages, the second component will be presented: the theory. The theoretical framework exposes the positioning of this research in relation to the landscape in a peripheral reality, such as the Brazilian one. In this context, socio-political issues are inseparable from decisions related to the landscape. This becomes even more important when the research focus involves a human right, which is at the same time one of the most valuable assets of a land: water. The chapter also presents the definition of terms used throughout this work, such as wetness, sustainability, democratic water management.

2. THEORETICAL FRAMEWORK

2.1 LANDSCAPE DEMOCRACY

"Land belong to someone, but landscape belongs to everyone."
- Simon Bell[1]

In 2000, the Council of Europe created the **European Landscape Convention (ELC)**, whose main objective is to establish a true **Landscape Democracy**, as well as promoting landscape protection, management and planning in member countries, while establishing cooperative measures within Europe. (ARLER, 2008)

Rahul Mehrotra defines landscape democracy as the scenario where plural voices work together. A means by which landscape-related actions are negotiated and contested. This concept is thus opposed to the **landscape of autocracy**, in which decisions are imposed from top to bottom, strongly shaped and influenced by the forces governing the economic market. (MEHROTRA, 2016)

(1) President of the European Council of Landscape Architecture Schools (ECLAS), commenting on the book Landscape Democracy: a path of social justice (2018)

In discussing this issue in greater depth, ARLER (2008) builds on ELC's Explanatory Report (ER) to define landscape and democracy.

For the author, the landscape is seen as both space and place. Landscape is **space** insofar as it is well delimited by and defined in its physical aspects. These characteristics are therefore measurable and, provided they involve at least three or four of its dimensions, give basic and indispensable information for the understanding of the space.

However, landscape is also a **place**, since it is perceived and interpreted in different ways by humans. From this perspective, the landscape gains meaning and cannot be registered in a detached manner, as physical aspects can be. The features of a place are to be defined by **people**.

Understanding the landscape as space and place, the ER defines that its qualities must be assessed by maintaining a balance between the **physical environment and its elements, ecology, culture, society and economic activities**. Thus, even if these qualities are assessed by competent public authorities (represented by individuals with *expertise and connaissance*), this is to be done considering the aspirations of those concerned to the landscape: **local community, general public, and other stakeholders.** (ARLER, 2008)

In this way, the landscape that is shaped within a democratic setting recognizes the knowledge of the people themselves (knowledge that is derived from life experience within the context of the landscape.) It is, though, an inclusive landscape, that can lead to (and reflect) social justice.

At this point, it is necessary to discuss the meaning of democracy in the context of landscape to understand how it can be expressed in practice.

According to ARLER (2008), democracy is a multidimensional concept and cannot merely be reduced to freedom, majority, and equality. It should also include different sets of values (or principles), among which the author cites three: **a) personal freedom and self-determination; b) co-determination and participation; c) objectivity and impartiality.**

Personal freedom and self-determination concerns the fact that the individual in the democratic state is the one who knows what is best for him/herself and should follow his/her own scope freely. However, this personal independence can never overrule the common perspective of the good. The state only interferes when the individual, for some reason, cannot thrive on his or her own experiences or when one of the previous two maxims is not met.

Co-determination and participation is crucial for decisions to be taken in agreement with everyone. Therefore, it is necessary that the opinion of all people have the same weight, because only then the majority preference can be considered. In addition, it is necessary to recognize that nothing is invariable and to revise preferences during the deliberative process.

Finally, **objectivity and impartiality** concerns how each one's preference is considered throughout the process, requiring two basic questions to be addressed. The first is that preference is presented by argument (not by power, property, or financial condition). The second is that these arguments, while starting from personal perspectives, must concern the public as a whole, not just a particular individual or sectors of society.

Considering the above, if Landscape Democracy theory argues for rights and public engagement in landscape functions and formats, it is necessary to adopt instruments that put this discourse into practice. According to ARLER (2008), this participation can be given in various ways (focus groups, interviews, surveys, co-design) as long as the above three sets of principles are respected.

Naturally, this whole theory works only in a socio-political context in which the notion of democracy is already properly rooted, and is merely a matter of ensuring that it is also incorporated into decisions concerning landscape transformations and maintenance.

It is understood that in many other contexts of the world democracy as defined here not only does not exist but is criticized. In such cases, it is not for outsiders to impose the theory presented here.

However, there are contexts in which democracy is a socio-political premise, presented and protected by laws and understood as such by society, but not applied in the context of the landscape. This is because the market ends up having a major influence on the way the landscape develops.

It is in this last context that many Latin American nations are inserted, such as Brazil. Therefore, it is believed that, by taking water as central aspect of this research (and being it an element of dispute and political manipulation in the context of the Brazilian semiarid), the theoretical framework could not exempt itself from its position regarding the **democratization of water**.

2.2 DEMOCRATIC WATER MANAGEMENT

"(The) water crisis is largely our own making. It has resulted not from the natural limitations of the water supply or lack of financing and appropriate technologies, even though these are important factors, but rather from profound failures in water governance. Consequently, resolving the challenges in this area must be a key priority if we are to achieve sustainable water resources development and management".

- United Nations Development Programme[1]

After several decades of international debate, water, as well as sanitation, were recognized as **essential human rights** by the UN General Assembly in 2010. While many countries objected to it, others (such as Bolivia, Ecuador and Urugurai), excelled in promoting and approving the human right to water. This is particularly important for Latin America, where extreme inequality is a structural and historical issue, being a key element in explaining the water crisis in the continent. (CASTRO, 2015)

(1) Available at: www.ourwatercommons.org/sites/default/files/Water-commons-water-citizenship-and-water-security.pdf Accessed in: December 2019.

However, before discussing the issue of water in the context of this research, it is necessary to discuss **what the formalization of the right to water means for both the state and the population from the perspective of the landscape**.

To this end, two perspectives will be presented; the first on urban water and the other on productive landscapes.

In addressing the process of democratization of **urban water management** in Tamil Nadu, South India, SURESH AND PRADIP (2017) pointed out the challenges involved as well as guidelines.

According to the authors, the first step was to make an **assessment of the actual water availability** in the region. This assessment pointed out that groundwater aquifers, which account for 96% of all water supply in the region, were in the process of being greatly reduced due to overexploitation. Technically, this indicated that it would be necessary to work towards the recharge of aquifers and its the sustainable exploitation.

After that, they worked out to understand **how water was distributed**. The study pointed out that the marginalized population was completely excluded from the water supply, which relied heavily on technology to be extracted. Therefore, it was necessary to rethink public policies not only regarding extraction, but also regarding the management and distribution of this water.

Thus, the democratization of water management in Tamil Nadu required attitudinal changes by both water engineers and the community. Furthermore, public officials and citizens needed to work as partners to ensure an equitable water supply, as well as sustainable water management, by conserving natural resources.

With respect to water for **productive landscapes**, TENGBERG et al (2018) draw an interesting parallel between public participation in water monitoring ("citizen science") and sustainable management as a way to improve water quality and flow in Sweden. This was done by evaluating different cases for their *"management approaches and governance arrangements"*, in order to implement an everlasting "*sustainable management of landscapes*". (pp. 32)

In the Report 38 of Stockholm International Water Institute (SIWI), TENGBERG et al (2018), state that water management can frequently constitute a starting point to **recover degraded areas, boosting landscape resilience, which should bring benefits to the local community**. This is due to the critical pressure that water, land and climate change create in important production systems. Thus, the reformulation of water flows in productive landscapes is of utmost importance for overall sustainable development.

However, they recognize there is not enough public data sources about water flows, storage and quality at a landscape scale (beyond the watershed) to support this reformulation. Therefore, they recommend that sustainable management (or restoration) of productive landscapes follow five measures, to be adopted flexibly, tailored to each context:

i) expand knowledge of hydrological processes and integration of water in the landscape;

ii) provide support for the development of evidence-based knowledge in an integrated manner;

iii) strengthen governance at various levels, including stakeholder participation in decision-making related to landscape management.;

iv) study and adopt sustainable management practices and monitor water in the landscape;

v) adaptation and financing of services to increase the long-term productivity and sustainability of the landscape.

In general, from a **design perspective**, the authors advocate for **multifunctional productive landscapes**, *where a mix of trees, forests and agricultural lands support the livelihoods of people, produce raw materials, strengthen biodiversity and maintain the water cycle* (TENGBERG et al 2018, p 5)

Finally, they argue for a design focused on **nature-based solutions** to safeguard the hydrological functioning of landscapes and their resilience to climate change. This design, inspired and supported by nature, should embrace and implement **new knowledge to complement the traditional solutions and measures**.

That bring said, considering the perspectives presented for both urban and productive landscapes contexts, some common basic guidelines can be drawn up that dialogue with a democratic attitude to water management.

Firstly, the democratization of water is not only a matter of ensuring its distribution to all citizens, but also its efficient use. This is an essential step in preserving water resources, which is critical to ensuring water availability for all relevant uses. From this point of view, the democratization of water becomes inseparable from its sustainable management.

In this sense, it is necessary to understand the natural and cultural cycles of water, which, being highly complex information, demands an integrated approach between engineering, landscape and society. Recognizing popular knowledge about water flow and including people at this point is also part of the democratic process.

Finally, it is understood that nature-based solutions are extremely interesting to ensure maintenance of the hydrological cycle. However, knowledge about natural processes is strengthened when associated with both new technologies and traditional solutions.

2.3 WATER ISSUE IN BRAZIL

"Brazil is a great paradox in the field of water access: it has 12% of the fresh surface water reserves of the planet, but its cities experience the most serious supply problems".
- Marussia Whately[1]

In colonial times, the water in Brazil was considered "nobody's", which encouraged an uneven and predatory use. Only in some cases (e.g. when water was scarce) was its use regulated by the crown. Over time, the state expanded its operations with regard to water supply and regulation. Since then, hydrological resources have come to be seen as input (nineteenth century), infrastructure (1950s) and finally as a resource of the states or the Union (1980s). (GARZON, 2006)

In the 1990s, the state renounced its role as water provider, limiting itself to regulatory and planning functions. Water is now a public good, a limited resource with economic value. All questions regarding water use and management today are provided for by law valid since 1997.[2]

According to the mentioned law, water resources management must be decentralized and involve the **government, users and communities**. It should also always provide for **multiple water use**, although the priority use of water resources is **human consumption and animal de-sedation**. In addition, it clarifies that **charging for the use of water** resources aims to recognize its economic value and encourage rational use. The sums collected are applied to the concerned river basins and used to finance studies, programs, projects and works, as well as to cover administrative and implementation expenses of the entities that are part of the National Water Resources Management System.

That being said, it is possible to see that the legislation seeks to safeguard democratic processes when managing water. However, it is on this tariff issue that democratic water management finds its first barrier.

(1) Coordinator of "Aliança pela Água". Talk in the 3rd conference of Water and metropolis, organised by We Are Water Foundation and Casa Amèrica Catalunya. Available at: www.wearewater.org/en/brazil-so-much-water-and-yet-so-little_286801 Accessed in: December 2019.

(2) Law No. 9,433, of January 8, 1997. Institutes national water resources policy, creates national water resources management system. Available at: planalto.gov.br/ccivil_03/LEIS/L9433.htm Accessed in: December 2019.

About 50 million Brazilians (25.4% of the population) live on the so-called "poverty line" with a household income equivalent to $ 5.5 a day. The highest poverty rate occurs in the Northeast Region (focus of this research), where 43.5% of the population fall into this situation. (OLIVEIRA, 2017)

To alleviate inequality in terms of access to water, (cheaper) social tariffs have been set according to household income. However, BRITTO (2015) argues that this measure has not been sufficient to guarantee the supply of water and sanitary infrastructure to the poor.

The author comments on social tariff models and how they could be improved. Finally, she argues that water used for basic needs (e.g. drinking, cooking, hygiene) cannot be treated as a commodity when it comes to securing it as a human right. However, this possibility is currently refuted by service providers, who claim this would stimulate waste.

In addition, it is also worth discussing two other attempts regarding the expansion of water Accessed in the semiarid region. The first one is a **public action for rainwater harvesting**, while the second is a **public-private initiative for underground water extraction.**

In 2001, a program was set up to build one million **cisterns to capture rainwater** in rural areas.[3] These cisterns are constructed from pre-cast concrete slabs and have a storage capacity of 16,000 litres of water. The construction of the cisterns is accompanied by guidelines on purification of rainwater for consumption purposes and their conscious use. (GOMES et al, 2015)

GOMES et al (2015) applied empirical methods to evaluate the practical application of the program in two states (Minas Gerais and Paraíba) and concluded that the program is successful in terms of its immediate purpose but fails in the social dimension. This is because the program is a benefit of public assistance and not a citizen achievement, so the solution does not involve knowledge of traditional rural practices. The authors reinforce that each region has its particularities and that it is not for the state to impose on them all the same solution, as if the semiarid region were homogeneous in terms of economic and socio-cultural practices.

Regarding **private initiatives**, FERREIRA et al (2015)

(3) Training and Social Mobilization Program for Living with the semiarid - "One Million Rural Cisterns" (free translation, from the Portuguese Programa de Formação e Mobilização Social para Convivência com o Semiárido – Um Milhão de Cisternas Rurais.

list a series of solutions that they call “secondary capillary supply systems”: actions promoted directly by users and therefore not managed by the state. These include: private mineral water sources, excavation of tubular wells, construction of reservoir and treatment plants. In all cases, the end consumer purchases water for their own consumption, which is sold in carboys at retail, or by tank cars. Naturally, all these actions require state approval to be carried out. The state then evaluates each request and may or may not allow it to be made. In this sense, several companies are attracted by the possibility of profit from the commercialization of water, especially in places where it is scarce, as in the semiarid region.

Alternatively, the state itself may promote large-scale well drilling programs. This is what happened in Ceará, where the state government has encouraged the excavation of tubular wells in areas most affected by drought. These were made by private companies, which were funded by the state. Thus, between 2015 and 2018, 6,492 wells were drilled, which corresponds to 50% of all existing wells in the state. (SOHIDRA, 2018)

However, the audit performed identified a number of irregularities in this process. Among them: delays in the execution or execution of only part of the service and overpricing (indicative of corruption), as well as the absence of environmental study and soil analysis before excavation, which culminated in the construction of “dry wells”. (CGU, 2018)

Given what was discussed earlier in this chapter and the issues presented here, some points can be concluded. First, it is understood that the water legislation has a democratic intention, which reflects the governmental principles of the country. It is also understood that the programs and actions carried out by the state dialogue with the democratization of water in order to expand the access of this good in drier regions. However, the process moves away from the true democratization of water with regard to public engagement and the inclusion of marginalized communities.

The Brazilian government has opted for large-scale programs, which generally focus on numbers over quality. In order to meet high demand and fulfill the state’s function of ensuring water for all people, the state tends to standardize actions and repeat them at different points in a large area. In this sense, the programs not only ignore the knowledge of the population and their traditional practices but also fail in terms of effectiveness, as they miss the opportunity to optimize action in each particular case.

Similarly, it should be remembered that the issues discussed here, which generally reflect the practical positioning regarding water in the country, do not include nature-based solutions. Just as large-scale actions exclude the population, neither do they seem to consider the natural and cultural cycles of water and the influence of flora and fauna in this process. Especially in rural areas, programs have focused on obtaining immediate water (groundwater or rainwater) rather than understanding how its use occurs within productive flows.

In addition, there is the problem of water commodification. In an attempt to advocate for conscious use of water and to conserve resources, there has never been any real space to discuss access to water for those unable to afford it. On the other hand, the state that private companies profit from water extraction. This position brings the Brazilian semiarid closer to a landscape of autocracy, being strongly influenced by economic forces, even though Brazil is a democratic state.

Finally, it is understood that although many of the steps leading to the democratization of water go through political decisions (which is beyond the scope of this research), landscape design may reflect the desire for democracy by translating its ideas into spatial solutions. This means: studying the water cycle and productive flows and linking them as far as possible to people’s knowledge and traditional practices, culminating in a site-specific design. Thus, even if restricted to a certain area, it would be possible to make room for a landscape of democracy.

2.4 WETNESS AND SUSTAINABLE DEVELOPMENT

In this last part of the theoretical framework, important concepts will be presented, widely used throughout this work: wetness and sustainable development.

Wetness everywhere

If water separated to be somewhere is in crisis today, wetness negotiated everywhere holds the way forward.

- Anuradha Mathur and Dilip da Cunha[1]

MATHUR and DA CUNHA (2020) use the term wetness to differentiate it from the common understanding of what "water" means. For the authors, it was generally agreed that it was water than land, as if in the world these two differentiable entities existed. So the land would be the entity to be drained, while water is the entity that receives this drain.

The authors understand that this way of differentiating land and water was a dichotomy created to separate the inhabited surface of the earth from that not inhabitable by human beings. From this differentiation the works of architecture and engineering, as well as interventions in the landscape were made considering that this separation needs to be clear and reinforced through design.

However, this practice, being repeated over the years, now faces the reality in which we live: rising sea levels, due to melting glaciers, a consequence of climate change. And if, on the one hand, some areas are "threatened" by water pressure, others suffer from water scarcity: the effect of worsening extreme conditions. (MATHUR and DA CUNHA, 2020)

Thus, the mentioned authors propose the following reflection. If for years and years humanity has worked to maintain land and water as a separate entity and we find ourselves in a crisis situation today, what results would we have had if we changed the way of thinking? What if, instead of separating the entities, we negotiated the co-existence of the two in the same space? This space would therefore be one in which water and land cannot be fully dissociated from water. A space where wetness, to a greater or lesser degree, is everywhere.

Wetness, therefore, would be a term used to make clear the understanding that humidity is omnipresent. It is not just in the rain that falls or in the liquid that flows from the surface of the earth to the lagoons, rivers, seas and oceans. Rather, it is mixed with the soil, within the leaves, flowers and fruits, as a component of living beings, including humans. All elements of the landscape contain wetness, to a greater or lesser extent, just as every landscape has its share of wetness, from tropical forests to deserts.

Based on this understanding and this paradigm shift, we also changed the way of designing. A way that negotiates the concentration of wetness, which always seeks to expand in what possible understanding of the hydrological cycle. And it is under this paradigm that the present work is developed.

Sustainable development

The concept of sustainable development was first given in the Report of the World Commission on Environment and Development: Our Common Future, in 1987[2]. In it, the term was described as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (pp. 44) In this concept, the word "needs" refers to meeting the demands of those poorest on the planet, that should be a priority - which includes food, shelter, clothing and jobs.

Also according to the aforementioned report, inequalities will always eventually lead to crises in the environmental sphere, among others. In this sense, sustainable development requires economic growth and improvement in people's quality of life.

Thus, in general, the 1987 report established three pillars for sustainable development: **planet,**

(1) Available at: www.tandfonline.com/doi/full/10.1080/10464883.2020.1693843 (Accessed in May 2020)

(2) Known as the Brundtland Report. Available at: sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf (Accessed in May 2020)

people and profit. However, in 2010, a fourth pillar, **culture**, was officially proposed. The proposition was made through the document entitled *"Culture: the Fourth Pillar of Sustainable Development"*[3], presented at the third World Congress of United Cities and Local Governments (UCLG).

This addition recognizes the merit of the knowledge of the inhabitants, which was essential for the establishment of the community, in a resilient way, over the years. In this way, it is encouraged that culture and cultural heritage in general be considered in all sustainable development policies. Therefore, culture contributes to development insofar as it enables more effective interventions, promotes inclusiveness, diversity and equality in search of sustainability, resulting in benefits, whether economic or not. (BLOND, 2015)

At this point, it is important to tell apart the terms **sustainable development** and **sustainability** itself.

(3) Available at: cultureactioneurope.org/advocacy/culture-the-fourth-pillar-of-sustainable-development-a-uclg-statement (Accessed in May 2020)

According to UNESCO[4], sustainability is the ultimate goal, to be achieved in the long term through different processes and paths. On the other hand, sustainable development refers precisely to the set of ways adopted to achieve this greater objective.

Ultimately, it is important to stress how water relates to sustainable development. In the specific case of water, the Brundtland Report discusses the pressure that this resource has been suffering over the years, both in terms of pollution (carried out in water bodies, but also in groundwater), in addition to excessive changes in water bodies, which impacts the watersheds; citing as an example of this the construction of massive dams from the 60s. (WCED, 1987)

Furthermore, the report cites yet another harmful practice for water availability: degradation of soils. To produce food, fuel, wood, or simply occupy a land, the human being has, for years and years, destroyed the native vegetation.

(4) United Nations Educational Scientific and Cultural Organization`s website: en.unesco.org/themes/education-sustainable-development/what-is-esd/ sd (Accessed in May 2020)

In doing so, the soil loses its natural protection and suffers erosion due to the runoff of water, created by rain. With erosion, the soil is worn out and is no longer able to retain water, making it unsuitable for food and wood production to continue (since new vegetation is impossible to develop, leading to desertification). (pp 31).

Therefore, it is concluded that sustainable development is intrinsically related to local culture, the search for equality and the conscious use of basic resources, such as water. And although economic growth is an integral and inseparable part of achieving a more sustainable world, it can never be the only way to achieve it.

On the left: Puddle on cracked ground surface.
Source: dreamstime.com

METHODOLOGY

Closing the methodological triangle (defined by problem-theory-method), this chapter presents the remaining information for understanding the methodology of this research. First, the research strategy and data collection methods are explained. Subsequently, the methodological concept is presented.

3. METHODOLOGY

3.1 RESEARCH STRATEGY

This work follows the Research Through Design (RTD) strategy, which consists of a "*systematic search for the most efficient solution*" by means of designing. (NIJHUIS; BOBBINK, 2012)

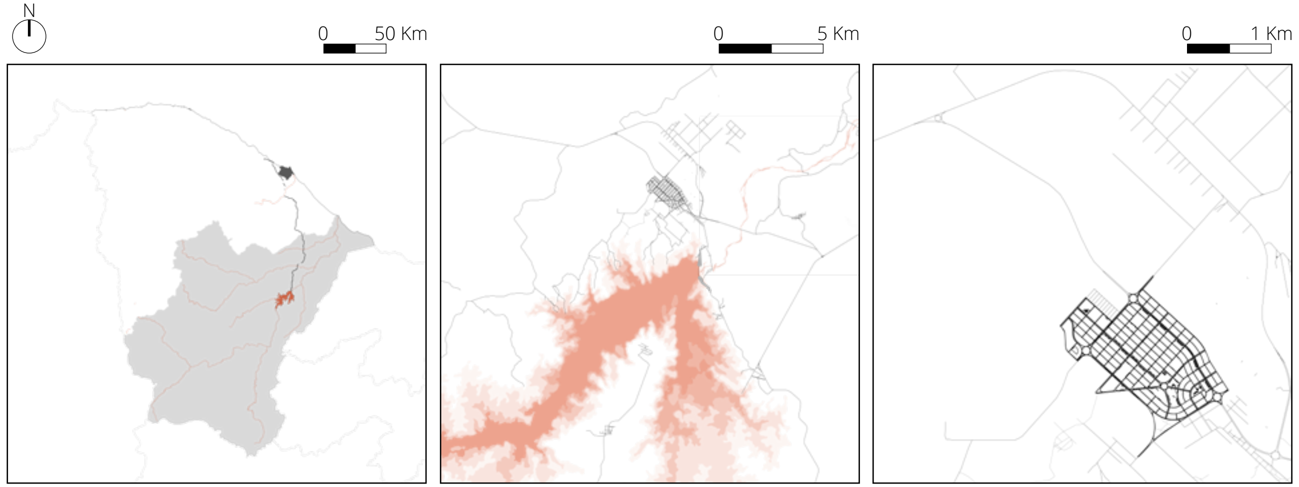
In order to achieve that, we worked through different scales. On a large scale (regional), the state of Ceará (1: 1,600,000), encompassing the regional water system and the hydro-graphic basin of the Jaguaribe river. On the metropolitan scale, we opted for the northern area of the Jaguaribara municipality, where the current urban centre is located, as well as part of the Castanhão dam reservoir, a stretch of the Jaguaribe river and the *Eixão das Águas* water channel (1: 50,000) . The local scale, then, consists of the current urban centre of Jaguaribara and immediate surroundings (1: 15,000). (image 3.1)

The research followed a mixed method approach, according to CRESWELL (2009), with both quantitative and qualitative data collection, obtained concurrently.

The quantitative methods adopted were: satellite images and remote sensing, georeferenced data (Geographic Information System - GIS) and other graphs and indices obtained in virtual portals of government and research agencies. Some of this information has also been extracted from scientific publications, especially specialized journals and theses. The quanti-data were used in mapping analysis for the regional and metropolitan scale.

The qualitative methods were use during the site visit, that took place in late January 2020. Interviews were conducted with inhabitants of the urban area of Jaguaribara, farmers (*Mandacarú*) and public sector representative (DNOCS). On the occasion, photographic and video records were also taken. Quali-data were used to produce analysis using the micro-story technique. (SECCHI; VIGANÒ, 2009)

Image 3.1: Limits of the study area at different scales.



Regional scale (Ceará) Metropolitan scale (Jaguaribara) Local scale (urban centre)

3.2 METHODOLOGY CONCEPT

Considering the larger perspective, understood here as the Brazilian semiarid region, we can see a range of conditions that unite different localities (e.g. weather conditions, recurring droughts). Each locality, however, is unique in its own history, social development, culture and even landscape features, existing inseparable from its own context.

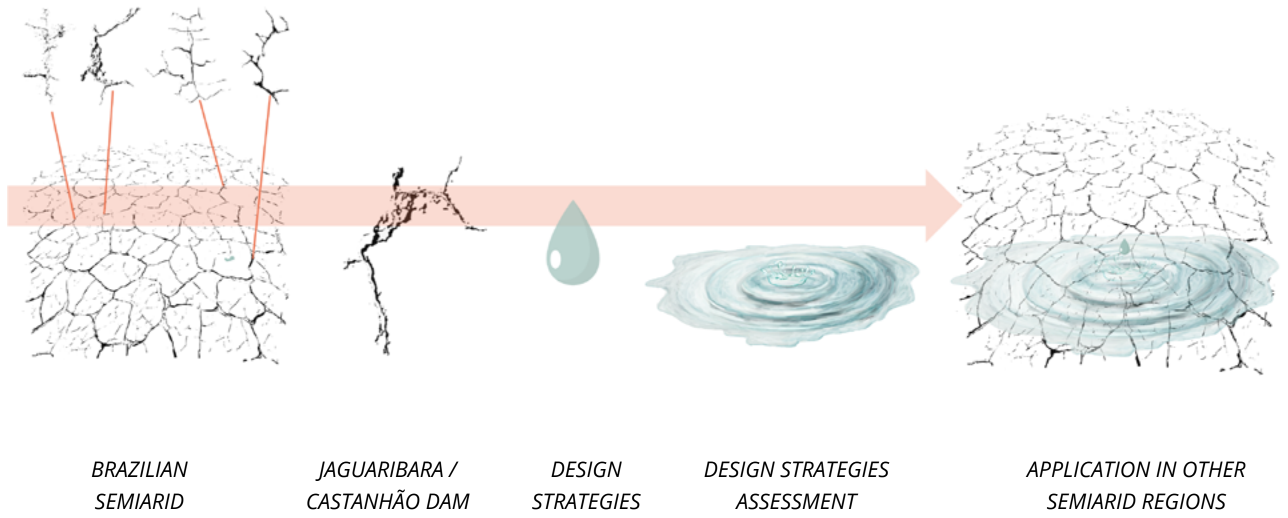
From a symbolic perspective, we can view the Brazilian semiarid as the ground cracked by excess the insolation while waiting for the coming rain. Each crack is unique in its size, shape and direction, just as each location of the Brazilian semiarid has its own singularities. The absence of water makes the ground cracks, as well as it is the drought that connects the different localities, stories and voices of the Brazilian semiarid.

Following the analogy, the proposed design strategies is here seen as a drop of water falling into a puddle. When the drop touches the surface of the water, it generates splashes and ripples that affect other points on the surface in different ways.

Thus, it is imagined that the design strategies represents the water drop itself, which touches directly on a specific point, understood here as the chosen area. Splashes, then, represent the different ways these ideas could be applied to other regions of the semiarid, adapted to respect the context of each locality.

Then, the first two stages of this process (**cracking pattern and zoom-in in one crack**) are presented in the next two chapters (Water and Flow and Micro (water) stories). The third step **(water drop**) is described in chapter 6. Finally, the last phase (**water splashes**) can be found in the final considerations of this work. Then, it is expected to provide fertile soil for further research to take forward what has been presented in work to be applied in other semiarid regions (**puddle on cracked ground**). (image 3.2)

Image 3.2: Illustrative diagram of the methodological concept.



On the left: Satellite image of the metropolitan scale
Source: Google Earth Pro (2019).

WETNESS AND FLOW

This chapter presents part of the analysis, corresponding to the regional and metropolitan scales. The analysis focuses on mapping wetness in the region, seeking its interfaces with the physical features of the territory, as well as land use. The analysis is followed by two concluding images that present the natural and cultural cycle of water, as well as the water flow in relation to the ecology and production flow in Jaguaribara.

4. WETNESS AND FLOW

4.1 CEARÁ

The Ceará state has 148,825 km² of area, being subdivided in 12 hydro-graphic basins, which aggregate rivers, streams, lagoons and dams (MEDEIROS et al, 2011). The Jaguaribe basin, comprises 50% of this whole area, draining surfaces occupied by more than four million and fifty-three thousand inhabitants. (NASCIMENTO, 2011)

As is generally the case in semiarid regions, the fluvial flow in Ceará, which is inconstant and week due to the irregular rainfall, has a low relief carving capacity, which reflects in small topographic differences between the inter-flows and the bottom of the valleys. (NASCIMENTO, 2011) The Jaguaribe river is the one with the greatest depth in the state, having recorded 4.16m in its deepest stretch when it was at its fullest at the end of the rainy season of 2020.[1]

On the other hand, unlike most semiarid regions in the world, where rivers generally flow into enclosed depressions, rivers in Ceará flow into the Atlantic Ocean. It is precisely in an attempt to "hold" this water that the dams are built throughout the entire territory. The construction of the dams, though, alters the flow (input and output) of solid and dissolved substances, culminating in changes in the hydro-chemical conditions of the waters. For this reason, 85% of the state's surface waters are considered of only reasonable quality. (image 4.1) (NASCIMENTO, 2011)

Following the same trend as surface water, the underground water in Ceará is also mostly of reasonable quality, being of good quality close to the mountains (south and west of the state) and of poor quality in the northeast portion - where there is a concentration of shrimp farming, which release high amount of salt into the soil In addition, the productivity of aquifers is also considered low or very low in most of the state, with flow rates between 1 and 5 m³/h. (image 4.2) (IBGE, 2013)

Aquifer productivity is linked to the state's

(1) Information obtained from a news site available at: www.iganalapraca.com.br/rio-jaguaribe-ultrapassa-4m-de-profundidade-no-trecho-em-iguatu. Accessed in May 2020.

The water potability is evaluated in terms of its physiochemical characteristics and based on the parameters established by Schoeller (calcium, sodium, magnesium, chloride, sulphates and dry waste), which define six potability classes: good, passable, mediocre, bad, momentary and non-potable. IBGE (2013)

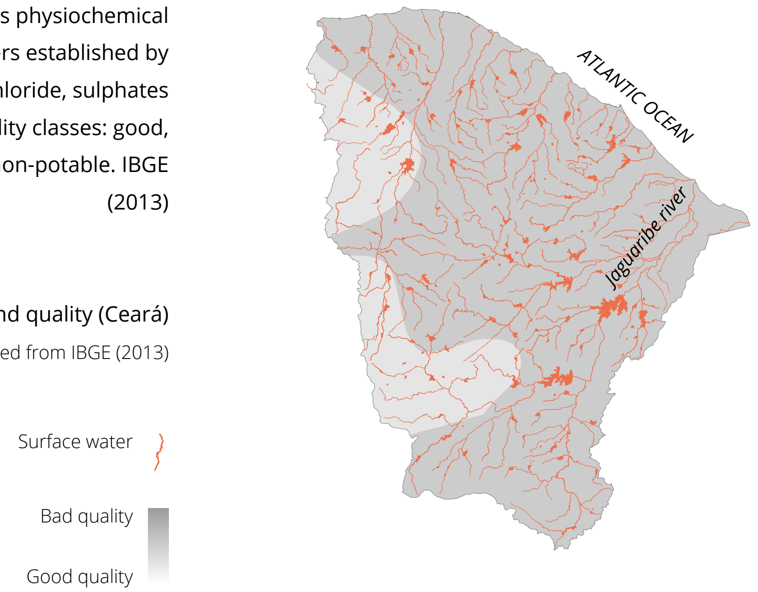


Image 4.1: Surface water: location and quality (Ceará)

Source: Created from information extracted from IBGE (2013)

The productivity of the aquifers was given from the flow values of monitored tubular wells in the region. IBGE (2013)

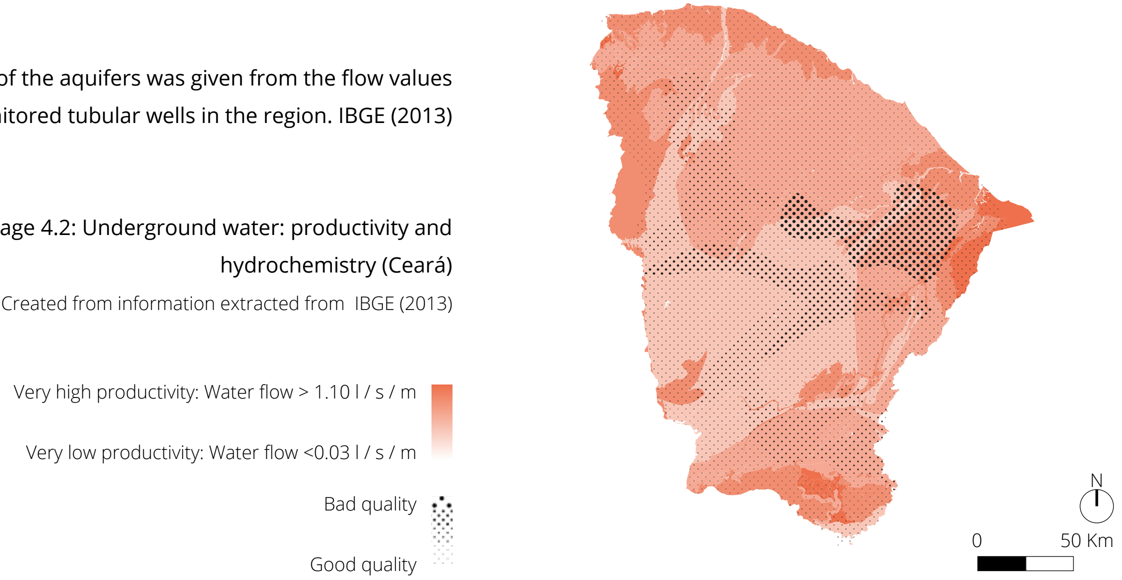


Image 4.2: Underground water: productivity and hydrochemistry (Ceará)

Source: Created from information extracted from IBGE (2013)

Image 4.3: Geomorphology (Ceará)

Source: Adapted from IBGE (2013).

- Recent sedimentary covers
- Sedimentary rocks
- Metamorphic rocks
- Intrusive igneous rocks

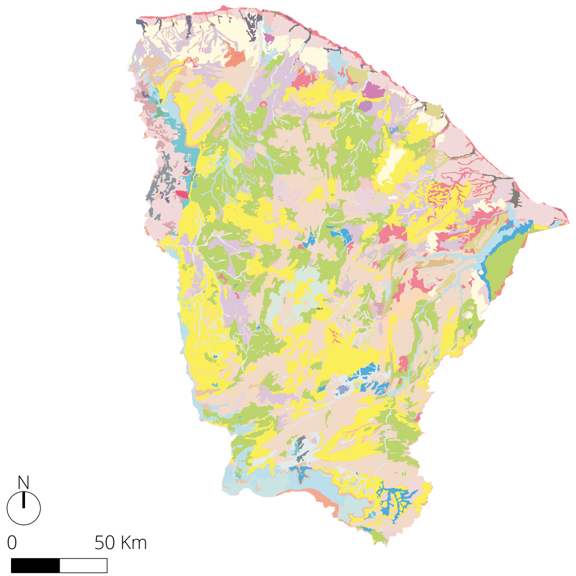


Image 4.4: Soil map (Ceará)

Source: Adapted from IBGE (2013).

Clay (-- permeability)

Sand (++ permeability)

Image 4.5: Phytoecological Units (Ceará)

Source: Adapted from IBGE (2013)

- Cerrado / Xeromorphous rainforest (cerradão)
- Carrasco
- Tropical subperenifolia forest (wet forests)
- Semideciduous tropical forest (dry forest)
- Thorny deciduous forest (arboreal caatinga)
- Dense shrub Caatinga
- Open shrub Caatinga
- Complex of coastal zone
- Mixed forest (riparian forest + carnauba + dicots)
- Maritime evergreen forest (mangrove)

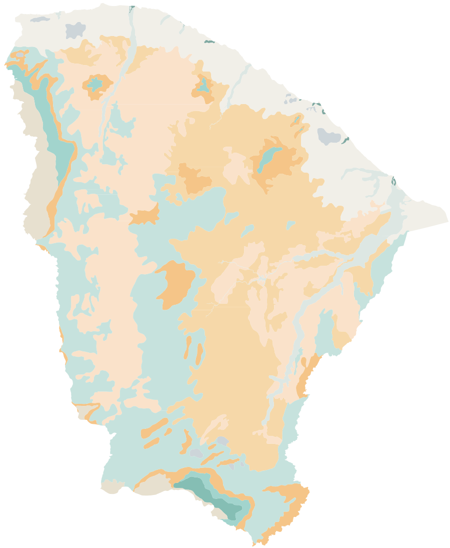
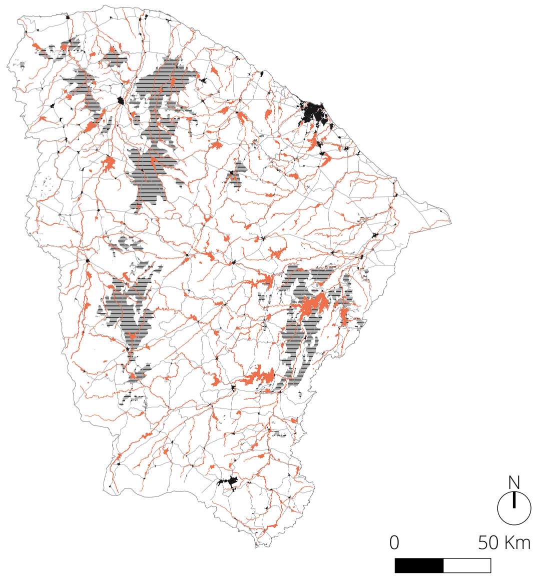


Image 4.6: Areas susceptible to desertification, urban areas and road network in Ceará.

- Road network
- Surface water
- Urban areas
- Areas susceptible to desertification



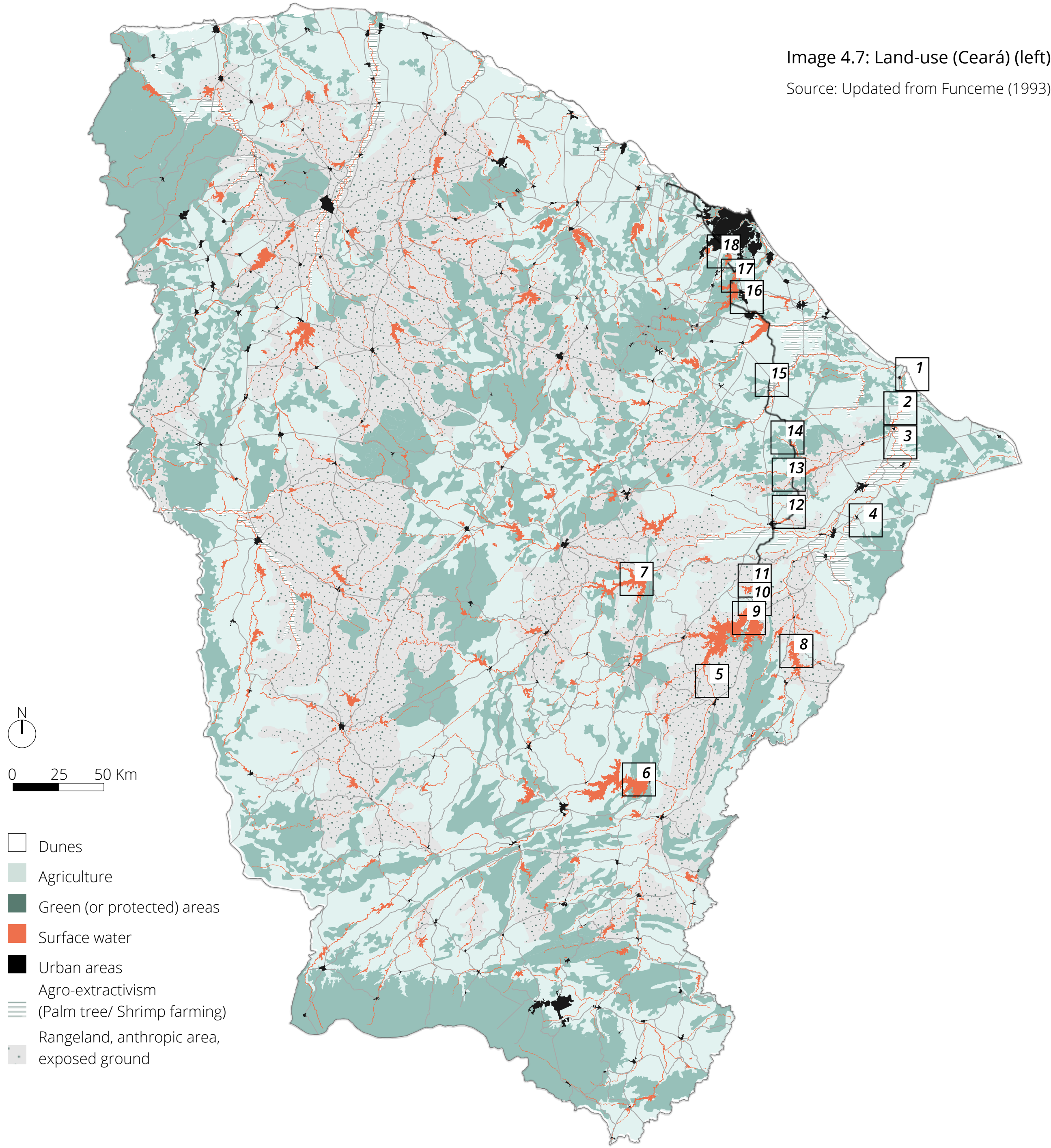


Image 4.7: Land-use (Ceará) (left)

Source: Updated from Funceme (1993)

geomorphology. Roughly speaking, the least productive in Ceará are fissural aquifers, found in metamorphic and igneous intrusive rocks, while the most productive ones correspond to those of sedimentary rocks. (image 4.3)

At this point, it is important to point out that only 8.6% of the surface water seeps into the sea, while 3.4% follow that same destination via underground routes (aquifers), totalling 12% of losses from the continent's waters to the ocean. The remaining 88% of water loss occurs through evaporation or evapotranspiration. (MARINS et al, 2003) This is not only because of the high insolation intensity (6,250 Wh/m².day), but also due to the weak surface protection capacity. (MARINS et al, 2003)

The protection capacity is given by vegetation and soil. The soils of Ceará are more clayey the closer to the water bodies and more sandy in the inter-flows. However, highly sandy soils are rare, which makes rainwater run off the surface instead of seeping in. (image 4.4) When running on the surface, in addition to being vulnerable to evaporation, the water ends up eroding the soil surface culminating in increasingly shallow soils, with a low capacity to hold both moisture and organic matter. This last fact ends up being negative not only for agriculture, but also for the recovery of native vegetation in general. (NASCIMENTO, 2011)

The vegetation in Ceará has high variability and is extremely adapted to climatic conditions, being able to develop and leave the state of hibernation in the first rains of the year. (image 4.5) It is also able to reduce the flow of water on the surface, protecting soil from erosion. However, the state's land occupation has occurred in such a way that the native vegetation cover has suffered considerable deforestation. Because of this, some regions in the state are in the process of desertification. (image 4.6) (NASCIMENTO, 2011)

The activities that are most responsible for deforestation are agriculture and cattle grazing, with the latter having a greater impact on this process. This is because cattle consume pioneer vegetation at a much faster rate than the regenerative capacity of the vegetation, due to the soil being poor in organic matter because of the erosion caused by the run-offs. (image 4.6)

The map in image 4.7 shows land use in Ceará. The numbered squares correspond to zoom-ins (10kmx10km) along the Jaguaribe river (1-9) and along the water channel *Eixão das Águas* (10-18), which can be seen on the following pages.

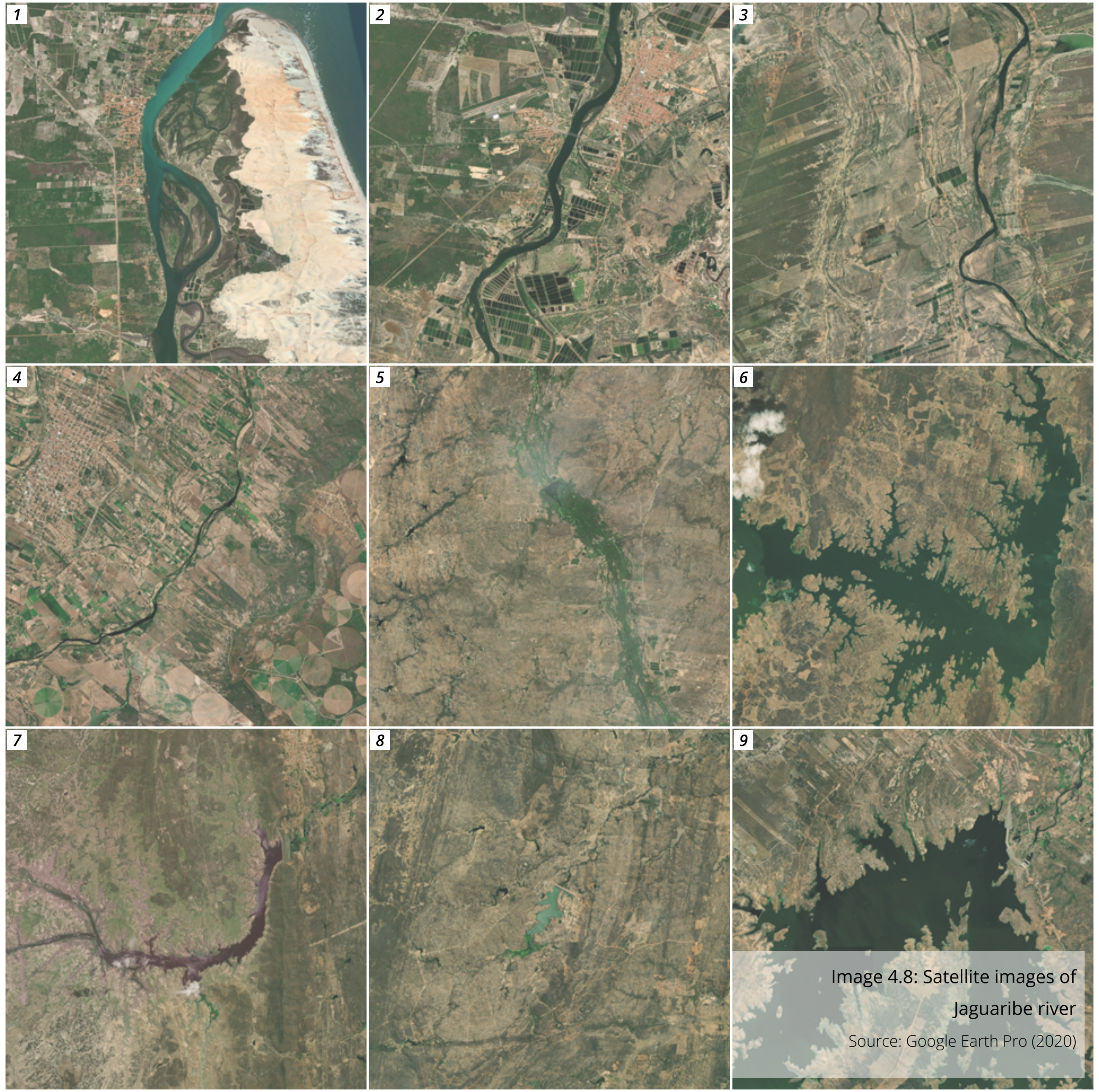


Image 4.8: Satellite images of Jaguaribe river

Source: Google Earth Pro (2020)

Image 4.9: Satellite images of the water channel *Eixão das Águas*

Source: Google Earth Pro (2020)

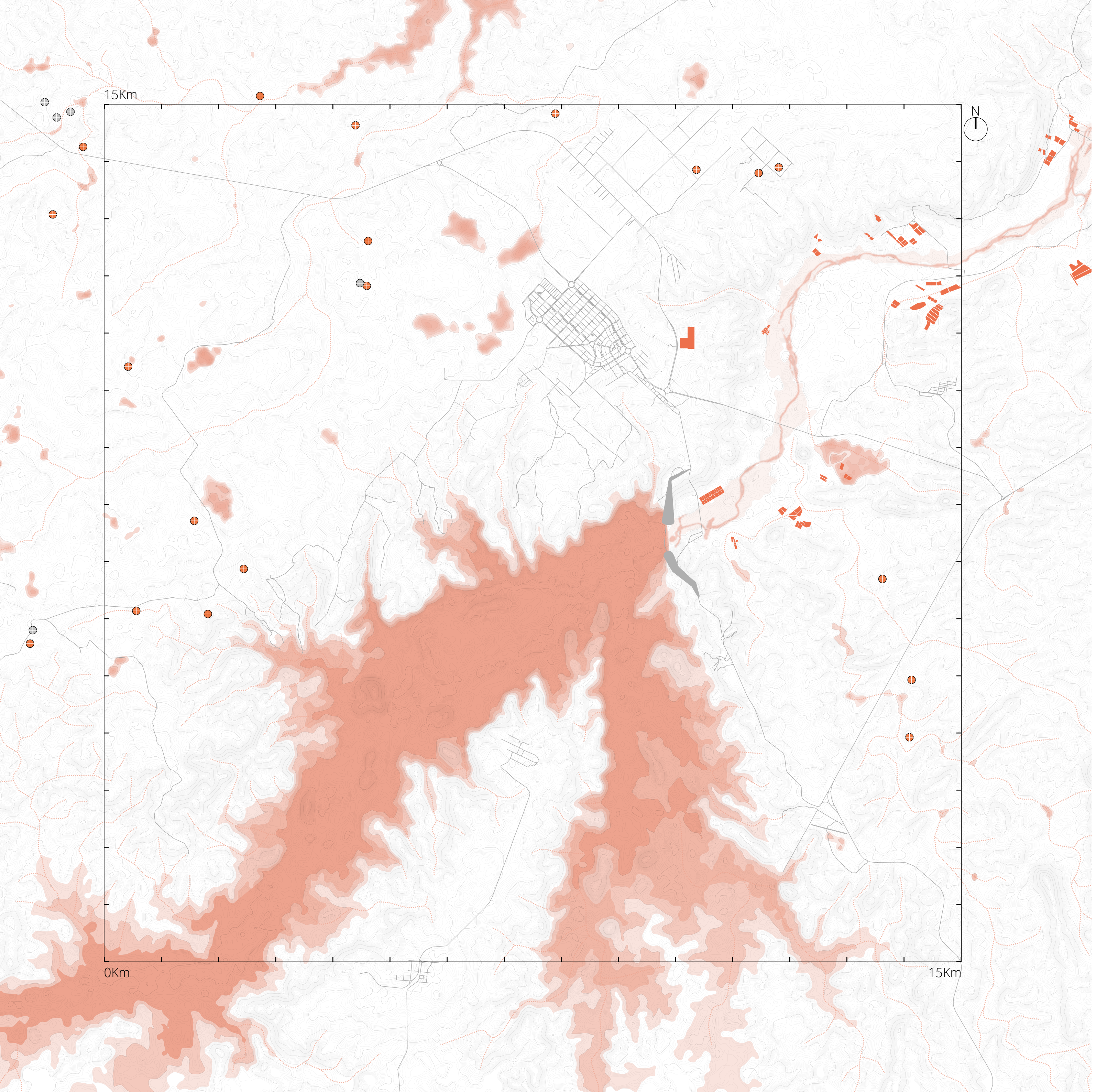


Image 4.10: Surface water, contour lines and registered wells.

- Jaguaribe river
- Castanhão dam / reservoir
- Water channel (*Eixão das Águas*)
- Irrigation channel (*Mandacaru* and *Curupati*)
- Thalweg (higher water volume lines during run off)
- Dry wells
- Registered wells
- Water treatment plant
- Aquaculture (river plains)
- Accumulation of surface water during rainy season
- Buildings and streets

4.2 JAGUARIBARA

Mapping the wetness

The map on the left illustrates the water available at a given time in the metropolitan scale of this work. In it, we can observe the water reservoir held by the Castanhão dam, and the stretch of the Jaguaribe river that flows downstream, east of the dam.

It is also possible to see the water lines: a stretch of the *Eixão das Águas* water channel, which transports water from Castanhão to the metropolitan region of Fortaleza, as well as the irrigation channels of the productive areas Mandacarú and Curupati irrigation agriculture.

In addition, it is possible to check the location of wells registered in the region, as well as the excavated tanks of aquaculture practice.

Finally, the paths on which the run-off water is concentrated, as well as the points where the water is concentrated on the surface are also represented.

Comments and images related to each of these forms of water can be seen on the following pages.

Castanhão

The Castanhão dam has water storage capacity up to the quota 91, when the spillway was installed. With the reservoir completely full, the dam reaches its maximum capacity of 6.7 billion m³. However, this actually happened only once, in 2009, although the floodgates were also opened in 2004. (image 4.11)

Image 4.11 shows the variation in the volume of water stored by Castanhão from its inauguration in 2002 until January 2020. It is also possible to observe the relationship between precipitation stored volume, as well as the spatial variation, in the shape of the water, over the years.

It is possible to perceive, therefore, that the water shape of the Castanhão has varied a lot over the years, which does not occur within the same year. Due to the high dimensions of the reservoir, the volume difference of up to 18% in dry months and rainy months is not so noticeable. (image 4.12)

Since its inauguration, the lowest level recorded occurred in 2018, when the water was in the 65.76 quota, which corresponds to 2.08% of the dam's storage capacity. In 2020, the waters were close to that level, reaching 66.46 (2.39% of capacity).

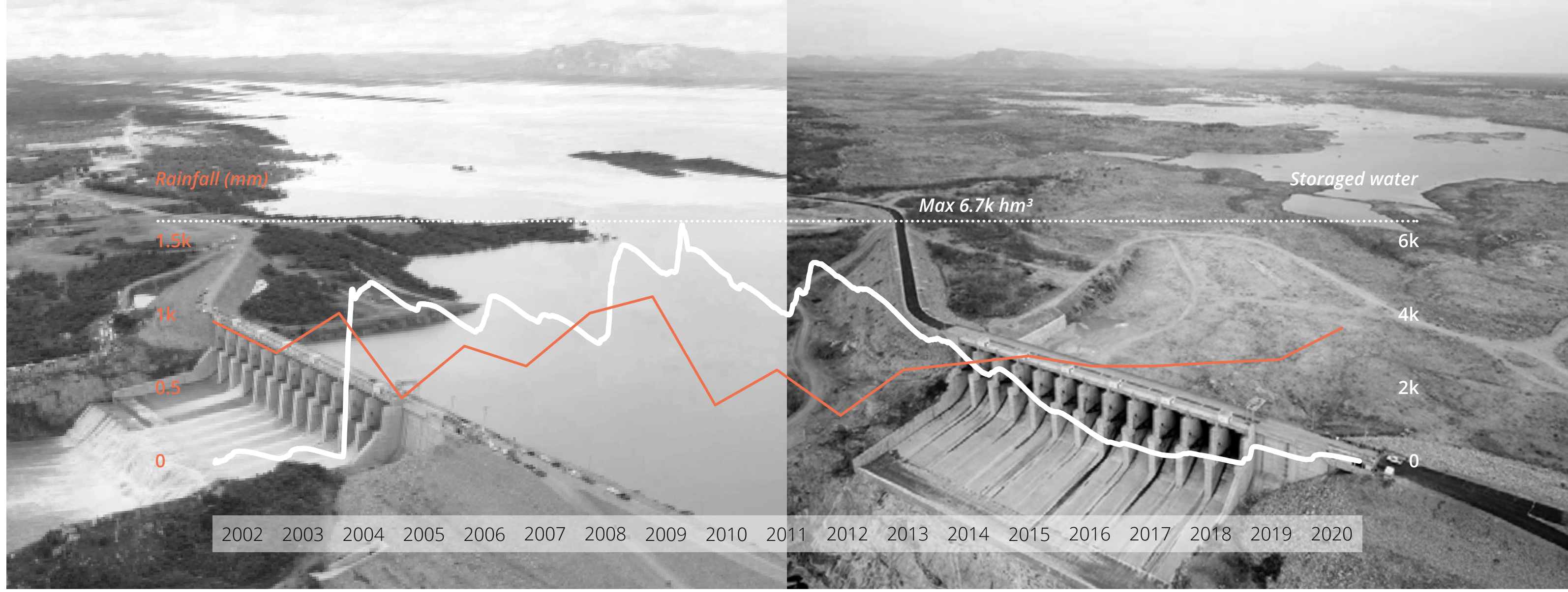
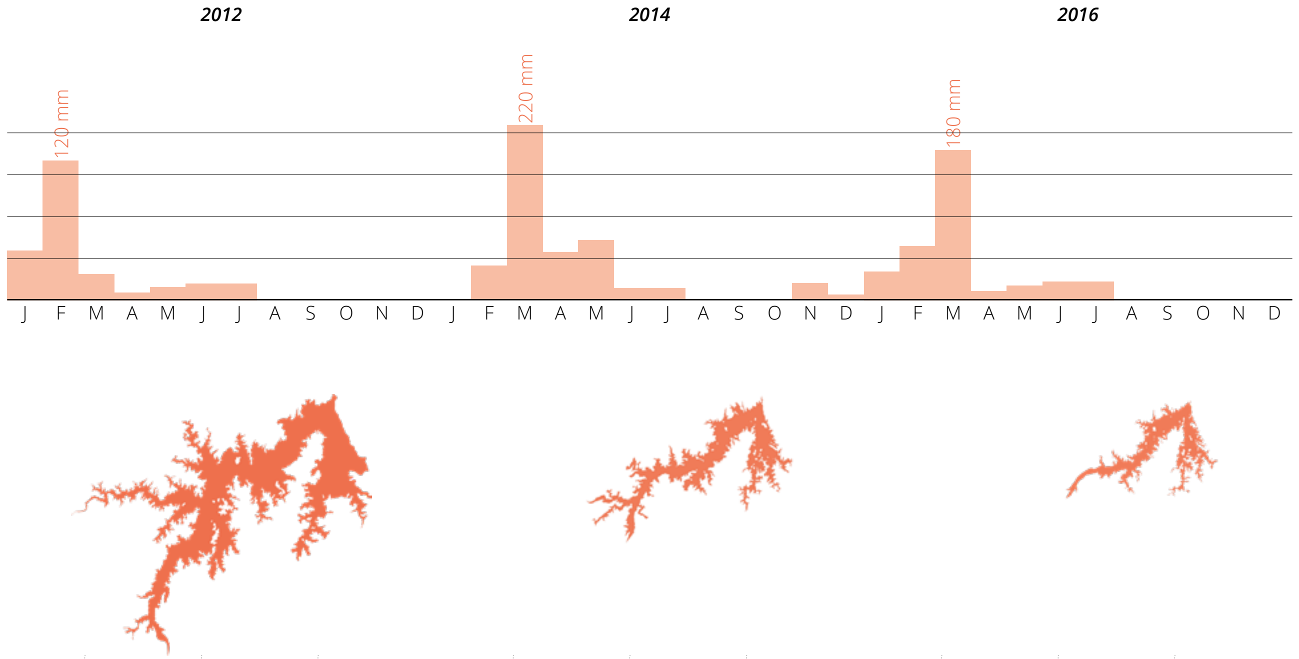


Image 4.11: Changes in the volume stored in Castanhão over the years and its relationship with the rainy season.

Source: created from information extracted from HIDRO.CE (2020)



	JAN	JUN	DEZ		JAN	JUN	DEZ		JAN	JUN	DEZ
hm³	4.929,35	4.659,41	3.725,88	hm³	2.693,31	2.625,68	1.728,09	hm³	741,93	613,19	341,54
%	73,57	69,54	55,61	%	40,18	39,19	25,79	%	11,07	9,15	5,1

Image 4.12: In-depth data on the variation of stored water volume and precipitation at the beginning, middle and end of the year in 2012, 2014 and 2016.

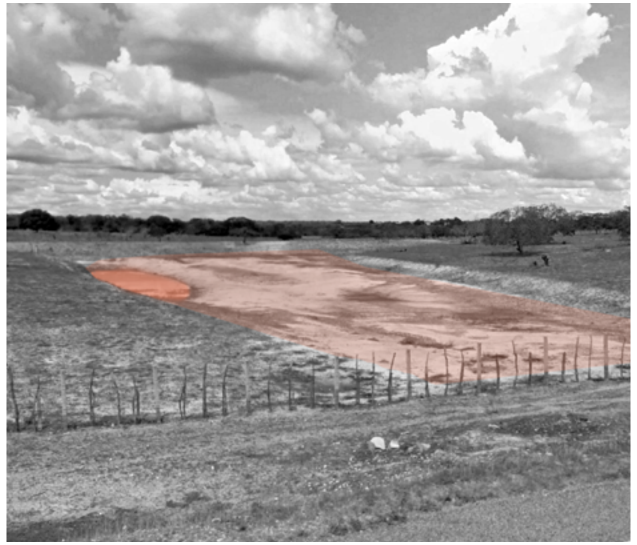
Source: created from information extracted from HIDRO.CE (2020).

Jaguaribe river

Before the construction of the dams, the Jaguaribe river was known as the largest dry river in Ceará, because its bed dried completely during droughts. Nowadays the Jaguaribe river has flow controlled by dams and check-dams along its course, which allowed its perpetuation. Except for the dams, though, the river flows naturally through the territory - it is therefore a meandering river. However, as its flow is low (9m³/h from Castanhão), its waters cause little change in the relief, culminating in a shallow river with wide river plains.

Thalwegs (temporary creeks)

The thalwegs are lines that are found in the deepest part of the topography, where most of the run-off waters flow - in simple terms, they are literally the preferred routes for rainwater. These are valuable potions for landowners, who try to make the most of the water that runs down the surface. For this reason, some of them dig the ground in the thalwegs so that water is accumulated in the region and can be drunk by cattle.



Accumulation of surface water

After running through the thalwegs, the waters of the runoff can find rivers, lakes or depressions on the surface of the soil - which end up becoming temporary lakes, only existing during the rainy season. On the metropolitan scale, we can see many of these temporary lakes in the north-western portion (image 4.10). These are extremely important to hydrate the fauna of the Caatinga. Landowners naturally give these waters for their own cattle to drink.

Image 4.13: Water in Jaguaribara: Jaguaribe river (left), thalwegs (middle), temporary lakes (right).

Adapted from Google Street View (2020)

Irrigation channels

The water lines seen on the map correspond to the water channels. In addition to *Eixão das Águas*, about which much has already been said in this work, we also see two irrigation channels in this region: irrigated agriculture (Currupati irrigação, south of Castanhão) and irrigated farming (Mandacarú, north of the dam). Both channels are made of concrete and assist in the transport of water from Castanhão to the productive areas.

Aquaculture

It is possible to observe a reasonable number of water tanks north of the Jaguaribe river. One of these tanks corresponds to the fish farming linked to the Castanhão river. It supplied young tilapia fish for the fish farming inside Castanhão until March 2020, but now the fish produced are released into the river to compensate for the dam's ecological damage. The rest of the tanks are shrimp farming, an activity that has spread to the Jaguaribe river alluvial plains over the years, although its greatest concentration is closer to the mouth of the river.

Wells

Although most of the state's aquifers are of low productivity, the areas just above the dam and along the north bank of the Jaguaribe river are suitable to the installation of wells. This is because this region is composed of sedimentary rocks, with porous aquifers of productivity of around 10 m³/h that can be reached at a depth of 7,5 m. In the other regions surrounding Castanhão, however, fissural aquifers predominate, whose flow is between 1-3 m³ / h, found at a depth of about 60m.

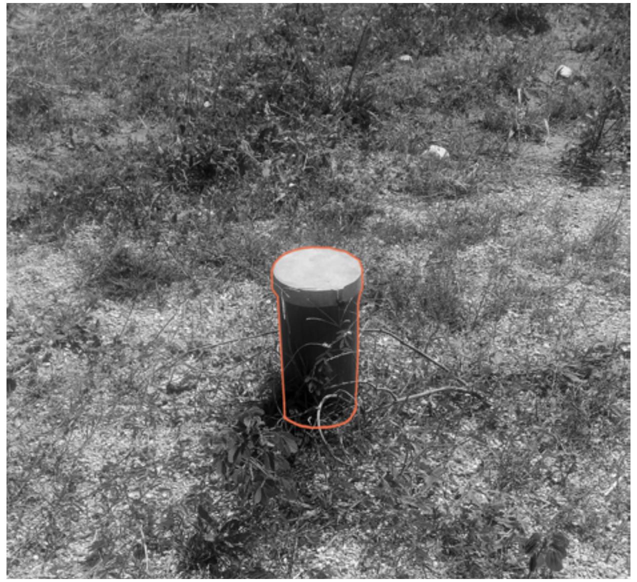


Image 4.14: Water in Jaguaribara: Irrigation channel, aquaculture tanks, well (missing the fountain).

Source: Adapted from Google Street View (2020) and personal collection.

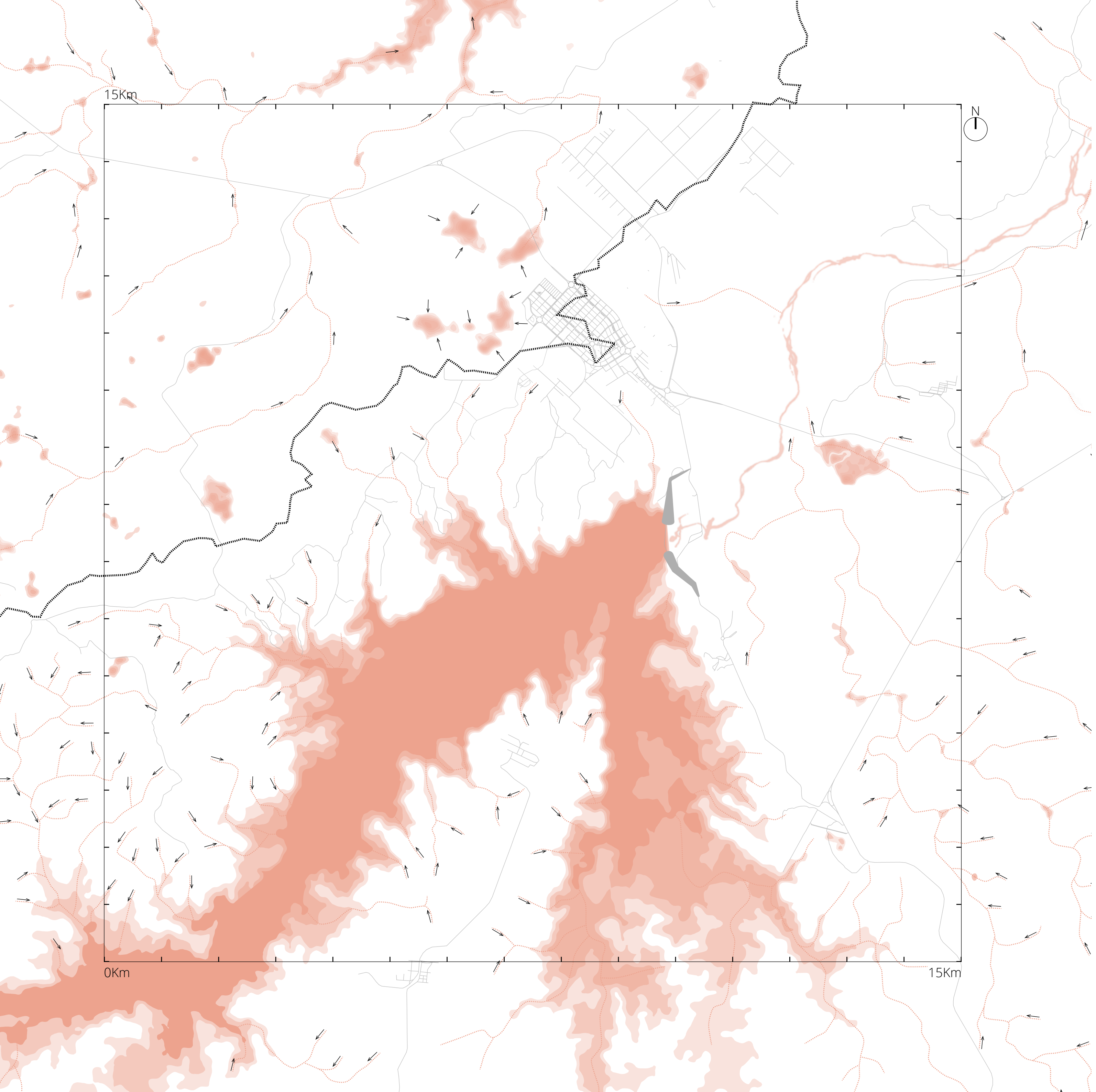
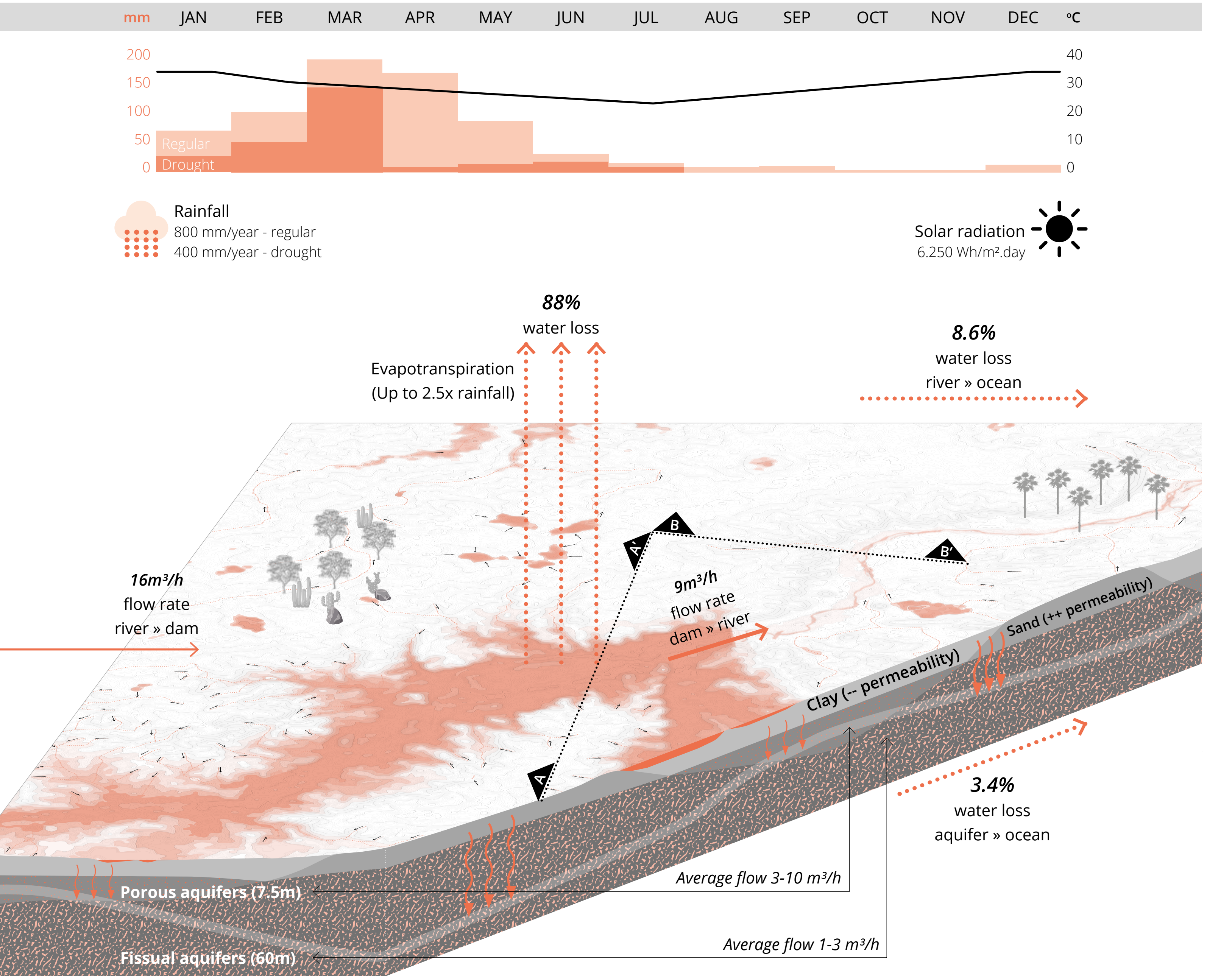


Image 4.15: Water drainage, run of direction, and ridges.

Water drainage

The map in image 4.15 illustrates how the region's waters are drained. Below the Northwest portion of the map, there is a dashed black line cutting the region at the height of the urban centre of Jaguaribara. This line corresponds to the ridge, a topographic characteristic related to the highest points of the terrain. Therefore, from this line, the waters flow to one side (from Castanhão and the main course of the Jaguaribe river), or to the other (Banabuiú River, a tributary of the Jaguaribe river). The urban centre of Jaguaribara, therefore, is located not only on the drainage boundary, but also in the highest sector of the region - having been chosen by the inhabitants precisely because of this characteristic.

In addition, the map shows the direction of runoff of surface waters, thalwegs and areas of water accumulation on the surface (temporary lakes). It is possible to see that close to the urban centre of Jaguaribara there is a natural tendency to accumulate water. This can sometimes be observed in the landscape from a distance, since in flooded lands grows vegetation typical of Caatinga's riparian forest, with carnauba palm trees (*Copernicia prunifera*), which reach up to 15m as adults, among other dicots. Flooded areas where



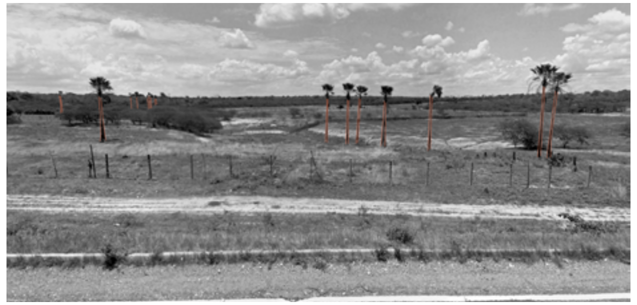


Image 4.16: View of occasional wetland from the road (rangeland).

Source: Adapted from Google Street View (2020)

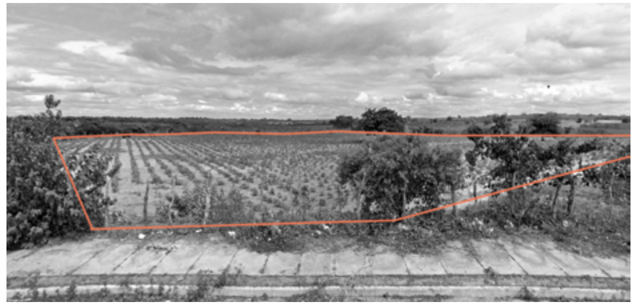


Image 4.17: View of occasional wetland from the road (agriculture).

Source: Adapted from Google Street View (2020)

Image 4.18: Natural and cultural water cicle in Jaguaribara. (left)

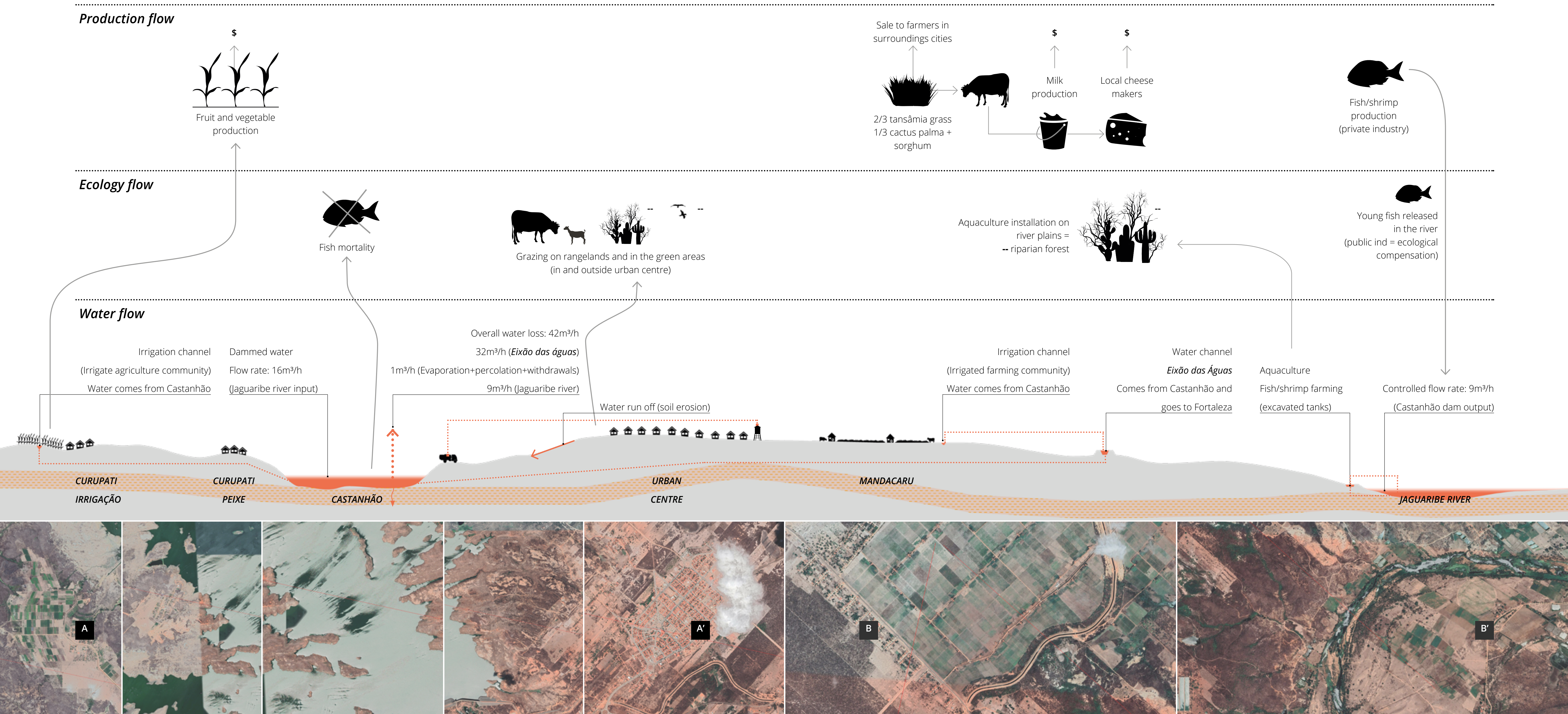
Image 4.19: Flows in Jaguaribara: water, ecology and production (current situation). (next page)

no carnauba palm trees are observed, constitute strong indication that it undergoes anthropic transformations (deforestation, agriculture, or rangeland).

The photographs on the right show the view, from the road, of two wetlands close to the urban centre of Jaguaribara. In one of them it is possible to observe a few specimens of carnauba palm tree (area is used as rangeland) (image 4.16), while in the other none was found (area used for planting short cycle crops) (image 4.17).

As a conclusion of the information collected so far about wetness and how the physical characteristics of the region interface with the water issue, the image 4.18 illustrates the region's water cycle, considering both natural and cultural cycle in the metropolitan scale.

The cuts AA 'and BB' show the profile of the region and how the water flow is related to the ecological and productive flows in the region in the current situation. (image 4.19)


Production flow
$
Fruit and vegetable production
Sale to farmers in surroundings cities
2/3 tansâmia grass 1/3 cactus palma + sorghum
$
Milk production
$
Local cheese makers
Fish/shrimp production (private industry)
Ecology flow
Fish mortality
Grazing on rangelands and in the green areas (in and outside urban centre)
Aquaculture installation on river plains = -- riparian forest
Young fish released in the river (public ind = ecological compensation)
Water flow
Irrigation channel
(Irrigate agriculture community)
Water comes from Castanhão
Dammed water
Flow rate: 16m³/h
(Jaguaribe river input)
Overall water loss: 42m³/h
32m³/h (Eixão das águas)
1m³/h (Evaporation+percolation+withdrawals)
9m³/h (Jaguaribe river)
Water run off (soil erosion)
Irrigation channel
(Irrigated farming community)
Water comes from Castanhão
Water channel
Eixão das Águas
Comes from Castanhão and goes to Fortaleza
Aquaculture
Fish/shrimp farming
(excavated tanks)
Controlled flow rate: 9m³/h
(Castanhão dam output)
CURUPATI IRRIGAÇÃO
CURUPATI PEIXE
CASTANHÃO
URBAN CENTRE
MANDACARU
JAGUARIBE RIVER
A
A'
B
B'

Cistern for rainwater storage in the backyard of a residence in the urban centre of Jaguaribara (January, 2020).

MICRO (WATER)STORIES

This chapter presents the analysis of the wetness on a local scale, focusing on the use of wetness by inhabitants in Jaguaribara. The information was collected during the site visit that took place in January 2020 and constitutes what is here called micro (water)stories. The data was collected both from areas in the urban centre, as well as in productive landscapes. Together with the information from the water mapping presented in the previous chapter, it composes the panorama of wetness in the study region.

5. MICRO (WATER)STORIES

5.1 PRODUCTIVE LANDSCAPE

Irrigated farming and agriculture

The modern method of irrigated agriculture, which has been taking place in Jaguaribara since the construction of the Castanhão dam, is very different from traditional practices. In both *Mandacarú* and *Curupati irrigação* communities similar irrigation systems are adopted.

In the case of the irrigated farming community *Curupati irrigação,* the water is extracted directly from the Castanhão reservoir by means of a water pump and poured into the irrigation channel, which distributes the water to the different lots.

In the case of the irrigated farming community *Mandacarú*, the water is extracted from the water channel *Eixão das Águas*, This action being carried out by a pumping station, which pours water into the irrigation channel. (image 5.1)

In both communities, water is transported to cultivation plots through smaller pumping stations and irrigation is carried out using sprinklers.

Image 5.1: The water route and elements in the irrigated farming system.

Sprinkled in the air
Surface flow
Underground flow

In Curupati, the cultivation is of fruits (like acerola, guava, passion fruit and papaya) and vegetables (like beans and cassava). In each 3 ha plot of Mandacarú, 2.5 ha of tanzania grass (*Panicum maximum* cv.Tanzania) and 0.5 ha of complementary crops are grown, such as palm cactus (*Opuntia ficus indica*), sorghum grass (Sorghum bicolor) and elephant grass (*Pennisetum purpureum*). This crop is used to feed livestock, since the main purpose of irrigated farming is to produce milk.

In addition to being used for irrigation, this water is also given to cattle. For this purpose, this water is reserved in a circular semi-buried concrete tank (called *manilha*).

Image 5.2: Ways of feeding the cattle adopted in Mandacarú: free grazing in the cultivated lots or in the feeders after the grass was ground using the grass shredder.

The flow rate of the sprinklers in Mandacarú is about 200 l / h, and the total water consumption is 6,480 m3 / day, considering all the lots. To keep this system running, the pumping station that draws water from *Eixão das Águas* consumes about €2,500 / month, while smaller stations spend €1,000 / month of energy to take water to the lots.

According to the reports collected during a field visit, the availability of water for these two irritated communities has varied with the amount of water stored in the Castanhão. After 2012, and the considerable reduction in the stored water volume due to the last drought, the water available to communities was reduced by 70% (570l / ha in 2012, 170l / ha in 2020).

Aquaculture: tilapia fish farming

The aquaculture system for the production of tilapia fish takes place close to the dam and the Jaguaribe river, on the downstream side of the dam, and is done intensively1 (meaning, in a controlled and artificial environment).

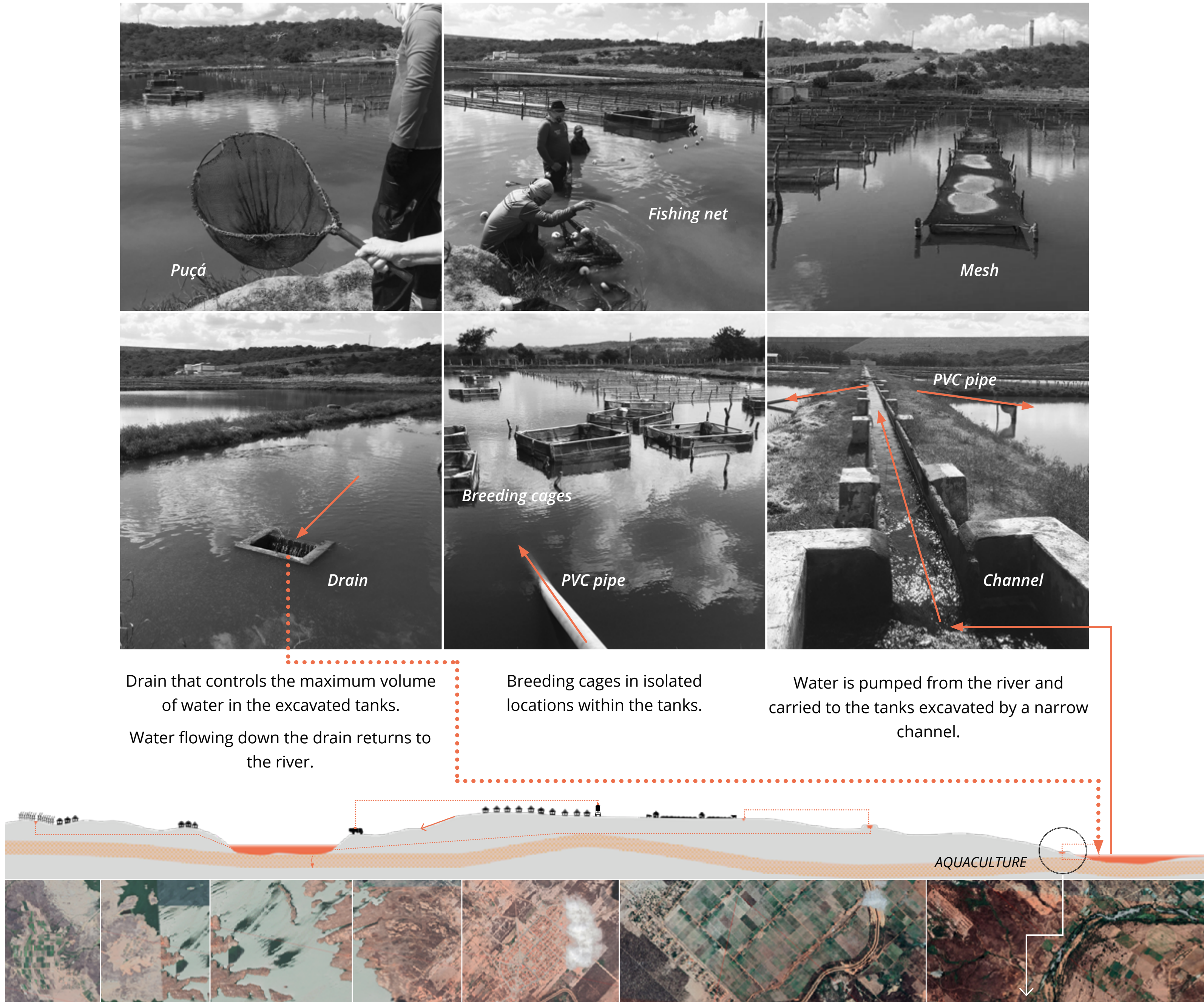
The fish are grown in 20 tanks excavated in the ground, with dimensions of 30x70 m each. The water used to fill each of these tanks comes directly from the Jaguaribe river and is brought into the system through a water pumping mechanism. The water flows through a concrete channel, coated with asphalt paint for better waterproofing. From there, water flows to the tanks through PVC pipes. At the other end of the tank, there is a drain constructed of concrete and connected to the Jaguaribe river by underground piping. The water level is then limited to the height of the drain.

For the system to function properly, it is necessary that the water is always flowing from the system, to ensure that there is oxygenation of the water in the tanks and that there is no accumulation of organic matter, which could lead to eutrophication and subsequent death of the fish. In this way,

(1) As opposed to extensive practice, which would be in the natural open environment, like researching the sea or river.

Fishing net and *puçá*: used to transport fishes from one tank to the other

Mesh protect young fish from birds



Drain that controls the maximum volume of water in the excavated tanks.

Water flowing down the drain returns to the river.

Breeding cages in isolated locations within the tanks.

Water is pumped from the river and carried to the tanks excavated by a narrow channel.

Image 5.3: The water route and elements in the aquaculture system.

Sprinkled in the air

Surface flow

Underground flow

the system is constantly receiving water from the Jaguaribe river and returning excess water back to the river.

Inside these tanks, fish are reproduced in separate cages inside the tanks, since this require a quiet environment to occur. Subsequently, the fish larvae are transferred to another tank, in which they receive mixed feed with male hormone. This process, called sexual reversal, is a way of forcing the larvae, which are born without definite sex, to develop as males. This is done because the male is larger than the female, therefore, having a higher market value. This process carried out in this way is 96% successful in terms of sexual reversal.

Image 5.4: Overview images of the excavated tanks.

As the larvae become small fish and they grow, they are transferred to other tanks, in such a way that in each tank there are only fish in the same stage of development, with the same feeding needs. The transfer of fish between tanks is carried out using an instrument called "puçá" and fishing nets.

Until March 2019, when cage fish farming practices still took place inside the Castanhão, young fish were delivered to producers, so they could be cultivated. Nowadays, young fish are released into the Jaguaribe river as ecological compensation for the environmental imbalances caused by the dam and the former aquaculture practice on the Jaguaribe river.

5.2 URBAN CENTRE

House water

In Jaguaribara, the houses are connected to the water supply system, whose responsibility is a private company, called **Cagece**[1]. This company, which has been operating throughout Ceará since 1971, has a wide concession of water and sanitation services and the Government of Ceará State as the main shareholder.

It is known[2] that Cagece makes a profit thanks to the market in the Metropolitan Region of Fortaleza. However, if only the semiarid region would be considered, with its low demographic density and great need for water works, it would be a loss-making company.

The field visit showed that, in addition, the inhabitants avoid the use of water from Cagece, in order to consider it of high cost; a cost that they would not be able to afford if they used this single source for 100% of their water consumption.

(1) Cagece: Companhia de Água e Esgoto do Ceará, "Ceará Water and Sewage Company", free translation.

(2) Information available online cagece.com.br and valor.com.br/valor1000-mobile/2017/as1000maiores/16884

Cistern stores rainwater 16.000 L

Manual procedure for removing stored water.

Water purification process (step 1) : boiling in common pots.

Water is stored in ceramic pots called "moringa"

Water purification process (step 2): filtration in ceramic filter.

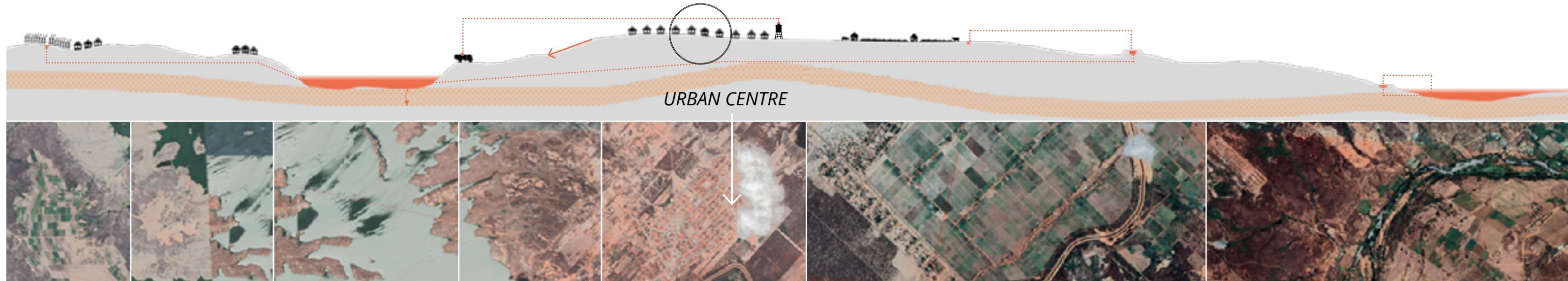


Image 5.5: Process of collecting, storing and purifying water for human consumption in Jaguaribara.

The main alternative for the use of water in Jaguaribara is also widely used throughout the semiarid region: rainwater harvesting. This collection is made from the roof gutters, made of PVC (polyvinyl chloride) piping, while the water is stored in semi-buried concrete cisterns.

The preparation of this water stored in the cistern for consumption is laborious. It is necessary to remove the lid of the cistern and collect the water with a bucket. Thereafter, the water needs to be boiled to eliminate microbes and bacteria. Then, the hot water is stored in a clay reservoir to cool. Gradually, the water to be used for human consumption must also pass through a clay filter, which finishes the water purification process. In addition, the clay filter reduces the water temperature by up to 6 degrees, proving to be an excellent way to store and cool water at low cost. The most common cistern has a storage capacity of 16,000 litres of water and is sufficient to be used for human consumption throughout the year in a residence with four people. Less frequently, this water is also used to water the vegetable garden and to feed animals raised in backyards. (image 5.1)

Image 5.6: Overview image house in the urban centre.

Another widely used water alternative is water from wells dug in the backyards of the house. These mostly consist of unregistered tubular wells, dug with the inhabitants' own resources. The rent for the machine to do this, however, is quite high (around R$ 5,000[3]), making this practice less common than the previous one.

(3) Around € 800, exchange rate in May 2020.

Farming in wetness

Before the construction of the Castanhão dam, the inhabitants of Jaguaribara use to practice agriculture in the floodplains of the Jaguaribe river. This traditional practice has no energy consumption, as it makes use of the wetness on the soil of the river banks.

In order to do so, it is only necessary that the soil is prepared to receive organic fertilizer (manure) and seeds or seedlings. The manure itself pulls water from the soil, ensuring natural irrigation. This was done throughout the whole year, mixing short and long cycles cultivation. (image 5.7)

Nowadays, Jaguaribara's inhabitants are still trying to make the most of the soil's wetness for cultivation. In the urban centre of Jaguaribara, it is common to find examples of how this is done.

In general, when the cultivation takes place in empty lots in the city. The inhabitants start preparing the soil at the beginning of the year, or at the end of the previous year, by burning the existing vegetation. After the fire is extinguished, the dry branches and trunks are collected and used to build fences to surround the site. This is even a way for the farmer to clarify to the

Image 5.7: Traditional agriculture on the river plains as practiced in the previous location of Jaguaribara urban centre.
Source: Adapted from oasisdonordeste.blogspot.com/2013/11/

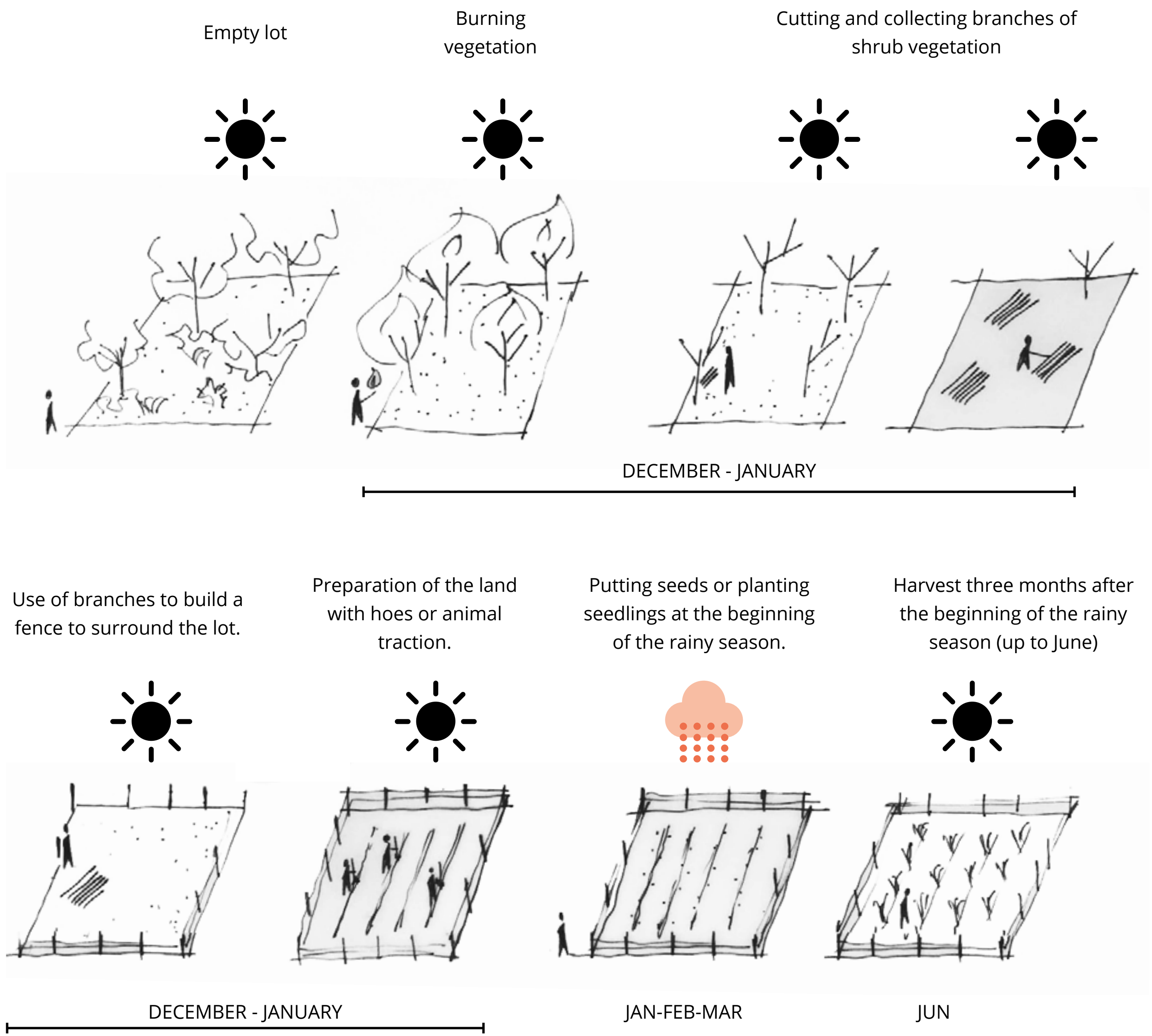


Image 5.8: Scheme for preparing empty lots for short-cycle agriculture, sketched during an interview with the inhabitants of Jaguaribara.

population his/her intention to cultivate in that space (empty lots usually means that the farmer is not the land owner). When the first rain comes (which may be in January, February or March, depending on the year, since the rain supply in the semiarid region is inconstant), farmers prepare the soil, put the manure, the seeds or seedlings from the plantation. The harvest will take place three months later, usually in June. This practice allows the cultivation of short-cycle crops (such as corn and beans). The lots chosen for this practice are the ones near thalwegs, were the run-off water concentrates. (image 5.8)

Lands on the edges of paved roads are also widely used. Run-off flow from the roads to both sides, where there is no sidewalk or gutter, making these areas quite wet during the rainy season. (image 5.10)

In addition, there were also signs of use of the city's public green areas (such as squares, sports fields and even the airstrip near the urban area) for grazing by goats, horses and donkeys. In this case, the inhabitants take advantage of the wetness retained by the vegetation in these areas. (image 5.9)

Image 5.9: Farming in wetness in Jaguaribara: empty lots (top), grazing in free areas of the city (middle), grazing in sports fields.

Source: Adapted from Google Street View (2020)

Image 5.10: Farming on the side of the road at the entrance to Jaguaribara (January, 2020)

Caatinga landscape in the rural area of Jaguaribara (January, 2020).

DESIGN STRATEGIES

This chapter presents the set of design strategies at different scales, starting at the local scale, in the urban centre of Jaguaribara, going through the metropolitan to the regional scale. The design strategies focus on the retention of wetness in the landscape, combining engineering and nature-based solutions with the productive practices and daily use of water, identified and presented in the previous chapter. This chapter ends by discussing ways to make it feasible to apply these practices in the state, by studying the phases and discussing stakeholders.

6. DESIGN STRATEGIES

6.1 DESIGN PRINCIPLES AND REFERENCES

Considering the analysis data presented in the previous chapters, some principles were considered for the elaboration of the design strategies to be presented throughout this chapter.

First, the proposed design strategies focus on protecting the wetness from evaporation and, at the same time, protecting the soil from erosion.

They also take advantage of the city's strategic position as a starting point for solutions that radiates from the urban centre, bringing wetness to the surroundings.

In order to do so, the idea was to combine wetness retention solutions with the inhabitant's knowledge of productive practices. (image 6.1)

In addition, references were sought in other semiarid regions, in order to identify techniques that follow the principles mentioned above. Though, it would also be necessary for these techniques to dialogue with Jaguaribara's productive and cultural practices, in addition to the conditions of the landscape.

In this sense, practices adopted in other countries, such as Egypt and Tunisia, have been studied, especially with regard to water storage and farming in wetness. In this regard, works like Prinz, D. (2002)[1] and UNEP (2009)[2] certainly provided inspiration for the proposed design strategies.

Finally, references were also sought in case studies in which permaculture practices were adopted. In this sense, platforms such as Permaculture Research Institute[3] and Climate ADAPT[4] were of great value.

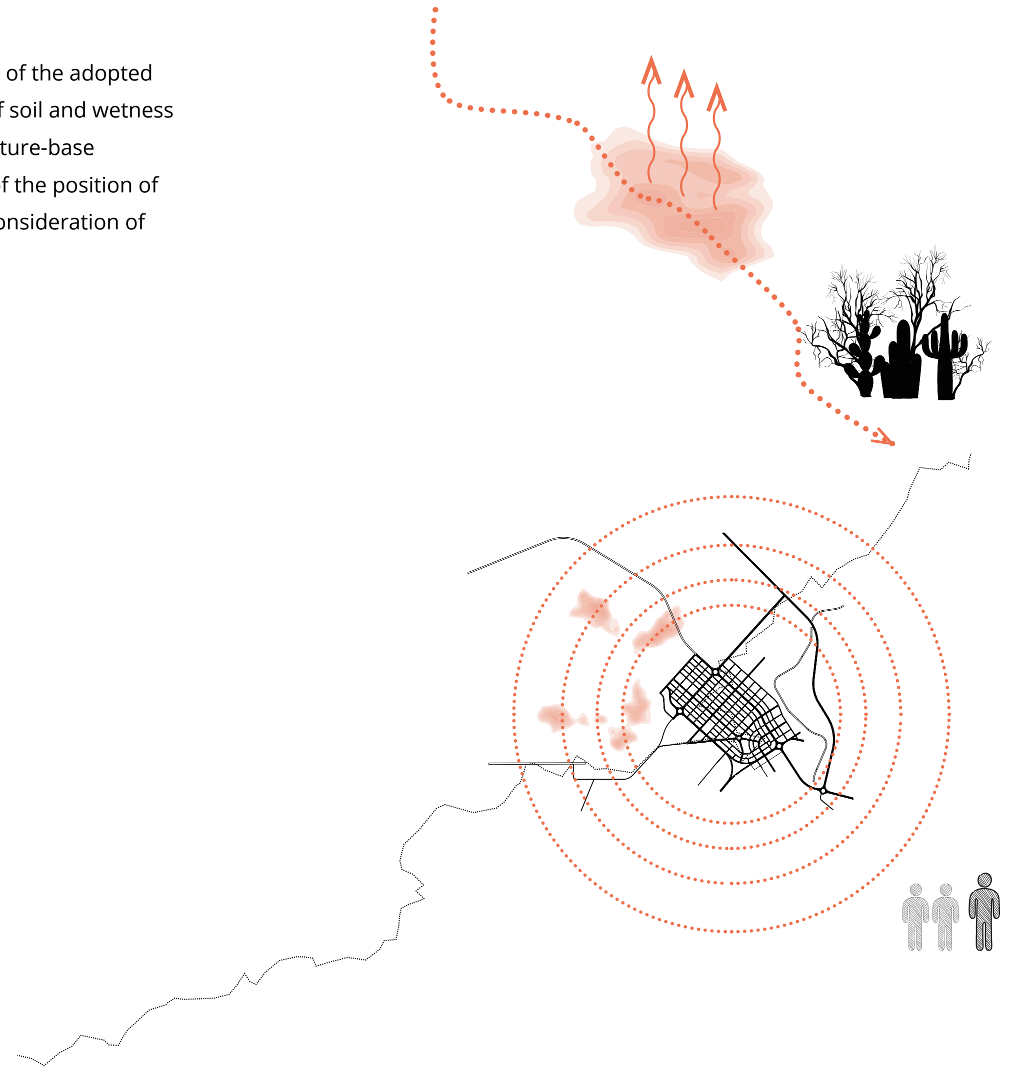
1 Prinz, D. (2002). The Role of Water Harvesting in Alleviating Water Scarcity in Arid Areas. Keynote Lecture, Proceedings, International Conference on Water Resources Management in Arid Regions. 23-27 March, 2002, Kuwait Institute for Scientific Research, Kuwait, (Vol. III, 107-122)

2 UNEP (2009). Rainwater harvesting: a lifeline for human well-being. A report prepared for UNEP by Stockholm Environment Institute.

3 permaculturenews.org

4 climate-adapt.eea.europa.eu

Image 6.1: Visualization of the adopted principles: protection of soil and wetness with the adoption of nature-base solutions; exploration of the position of the urban centre and consideration of local culture.



6.2 LOCAL SCALE

The design strategies proposed for the local scale (the urban centre of Jaguaribara and its immediate surroundings) aim to combine the production needs and the use of water by the inhabitants by applying water retention solutions. These actions aim to build a community resilient to drought and low water availability. By doing so, it is expected to turn Jaguaribara into an autonomous community, by exploring nature-based solutions.

The design strategies were applied both in the consolidated urban area and in the expansion areas provided for in the original city plan. For this, a specific area for urban growth was defined, in order to ensure that the proposed activities can take place in other areas. (images 6.2-6.4)

The set of strategies on this scale is divided in four main systems: **1) Urban wadi system (in the city centre); 2) Keyline cultivation 3) Undergound dam rangeland; 4) Underground water aquaponics.**

The **Swales system** is a vatiation of the keyline cultivation and, together with the **Green water channel** strategy, wil be further explaned at the metropolitan scale.

N

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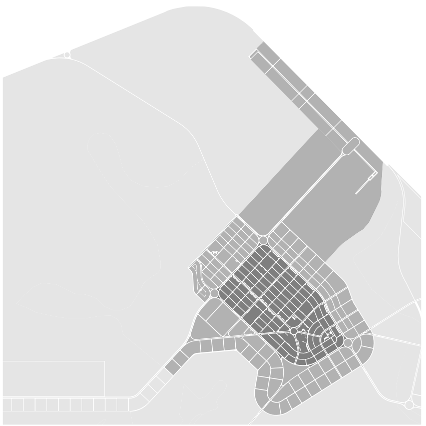


Image 6.2: Planning of Jaguaribara: consolidated urban area and expansion zones.

Consolidated urban area
Expansion area 1
Expansion area 2

Image 6.3: Current situation in Jaguaribara: buildings, streets, topography and wetness.

Existing buildings
Existing streets
Occasional wetness
Thalwegs
Topographic ridge
Direction of run off

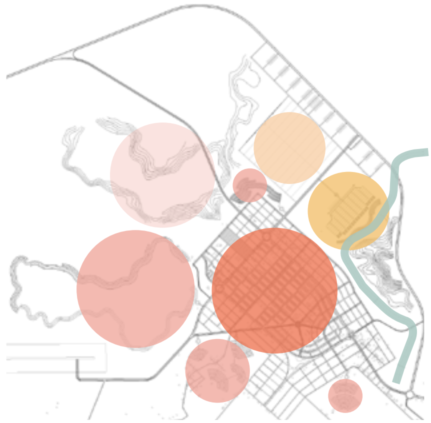


Image 6.4: Proposal for Jaguaribara: application of design strategies, in the consolidated urban area and in the expansion zone 2 and delimitation of the urban expansion areas.

Urban wadi system
Keyline cultivation
Swales system
Underground dam rangeland
Underground water aquaponics
Green water channel

Image 6.5: Set of design strategies at the local scale.

Access roads

Urban wadi system

Green water channel (*Eixão das águas*)

Fish farming and hydroponic vegetables (aquaponics) + salt grass cultivation (keyline)

Open caatinga rangeland (underground dam system)

Keyline cultivation (swales + fruits and vegetables - short and long cycles)

Caatinga reforestation (swales + natural succession)

Temporary lakes

Keyline agroforestry (fruit trees + swales + natural succession)

Dense Caatinga vegetation

The image 6.5 shows in more detail the applying of the design strategies at the local scale.

In addition to providing the spatial location of each of the strategies, it is possible to verify the presence of vegetation with different characteristics, linked to these strategies.

South of the bigger keyline cultivation area, north of the underground dam rangeland and around the underground water aquaponics system, it is proposed reforestation using native vegetation.

The presence of dense vegetation near these strategies can optimize their functioning. This would happen because the presence of dense vegetation would assist in the development of a micro-climate, reducing the temperature and evaporation of water from the soil, leading to a optimized use of wetness.

In addition, this action can also provide an interesting effect between open and closed areas. In this sense, this helps in the delimitation of places, which improves the legibility of the space.

Each of the four design strategies for this scale is presented on the following pages.

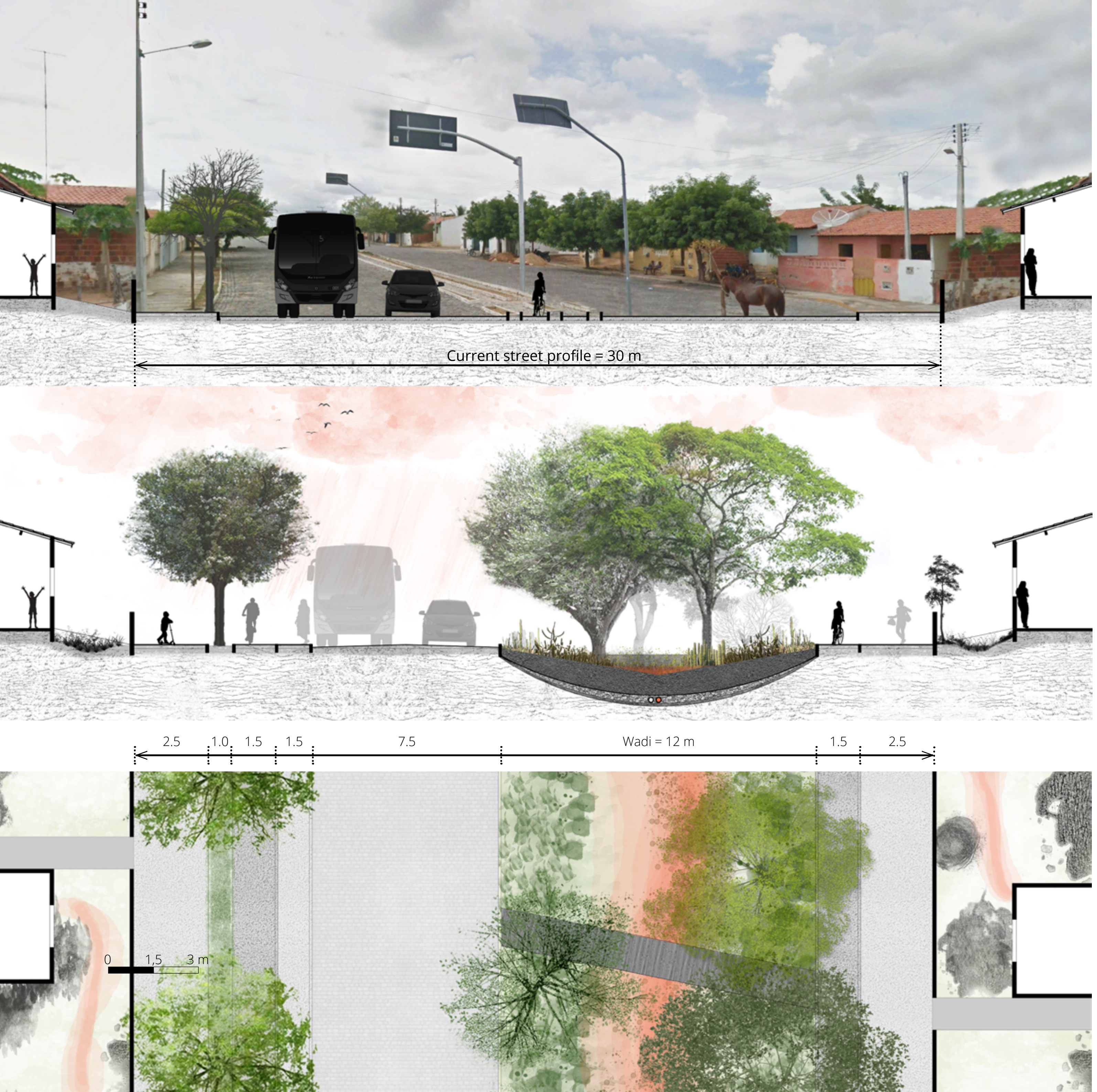


Image 6.6: Current profile of the main streets in Jaguaribara.

Image 6.7: Proposed profile and plan for the main streets, with the urban wadis.

Image 6.8: Wadi's catchment area, collector and infiltration wadis.

Urban wadi system

The Urban wadi system combines runoff water collection, rainwater storage and underground water transport. It is basically composed of green canals, here called **collector wadis**. Each wadi are about 12 meters wide, being built on the main streets of the city. This can be done by taking advantage of the generous dimension of these streets today (30 meters), which is incompatible with the scale and density of the city. (image 6.6-7)

During the rainy season, the wadis collect runoff waters, which infiltrate the soil and penetrate into multi-perforated tubes. From there, the water is transported to cisterns, located in different parts of the city. This stored water, therefore, can be used in the dry season and during droughts.

The system acts entirely by gravity, requiring no electricity costs to operate. It was designed, therefore, according to the topographical slopes. The image 6.8 shows the location of the wadis and their catchment area. It is possible to verify that, in some sections, wadis without pipes were proposed. These, called infiltration wadis, have the sole function of receiving runoff waters and optimizing the infiltration of these waters into the soil.

Surface runoff

Wetness absorbed by vegetation

Wetness that infiltrates the soil

Image 6.9: Collector wadi during the rainy season and the dry season. (left)

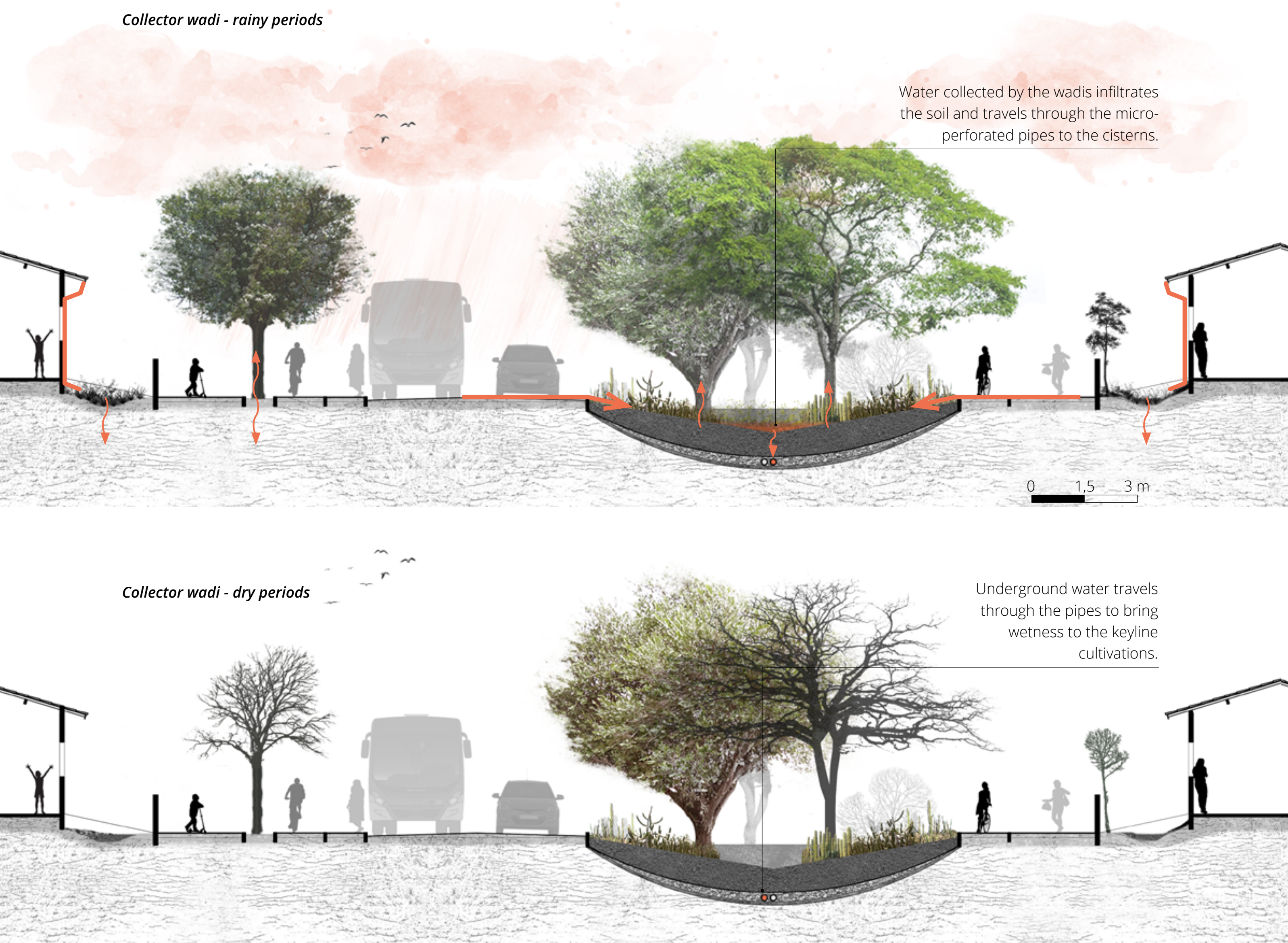


Image 6.10: Infiltration wadi during the rainy season and the dry season. (right)

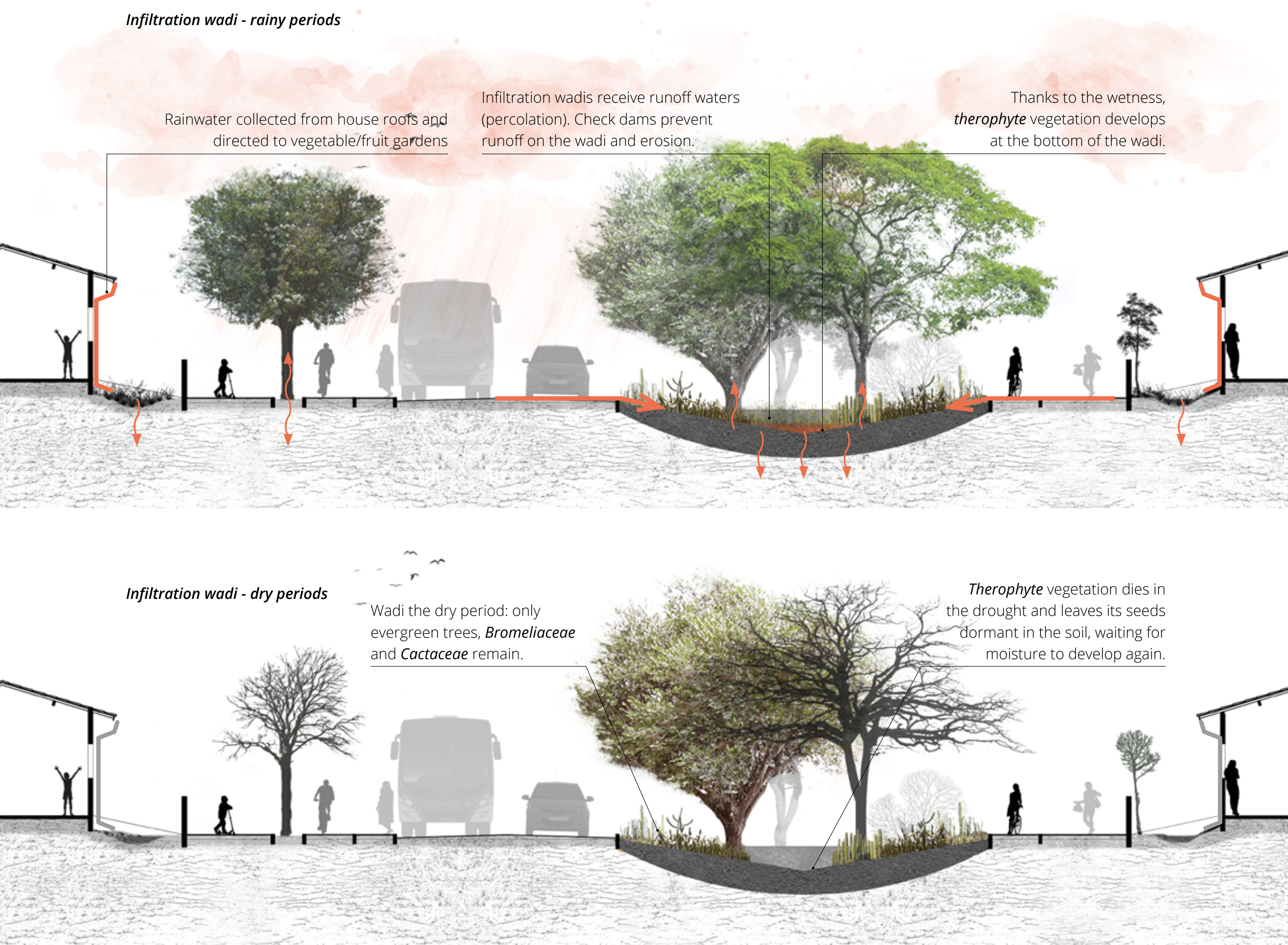


Image 6.11: Urban wadi system: water harvesting and redistribution.


Wadi streets


Rainwater harvesting square


Underground water pumping square


Adapted roundabouts (water redirection from the collecting wadis)

The images 6.9-10 on the previous page, show the collection and infiltration wadis and how they work during the rainy and dry seasons.

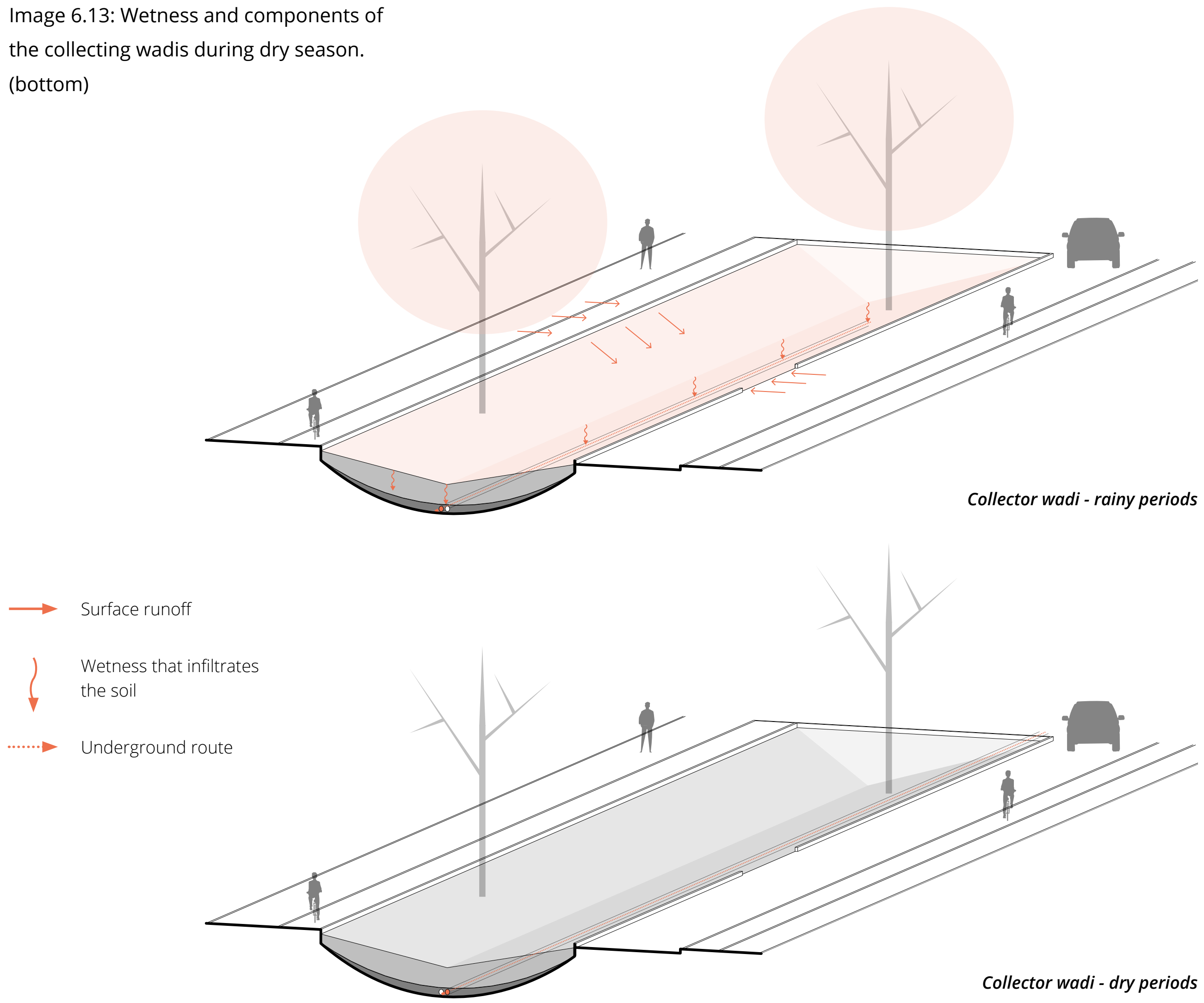
The map on the left shows the Urban wadi system proposed for Jaguaribara. It is possible to see, in addition to the wadis mesh, the cisterns in which the water collected and transported by the wadis are stored. In this work, these cisterns are connected to the Keyline cultivation system, which will be discussed later.

Part of the waters are also redirected to a roundabout in the city that has been transformed into a square. This square, called **Rainwater harvesting square**, has a cistern built underground in its central area. The water stored in it can be consumed by the inhabitants in the dry seasons. Thus, it acts as an extra reinforcement to the practice of rainwater consumption by the inhabitants of Jaguaribara.

In the city centre, at its highest point, another roundabout was transformed into the so-called **Underground water pumping square**. In its central part, it is proposed that a well be built, connected to the wadi system. During the dry season, after the waters stored by the cisterns, the water extracted from the aquifer through the well

Image 6.12: Wetness and components of the collecting wadis during rainy season. (top)

Image 6.13: Wetness and components of the collecting wadis during dry season. (bottom)



can be carried to these cisterns through the wadis.

Thus, each wadi must have two pipes: a micro-perforated pipe that receives the water collected by the wadi during the rainy season and a regular pipe, which carries the underground water from the Underground water pumping square to the cisterns.

The images 6.12-13 show how the variation of wetness occurs in the wadis during the rainy and dry seasons, as well as the components of this system. Images 6.14-15 show the direction of wetness in the urban wadi system at both seasons.

Image 6.14: Wetness direction in the urban wadi system during the rainy season (top)

Image 6.15: Wetness direction in the urban wadi system during dry season (bottom)

The wadis must be built by excavating the existing soil to a depth of 2.3m from the street level. The land subtracted in this phase must be stored in a ground bank, to be explained later. The soil must then be compacted to receive a waterproofing layer. This layer must consist of fabric coated with carnauba wax, waterproofing produced by extractive industries located on the Jaguaribe river.

In the case of collector wadis, two pipes of Ø20cm are installed (one micro-perforated and the other one regular); it is through this tube that the water must be transported to the cisterns. Once this is done, a layer of gravel is added (material also produced in Ceará, more specifically in the Metropolitan Region of Fortaleza). This layer is intended to filter out solid particles that may reach that level along with water. This layer must be followed by a geotextile blanket, to prevent runoff from the fertile soil, to the gravel layer. Above the blanket, the soil is then added, in which the vegetation will be cultivated.

Finally, check dams are added every 100 m, so that the waters do not cause erosion in the wadis' soil in rare cases of storms, as well as drains to prevent overflow. The water that may eventually overflow into the drains would then be directed to the city's sewer network.

Infiltration wadis differs from collectors wadis in that they do not have a waterproofing layer, micro-perforated tubing and gravel layer; since the purpose of this wadi is to allow water to seep underground, it is only necessary the geotextile blanket, the soil and the check dams. (image 6.16)

The vegetation chosen for the wadis was thought to be resilient both to periods of drought and rain. Tree species are native found both in the open caatinga phytoecological unit and in riparian forest. Also, it was sought to mix deciduous and evergreen species. The idea is that, even in dry periods, wadis provide green and shade to public streets, without losing the aesthetics of the landscape during the dry months. Regarding shrub vegetation, species of the genera ***Bromeliaceae*** and ***Cactaceae*** were selected for the sides of the wadis. As they store water inside, they are extremely resilient to variations in water availability. They are also species found both in the drier regions of the Caatinga and in the mountains of Ceará, under sub-humid and humid climate.

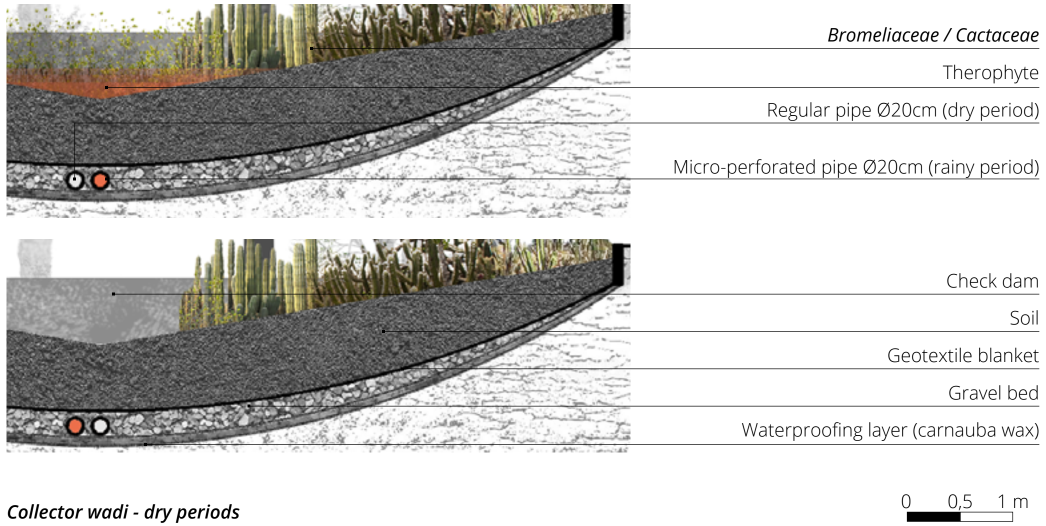
Finally, *therophytes* were indicated for the central part of the wadis. Native *therophytes* from Ceará were chosen, of the genera: ***Malvaceae, Portulacaceae*** and ***Poaceae***. These herbaceous plants are grow in the rainy season and and dry

as the soil also loses its wetness. Before they die, their seeds are thrown into the soil and remain dormant until the wetness comes back again.

The image 6.17 on the next page shows the materialization in the wadi street during the rainy and dry season.

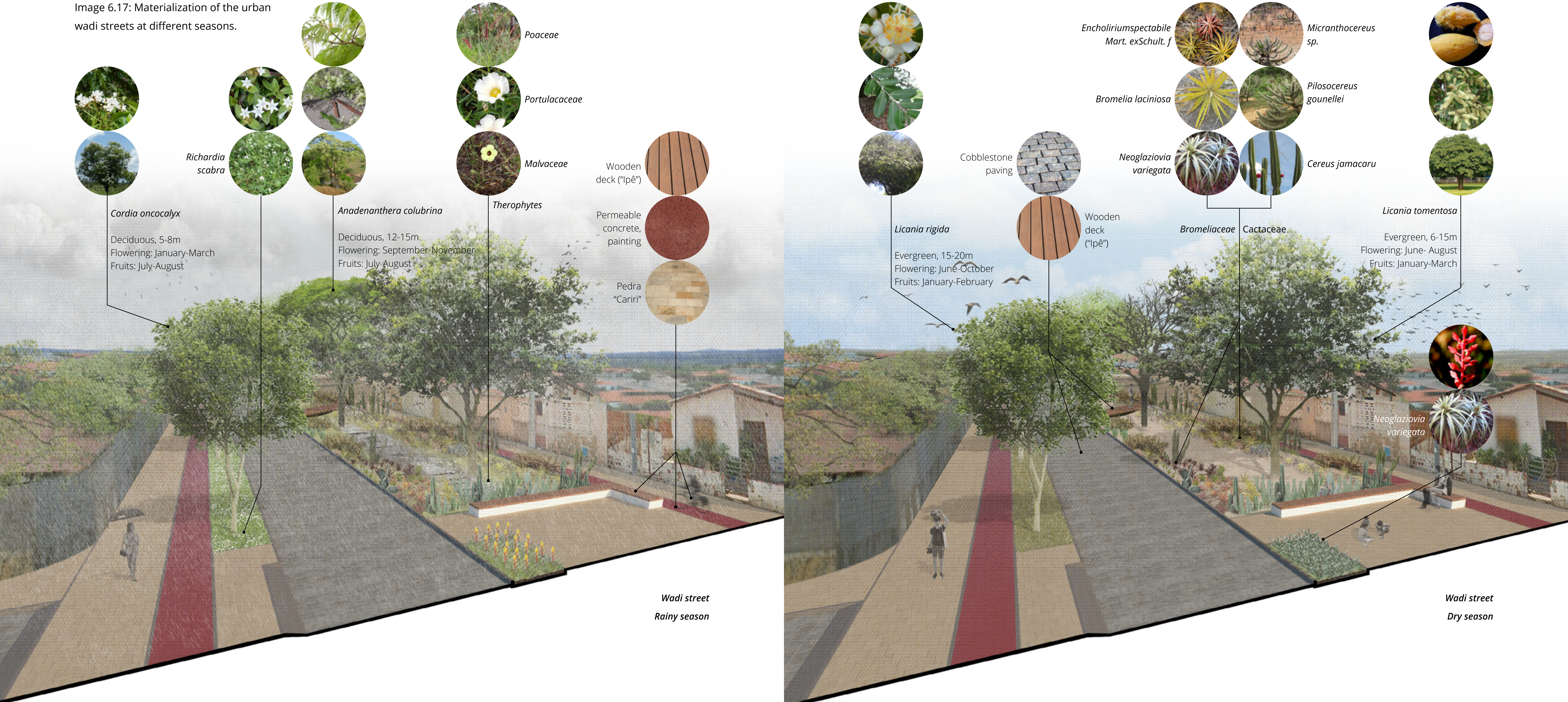
Image 6.16: Constructive detail of the collecting wadis.

Collector wadi - rainy periods



Collector wadi - dry periods

Image 6.17: Materialization of the urban wadi streets at different seasons.

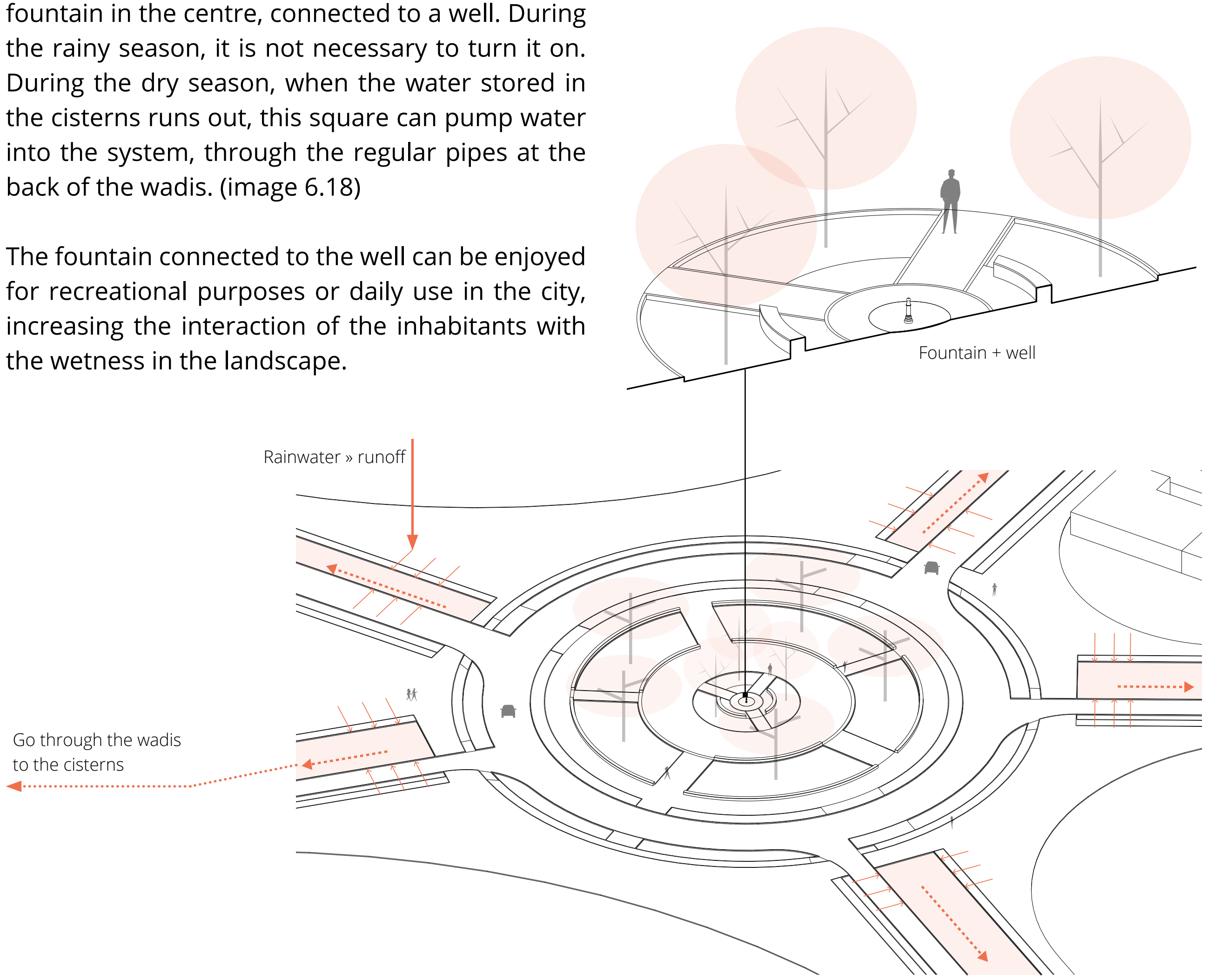


The **Underground water pumping square** has a fountain in the centre, connected to a well. During the rainy season, it is not necessary to turn it on. During the dry season, when the water stored in the cisterns runs out, this square can pump water into the system, through the regular pipes at the back of the wadis. (image 6.18)

The fountain connected to the well can be enjoyed for recreational purposes or daily use in the city, increasing the interaction of the inhabitants with the wetness in the landscape.

Underground water pumping square

Rainy season



Underground water pumping square

Dry season

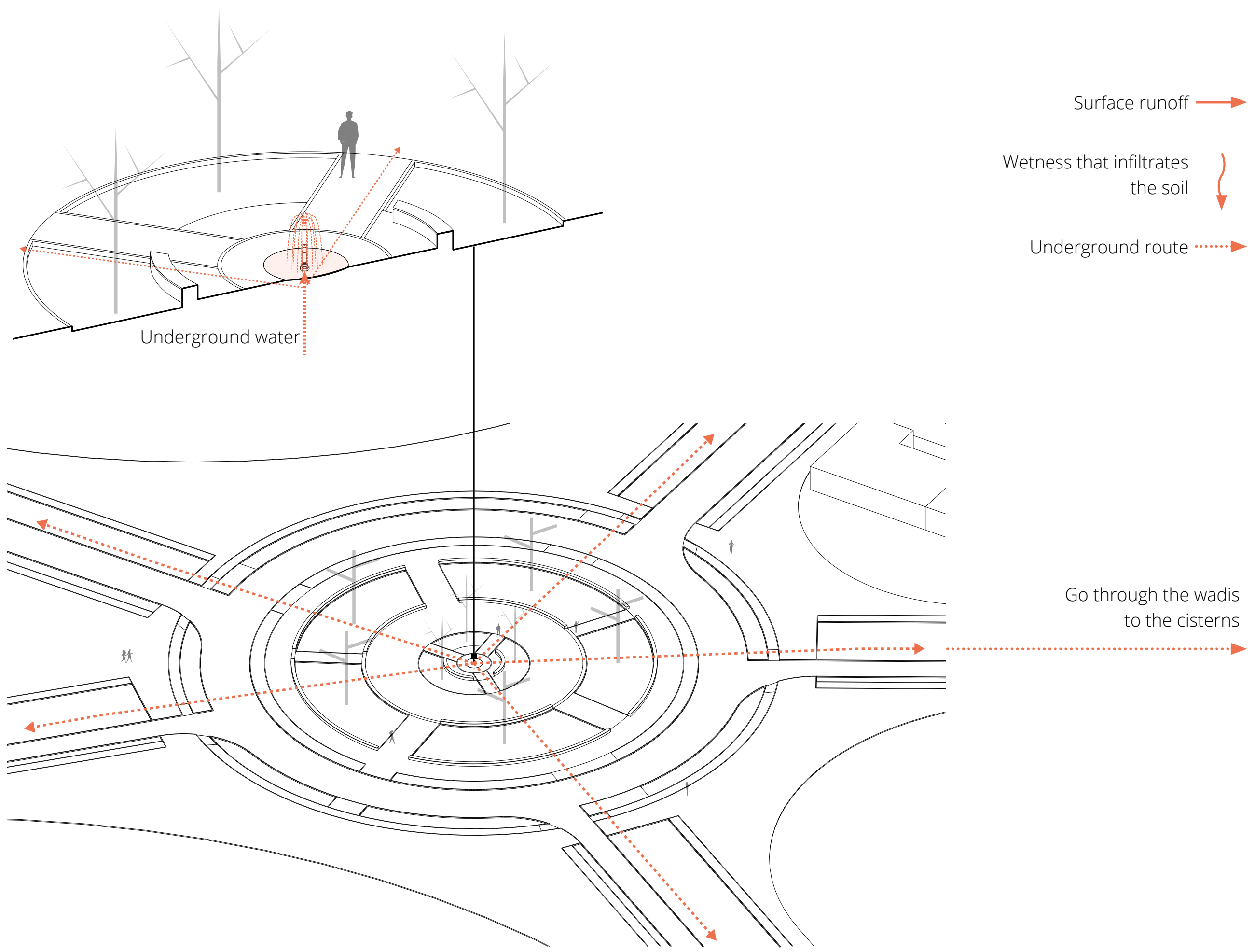


Image 6.18: Wetness and components at Underground water pumping square: rainy season (left), dry season (right)

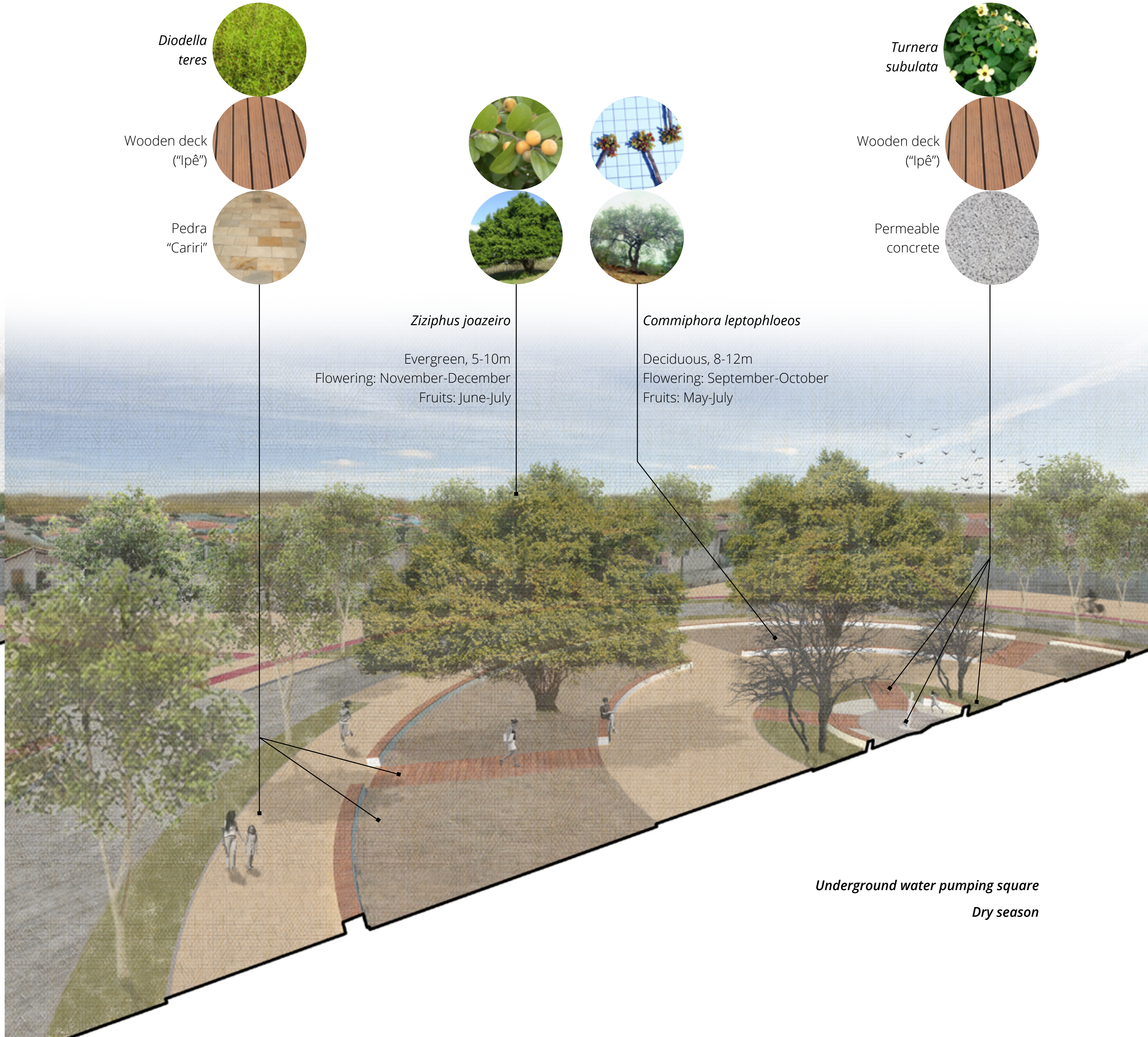
Image 6.19: Materialization of the Underground water pumping square at different seasons.

The vegetation specified for the square dialogues with the established function. In the external contour, trees of ***Ziziphus joazeiro*** were specified. This is known to remain green all year round due to its deep roots, which extract water from the subsoil.

In the internal contour, closer to the fountain and the well, ***Commiphora leptophloeos*** trees were specified. Because they are deciduous, these trees lost their leaves during the dry period, revealing the fountain. Thus, this is a symbolic way of revealing the wetness in the city during dry periods.

Underground water pumping square

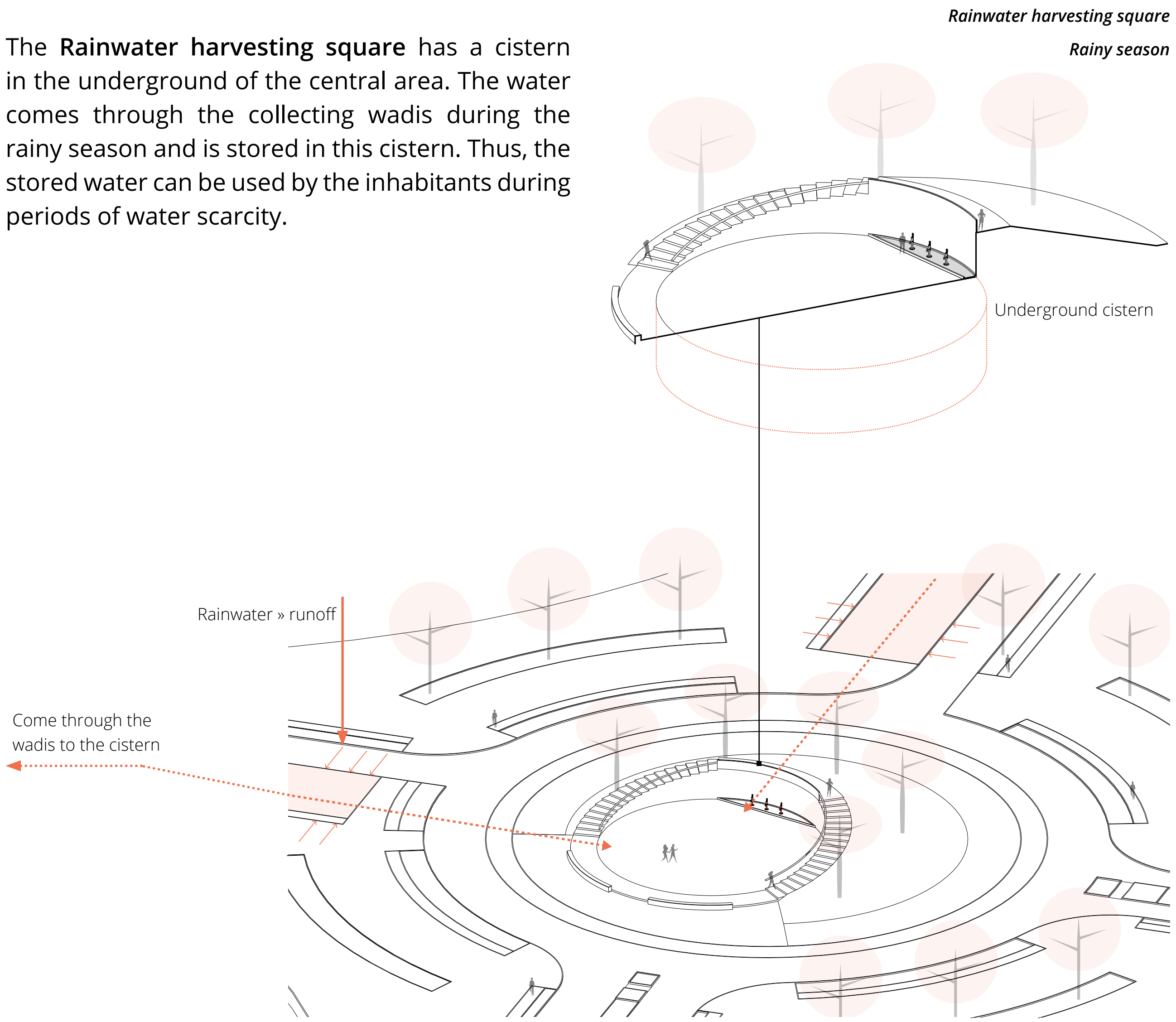
Rainy season



Underground water pumping square

Dry season

The **Rainwater harvesting square** has a cistern in the underground of the central area. The water comes through the collecting wadis during the rainy season and is stored in this cistern. Thus, the stored water can be used by the inhabitants during periods of water scarcity.



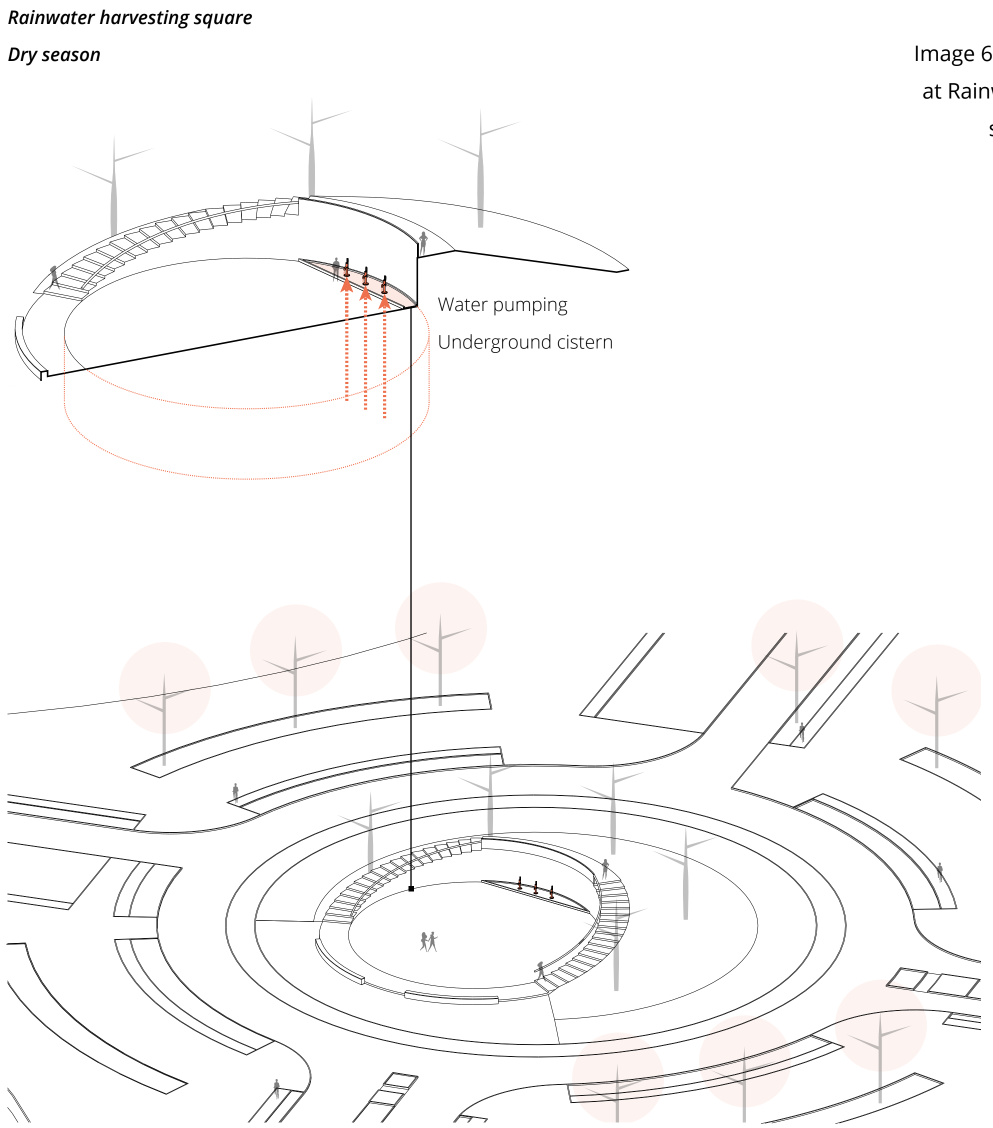
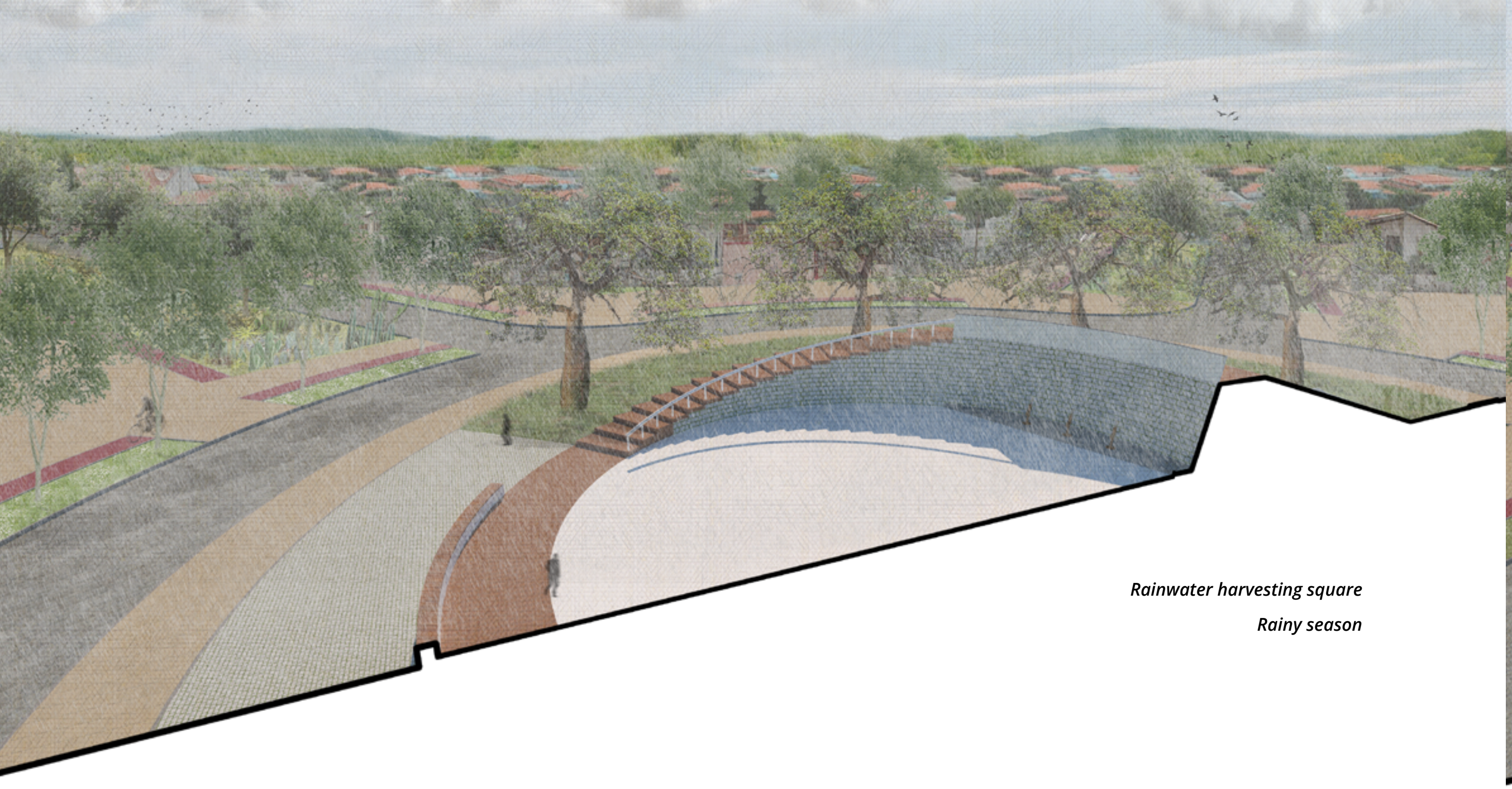


Image 6.20: Wetness and components at Rainwater harvesting square: rainy season (left), dry season (right)

Surface runoff
Wetness that infiltrates the soil
Underground route

The vegetation of the Rainwater harvesting square also dialogues with its use. Trees of the species ***Ceiba glaziovi*** were specified. This tree is known for storing water in its trunk, surviving the most severe droughts. In this way, tree and square, both keep water inside and are symbols of resilience to water scarcity.

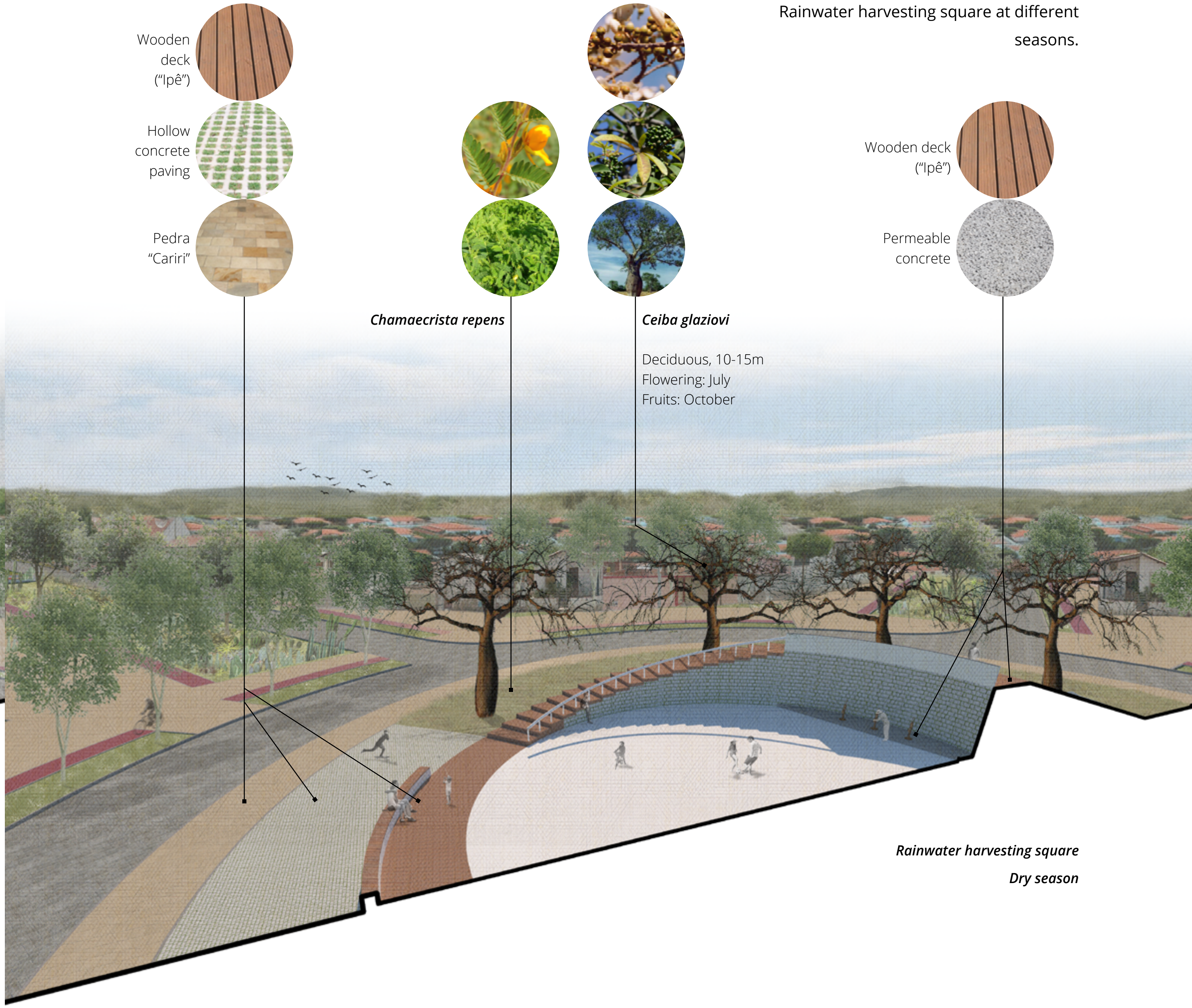
The square also has a lookout, with a maximum height of 4.5m. This was done because this is one of the few points in the city where you can see the Castanhão dam at ground level. In this way, the lookout allows to expand this visual contact with the dam, placing the observer's eye above buildings to be built in the future and that could block this view. Thus, there is a dialogue between two elements that store water and between the old and the current location of the urban centre of Jaguaribara.



Rainwater harvesting square

Rainy season

Image 6.21: Materialization of the Rainwater harvesting square at different seasons.



Rainwater harvesting square

Dry season

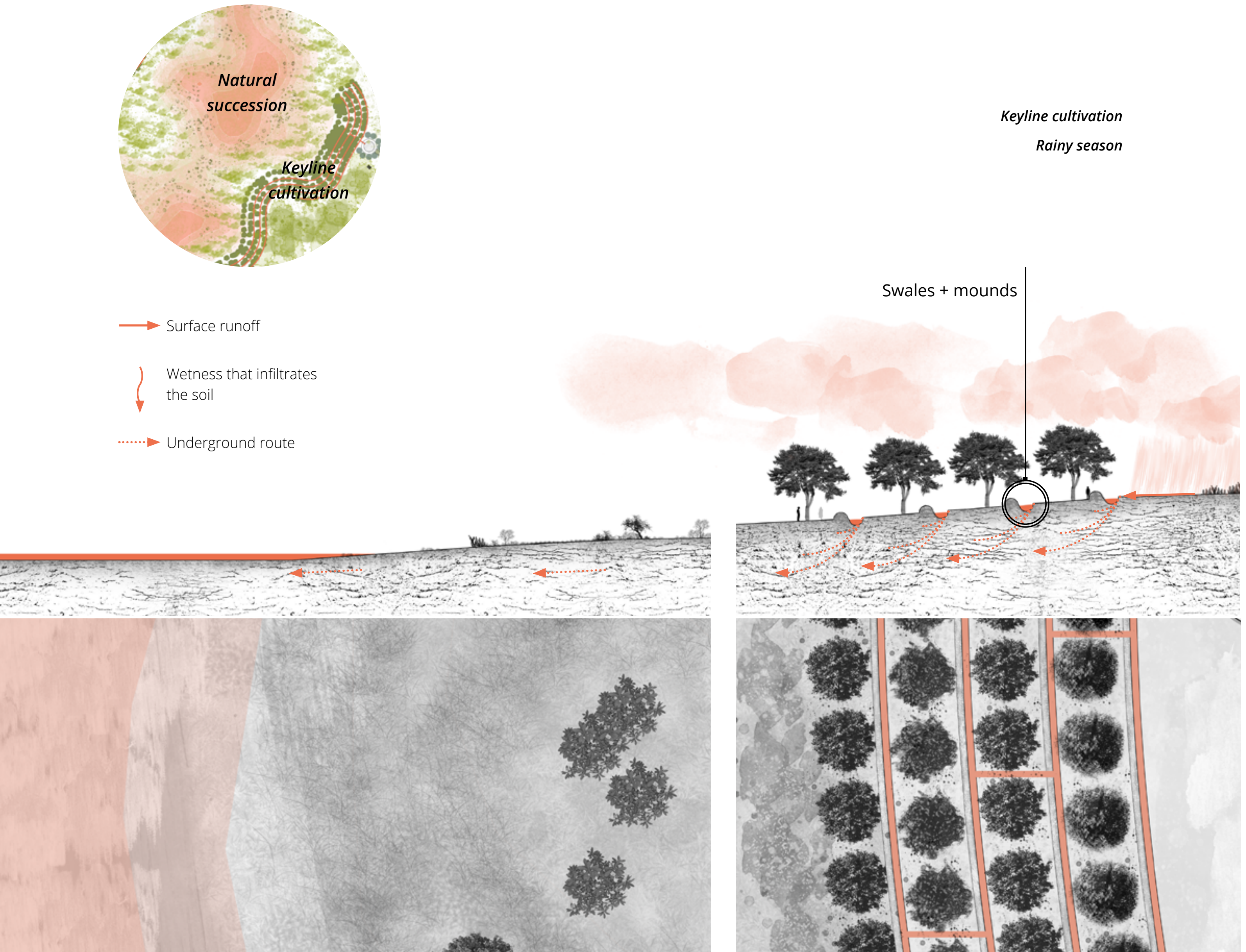


Image 6.22: Basic principle for carving swales on the ground.

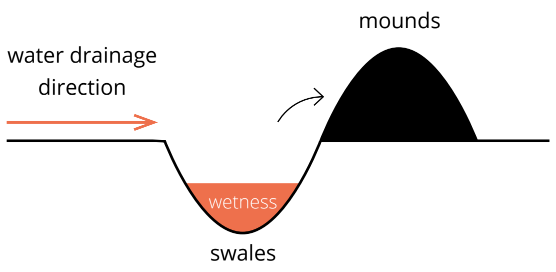


Image 6.23: Top view and profile of the Keyline cultivation system, linked to an area of natural succession.

Keyline cultivation

The keyline cultivation design strategy includes basic permaculture principles related to water: slow, spread and sink. Basically, the idea is to reduce the speed of the run-off water, spreading it over an even surface so that it can infiltrate the soil. This system is then opposed to letting the water run through the thalwegs, causing soil erosion.

Thus, the keyline cultivation strategy is based on carving swales (similar to ditches) and mounds parallel to the contour lines. The swales must be positioned facing water drainage direction. The land taken out in order to carve the swales is directly used to make the mounds. (image 6.22)

The run-off water that flows through the thalwegs is intercepted by the swales and spread itself along them. The mounds act as barriers, to ensure that the water does not overflow from the swales. This wetness then infiltrates the soil, emerging again at the lowest points of the topography. In Jaguaribara, the water must emerge in the so called "temporary lakes". (image 6.23)

After some time, the amount of water that accumulates in the surface will increase. This is because the water flows underground, protected

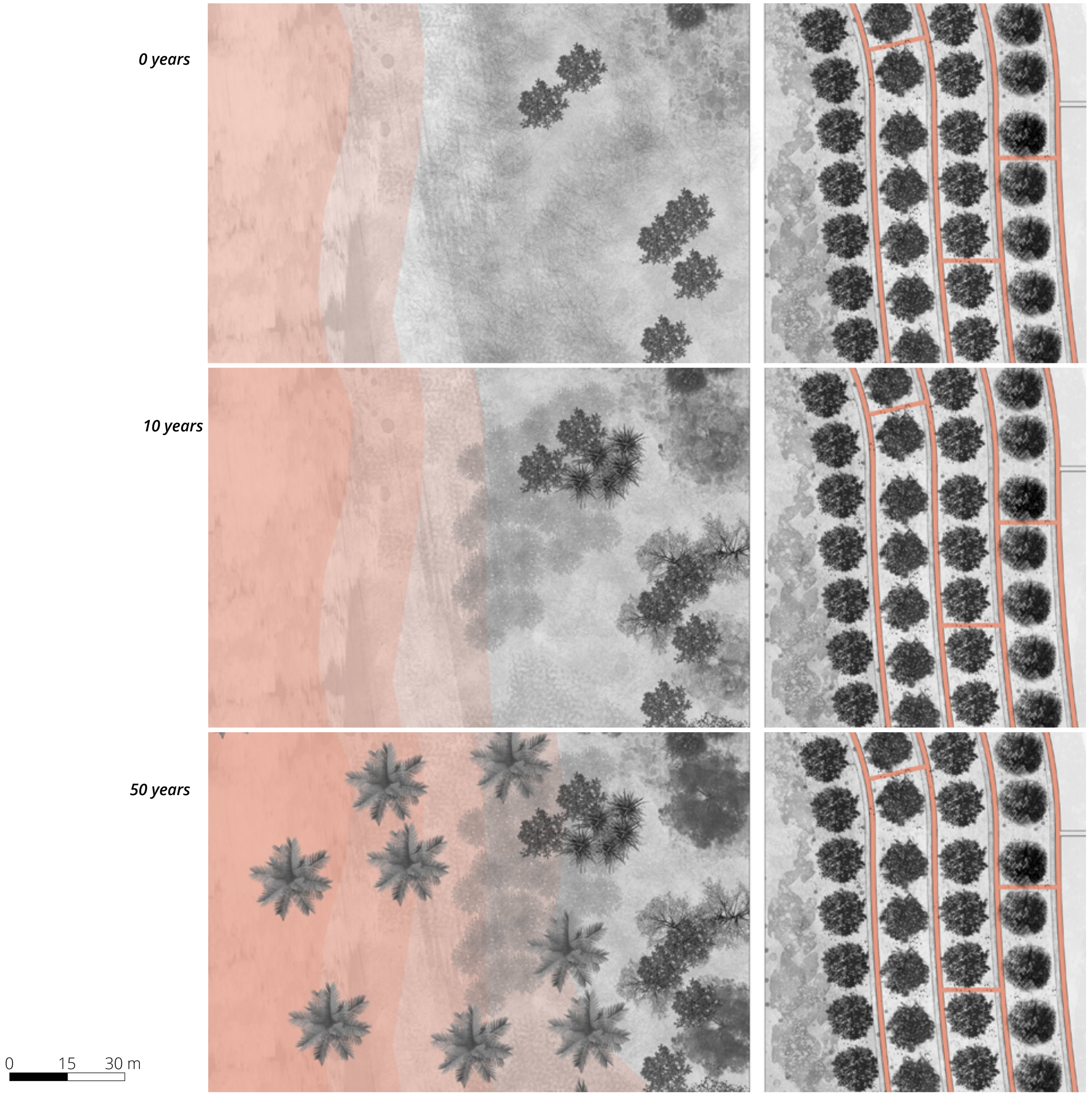


Image 6.24: Keyline cultivation and interface with the natural succession area in the natural lakes.

Over the years, with more wetness and less erosion, there is a process of soil creation. Therewith, the native vegetation recovers.

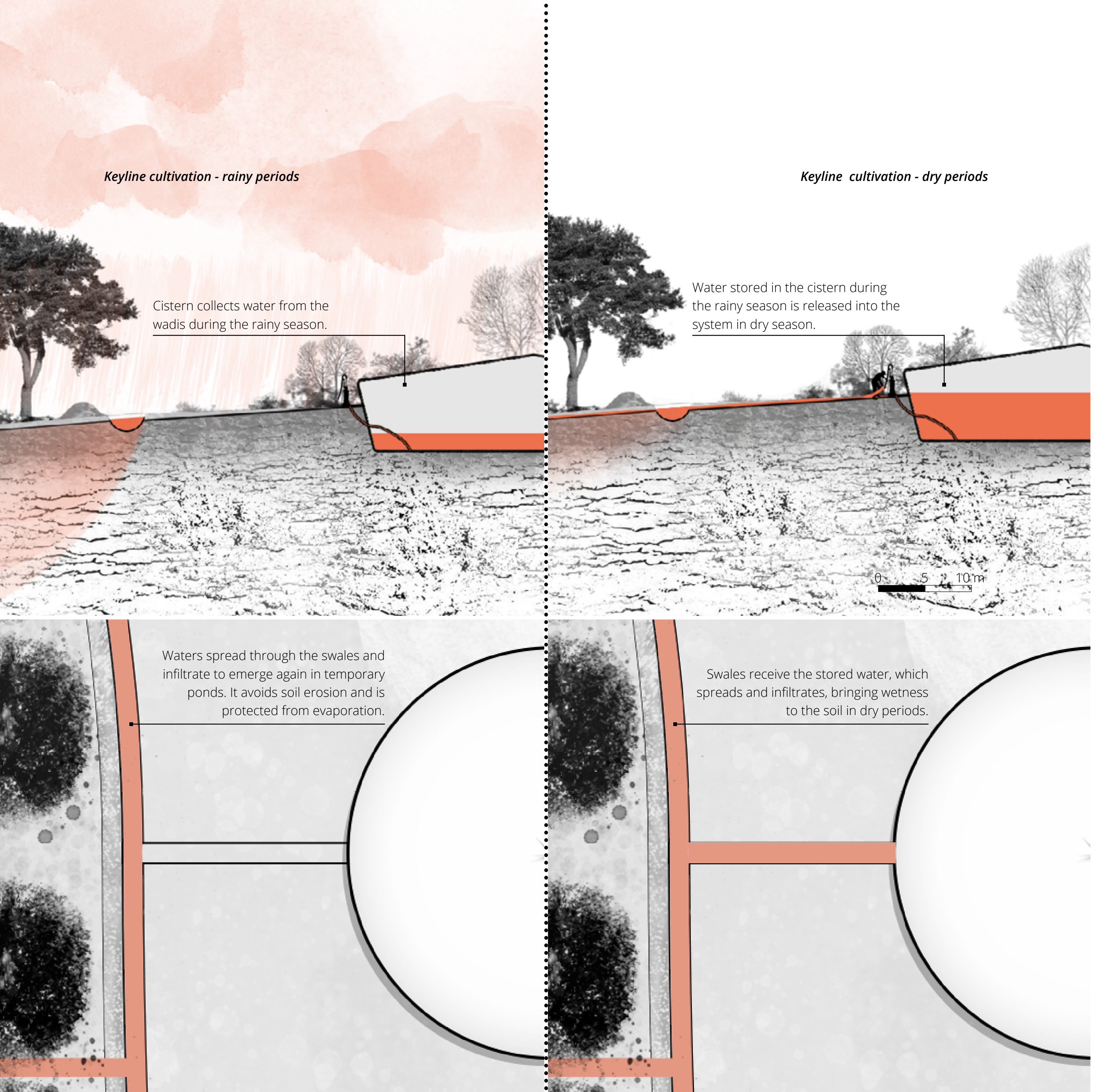


Image 6.25: Cisterns for storing water collected by urban wadis or use in agriculture (dry months)

from sunlight, instead of running on the surface, which would lead evaporation.

In addition, since water is flowing underground instead of flowing on the surface, it stops causing soil erosion. So, over time, there is a process of “soil creation”. This is nothing more than a natural recovery of the soil over the years.

These two consequences (soil creation and increased wetness) make the soil more and more fertile, which is ideal for cultivation or reforestation.

To provide stability for the mounds, it is necessary to plant trees between the swales (the roots “tie” the soil and guarantee this stability). Thus, it is proposed to practice agroforestry in the areas of Keyline cultivation.

In the “centre” of the system, where there will be accumulation of wetness on the surface, protection against evaporation is necessary. Thus, the idea is to work with natural succession in this area.

By protecting this “temporary lakes”, the typical wetland vegetation will fully develop in about 50 years. The climax of the wetland vegetation in caatinga biome consists basically in ***Copernicia prunifera*** and other dicots. (image 6.24)

To protect this area, it is also proposed a fence of ***Cactaceae*** to be planted surrounding it. Thus, the passage of cattle is not allowed, as they would eat the pioneer species of the wetlands, preventing the development of the vegetation and the natural succession.

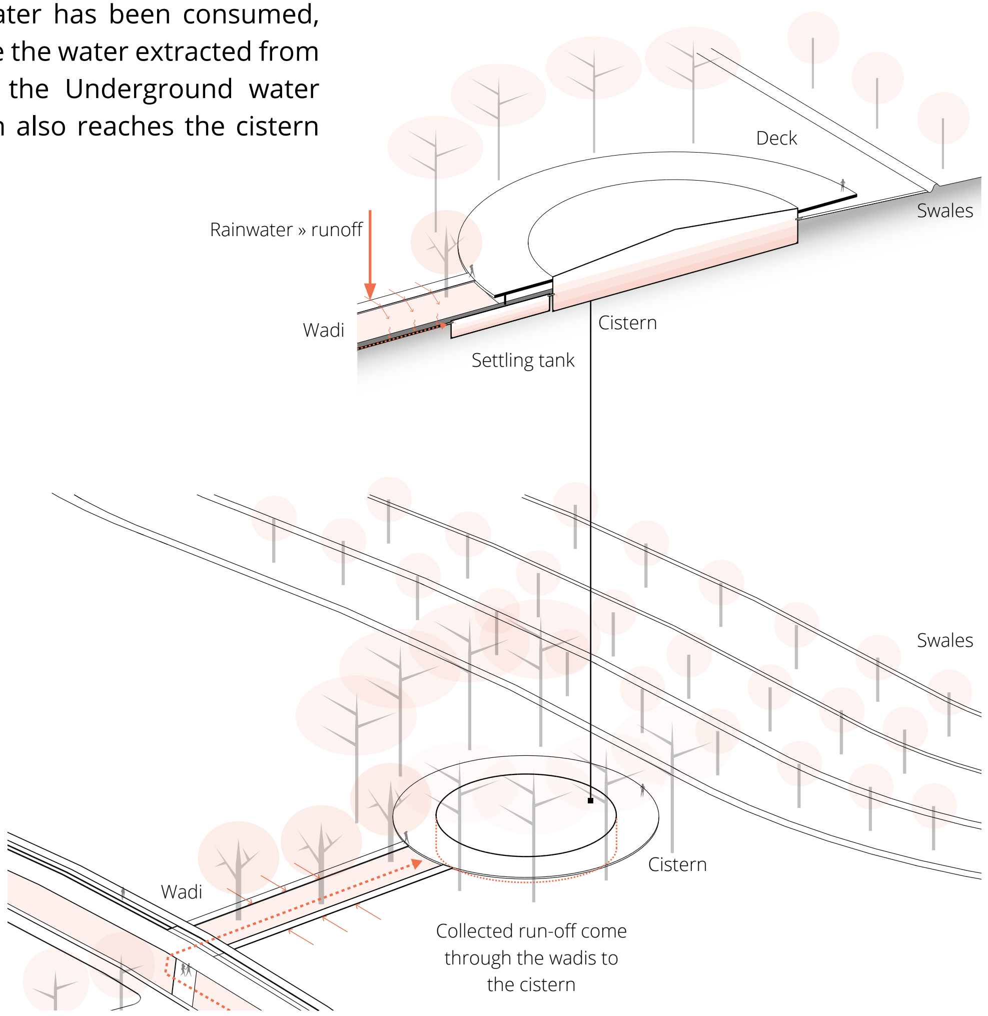
Finally, Keyline cultivation was associated with the Urban wadi system. The waters collected by the wadis during the rainy season are stored in cisterns connected to the swales. Thus, during the dry period, the stored water can be gradually released into the system, taking the necessary wetness for the cultivation to continue even in the driest periods. (image 6.25)

The diagrams on the next page show the flow of wetness in the Keyline cultivation in both seasons, in addition to the components of the space around the cisterns.

The **Keyline cultivation cistern** receives the water collected by the Urban wadi system during the rainy season. After all this water has been consumed, the cistern starts to store the water extracted from the underground from the Underground water pumping square - which also reaches the cistern through the wadis.

Keyline cultivation (cisterns)

Rainy season



Keyline cultivation (cisterns)

Dry season

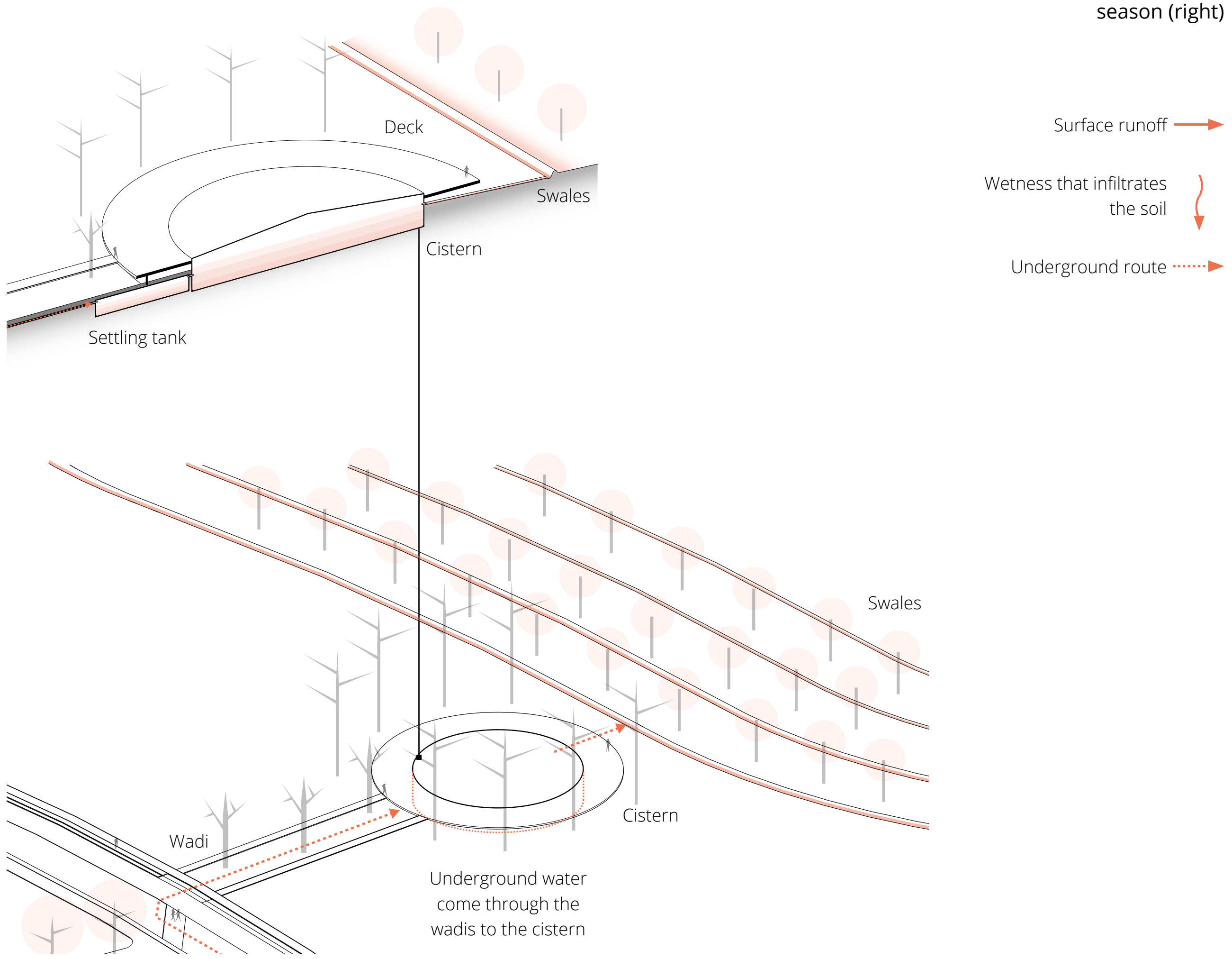


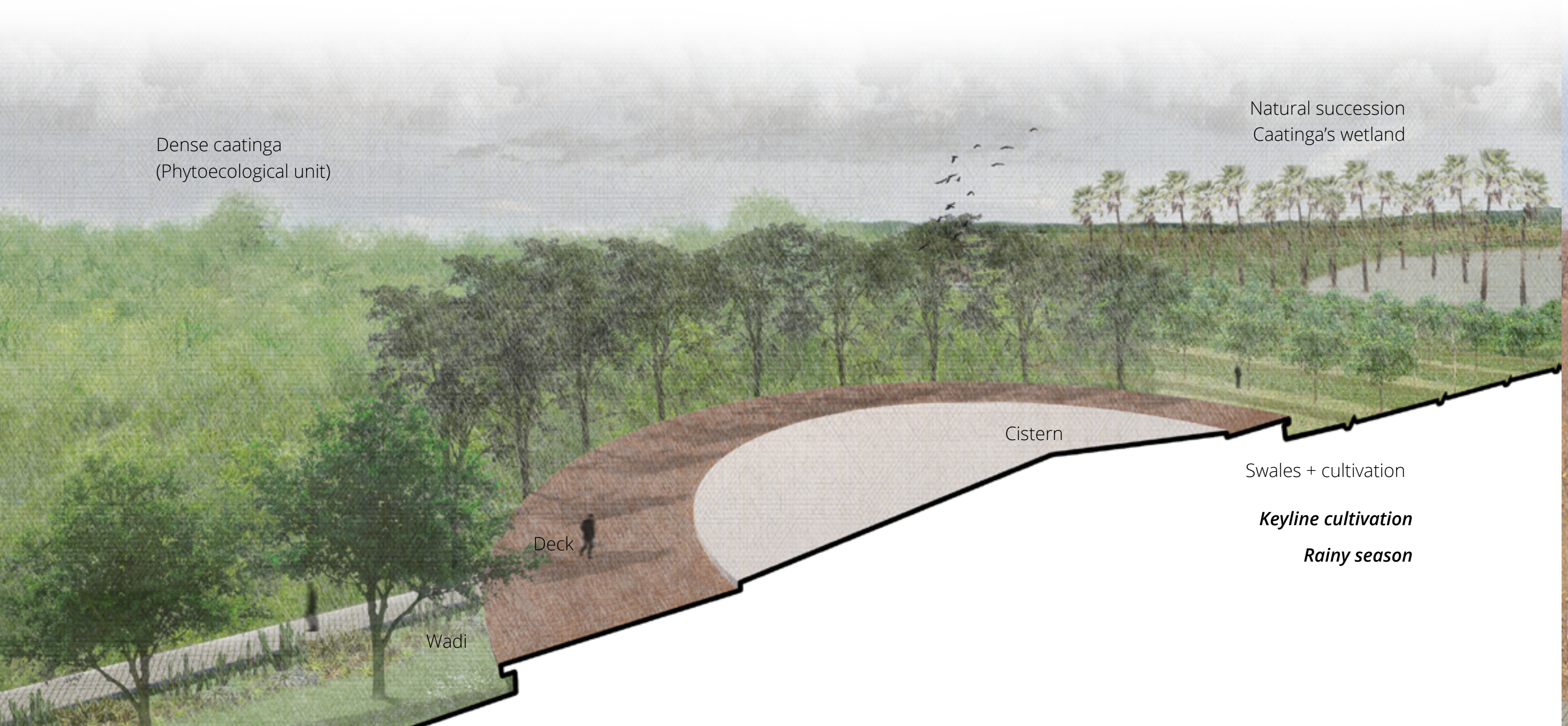
Image 6.26: Wetness and components at Keyline cultivation: rainy season (left), dry season (right)

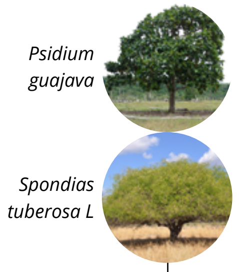
To explore the recreational potential of this area and also to raise awareness about the use of water in Jaguaribara, a wooden deck was designed around the cistern.

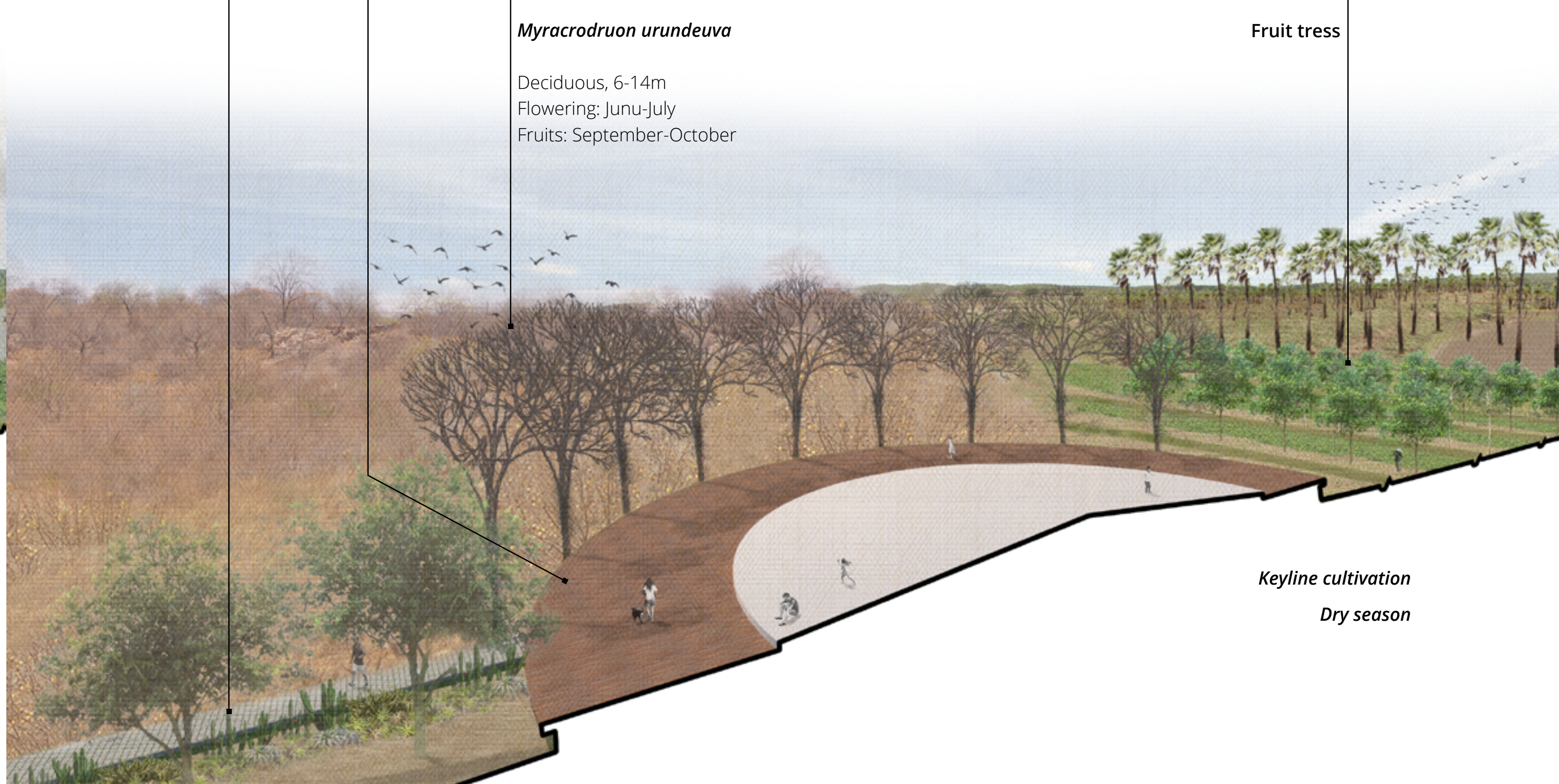
On this deck, it is possible to observe the effect that the different concentrations of wetness can have on the landscape: in the wadi, in the dense vegetation of the caatinga biome, in the cultivation area and, further on the horizon, the tall vegetation of the natural succession in this area.

In order to provide a "roof" and shading for the deck, trees of the species ***Myracrodruon urundeuva*** were specified.

Image 6.27: Materialization of the Rainwater harvesting square at different seasons.







Underground dam system

As it was already discussed, the traditional rangelands can lead to desertification. Therefore, a new model for rangelands is proposed. It consists of bringing wetness to the soil gradually and steadily, so that the vegetation can recover at a faster rate.

This wetness is brought into the system thanks to the installation of an underground dam, which blocks the natural flow of the underground water. This blockage is made by a waterproofing mat (as plastic tarps), which is to be installed vertically in a trench dug into the ground to the depth of the impermeable layer (rocks). The retained wetness then rises by capillarity, humidifying the entire surface under the underground dam's influence. (image 6.28)

A spillway must be installed at the top of the underground dam to ensure that a possible water surplus can overflow, instead of soaking the soil. The overflowing water then initially falls on a bed of gravel (to avoid soil erosion) and then infiltrates the soil. (image 6.29)

The designed rangeland is situated in an elevated position of the topography, just before a region of "temporary lakes". By applying the same swales strategy in this area, a sponge zone is created, which helps to absorb the excess water that overflows from the spillway.

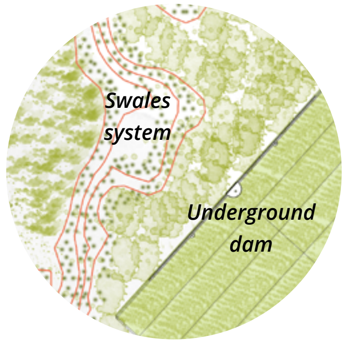
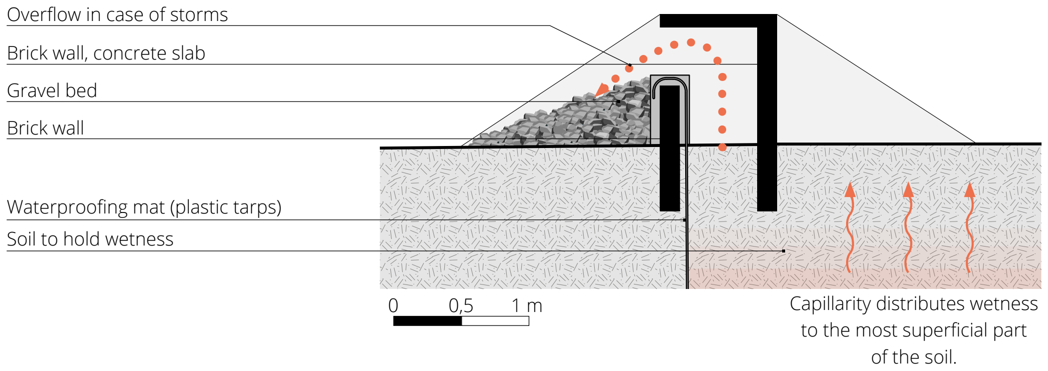
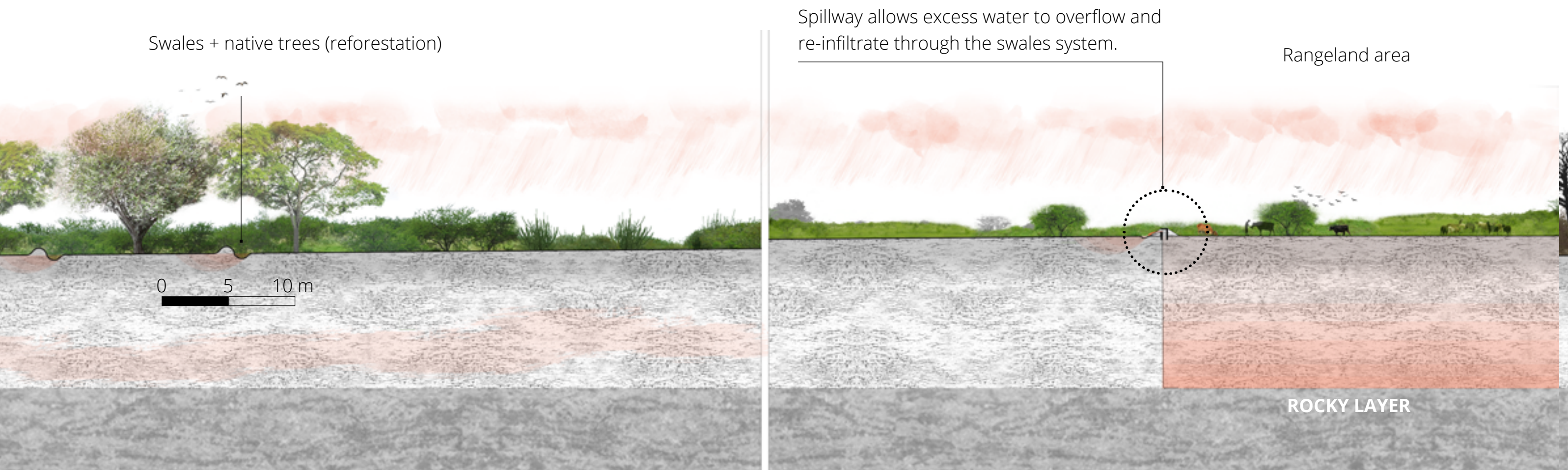


Image 6.28: Underground dam rangeland general profile: during rainy (left) and dry season (bottom)

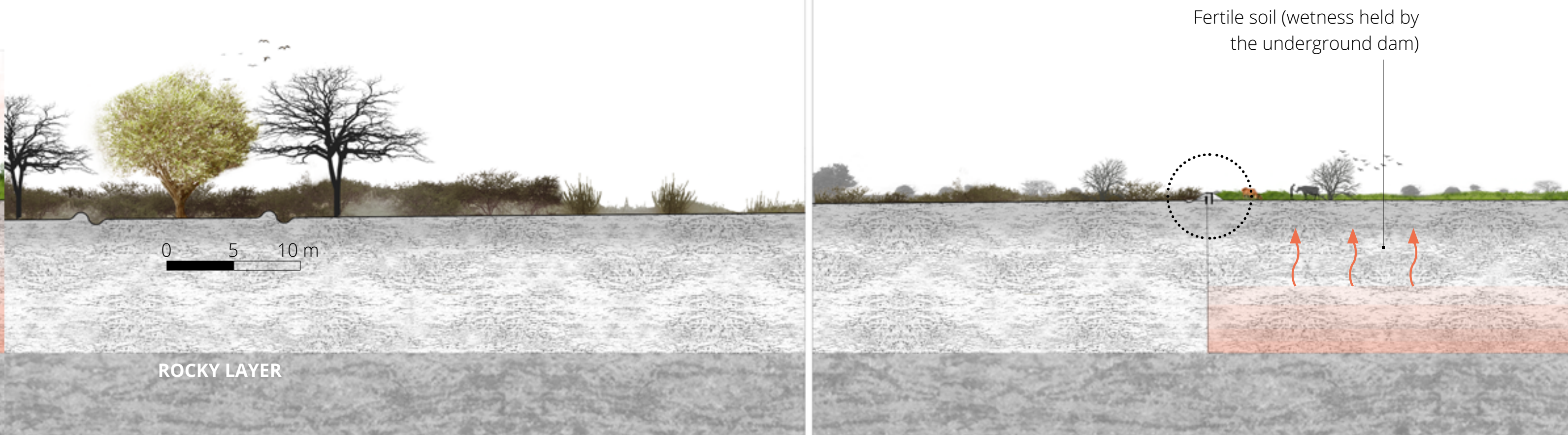
Image 6.29: Detail of the underground dam spillway.



Designed rangeland - wet periods



Designed rangeland - dry periods



Two spaces associated with the **Underground dam rangeland** were created. The first is in the spillway and the second in an intermediate area where it is proposed to insert a well.

The following diagrams show the components of each space and the flow of wetness in each of these spaces during the rainy and dry seasons.

Image 6.30: Wetness and components at Underground dam rangeland on rainy season and dry season: spillway (left), well (right)

Underground route

Surface runoff

Wetness that infiltrates the soil

Rising wetness

Underground dam (spillway)
Rainy season

Underground dam (well)
Rainy season

Underground dam (spillway)
Dry season

Underground dam (well)
Dry season

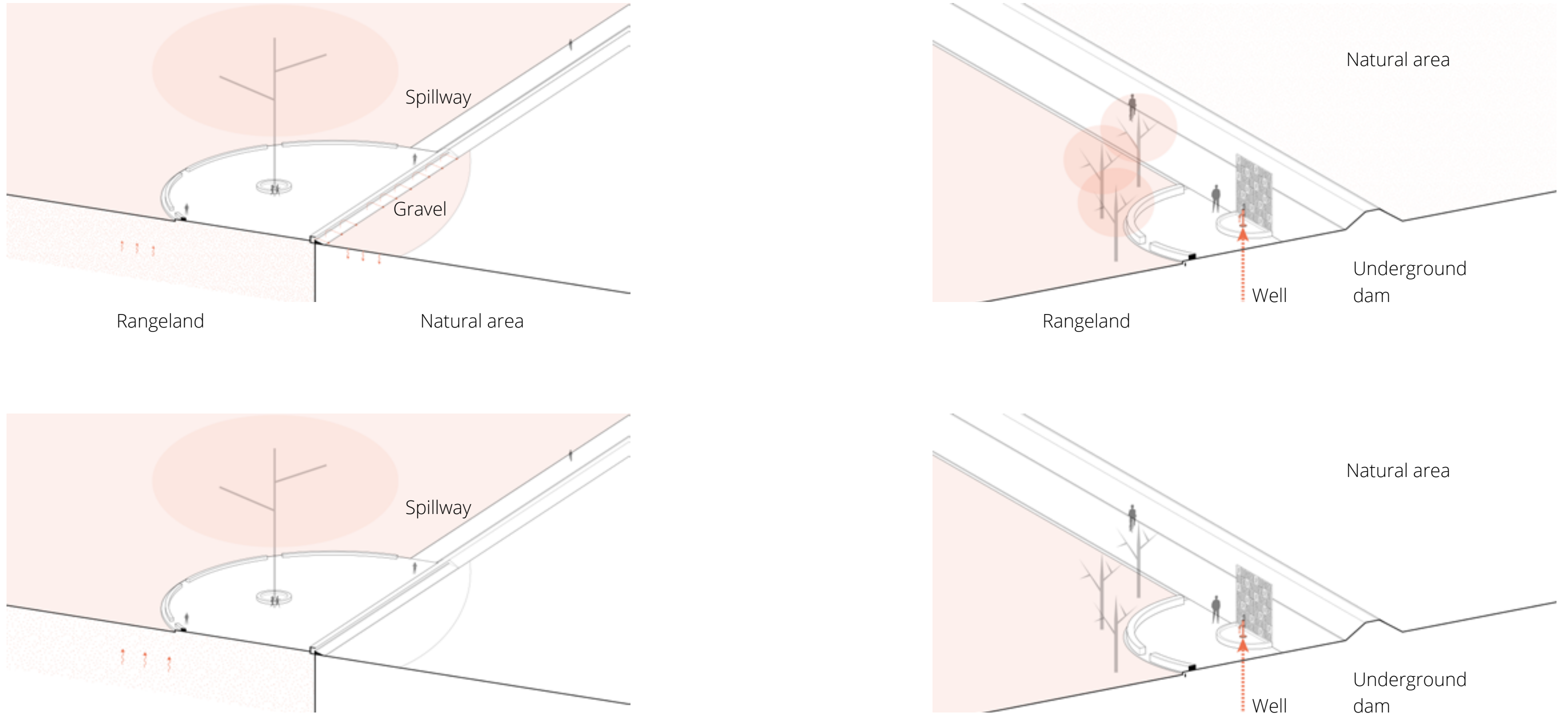


Image 6.31: Materialization of the underground dam spillway at different seasons and *Ziziphus joazeiro* in the caatinga landscape.

Source: luizcarlosbill.com.br. Accessed in December, 2019.

The spillway area was designed to have circular benches around a tree of the species ***Ziziphus joazeiro***. Due to its deep roots, the tree manages to remain green all year round. In the caatinga landscape, it often appears as an isolated tree and its green and leafy crown stands out from the dry landscape. This makes it a focal point and for passers-by and animals. Thus, the design recalls that image, which relates this tree to a place of relief from heat and drought.

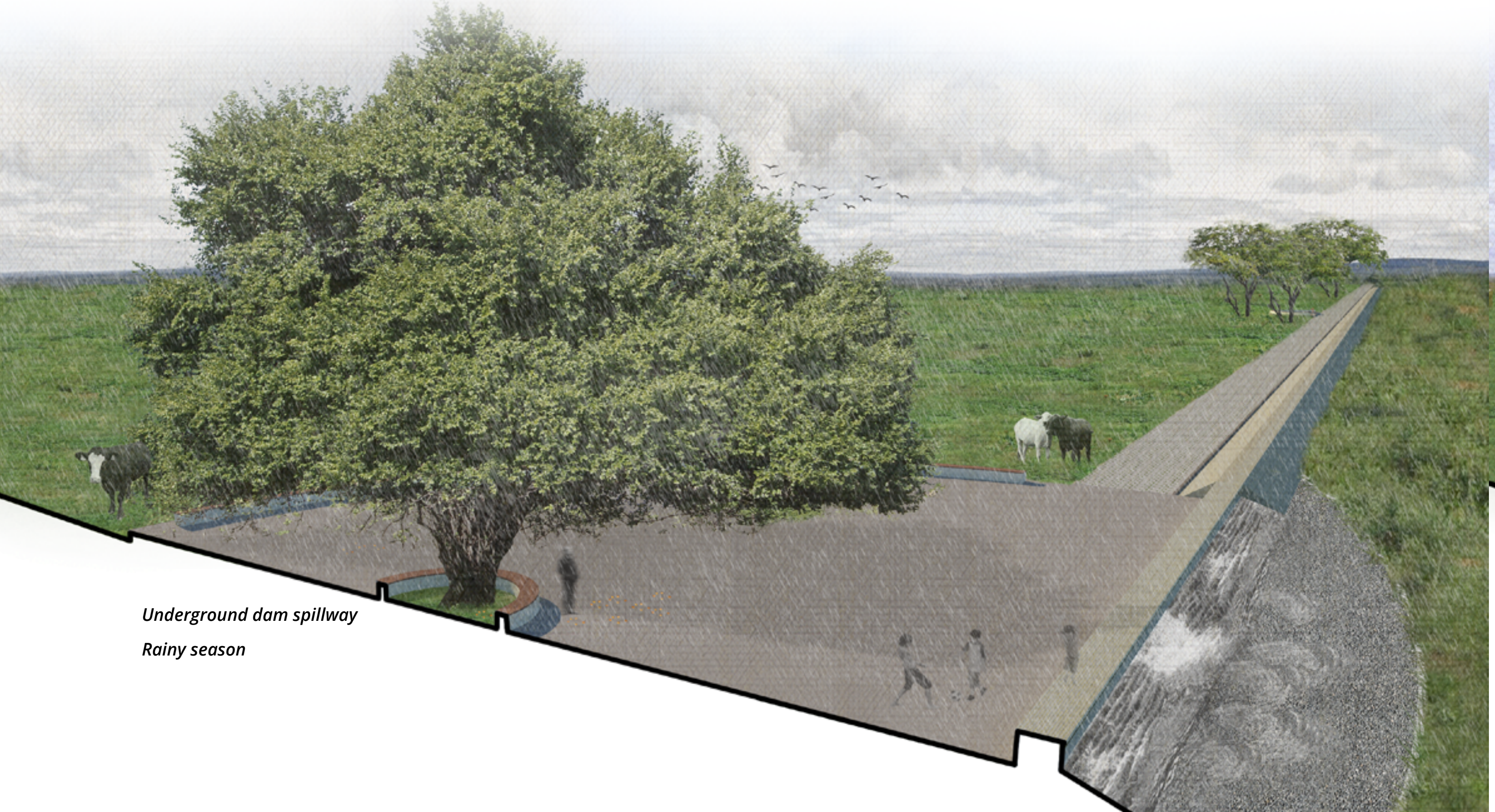
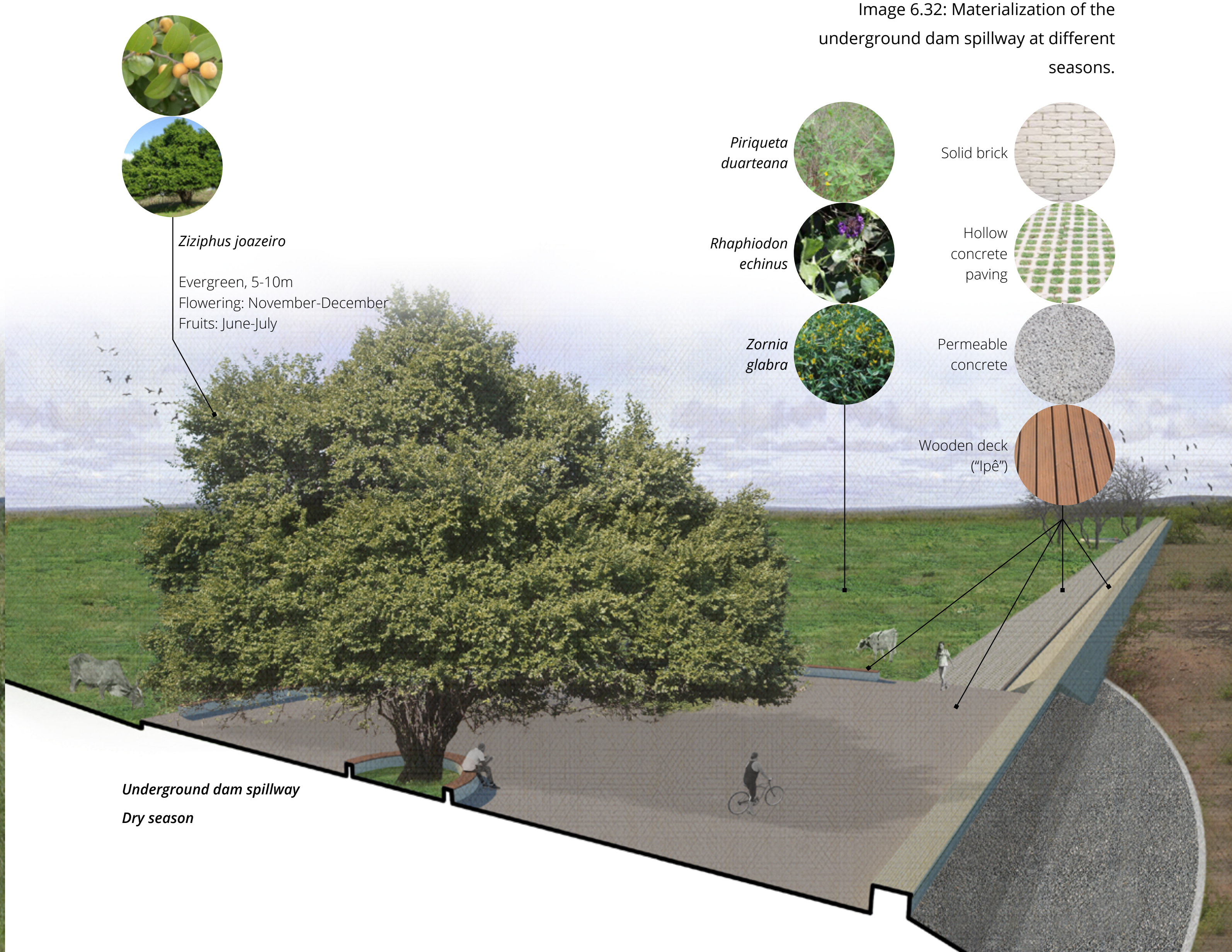


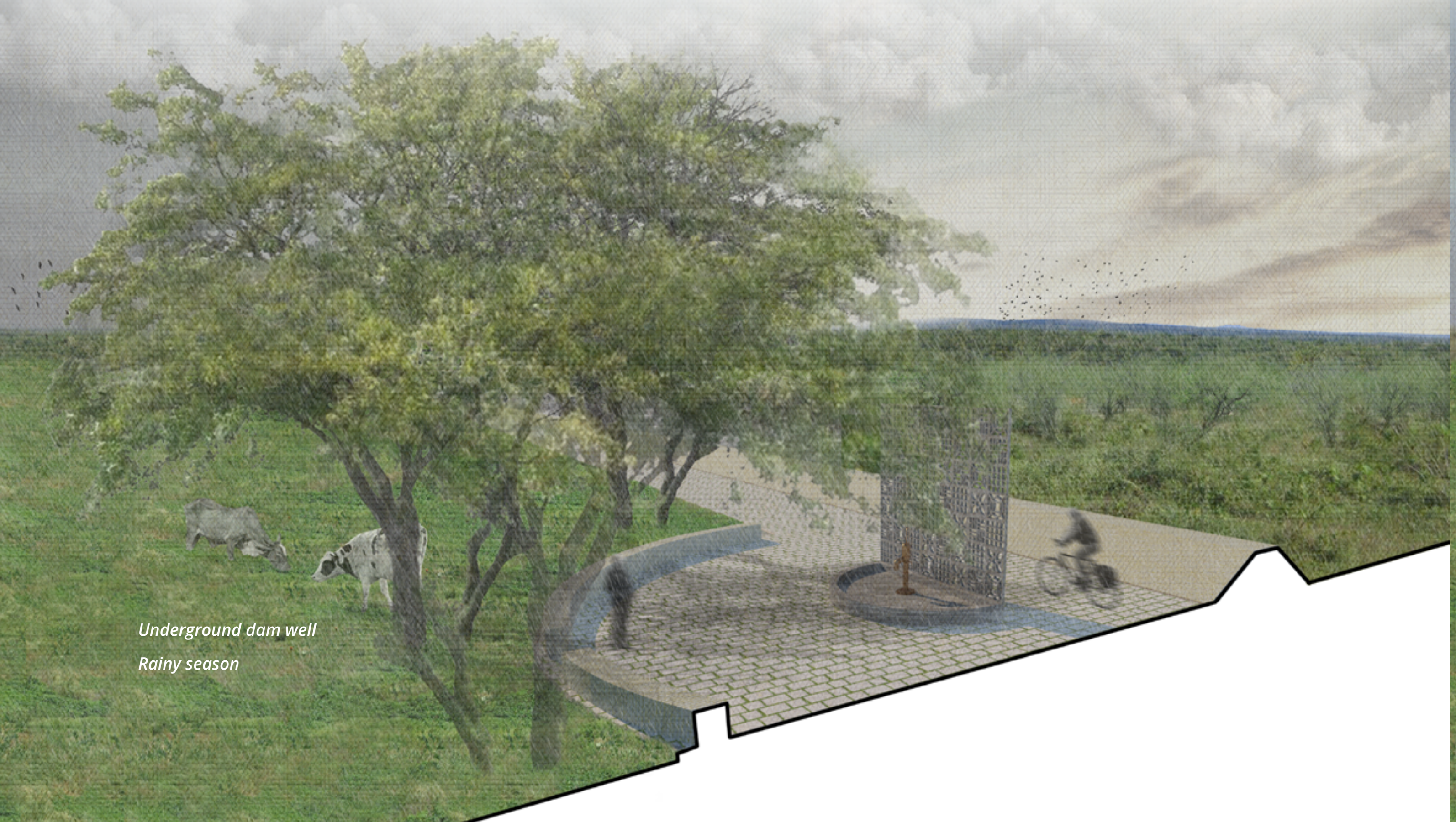
Image 6.32: Materialization of the underground dam spillway at different seasons.



Along the route that follows the underground dam, spaces around wells were designed. Through these wells, the inhabitant accesses the wetness retained in the soil. This underground water is also available for livestock.

For this area, trees of the species ***Commiphora leptophloeos*** were specified, which lose their leaves in the dry season. To mark the presence of the well and generate more shade for this area, a wall of hollow blocks, typical of the region, called "combogó", was also designed.

Just as the leafless tree is a symbol of drought-resistant vegetation, the "combogó" wall symbolizes the inhabitants' adaptation to conditions of low water availability.



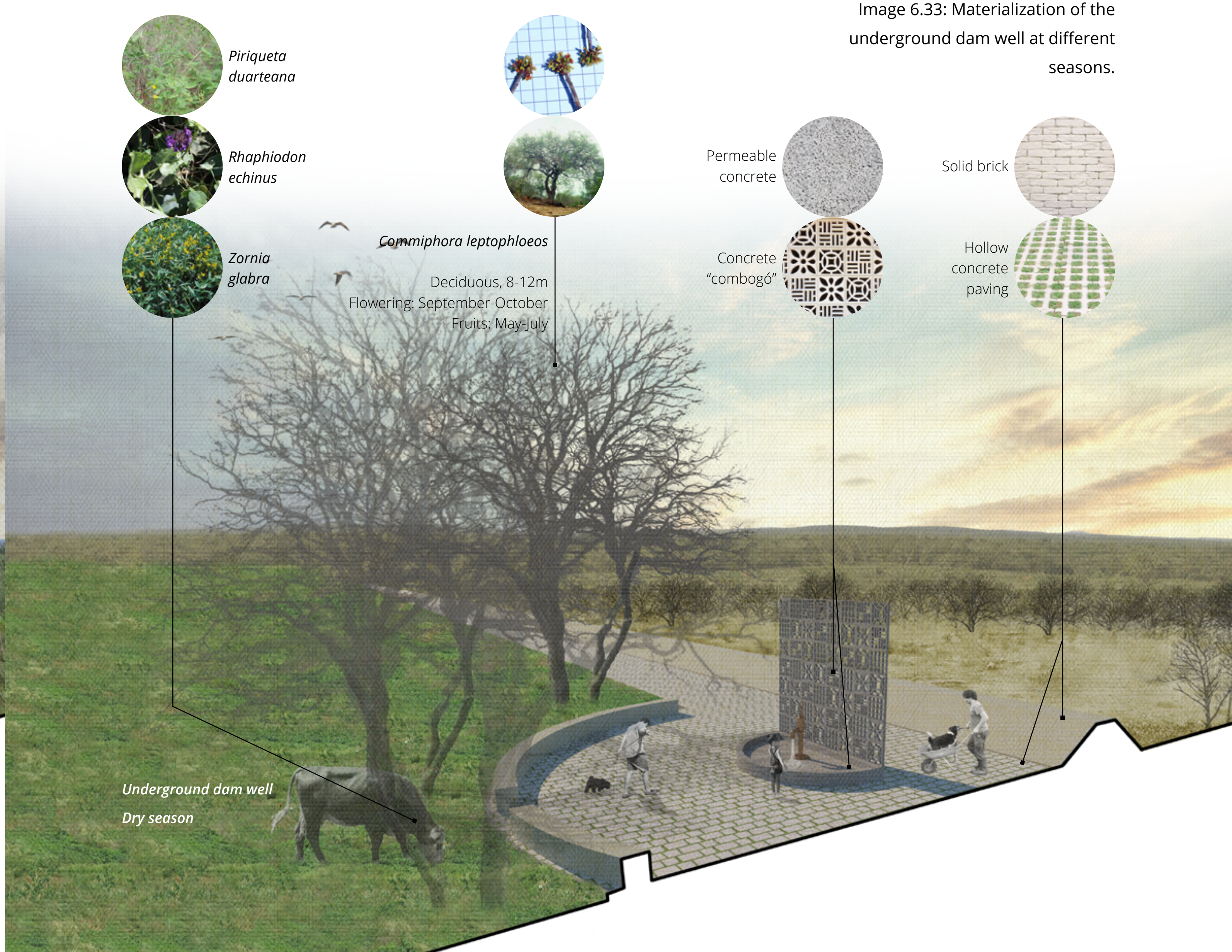
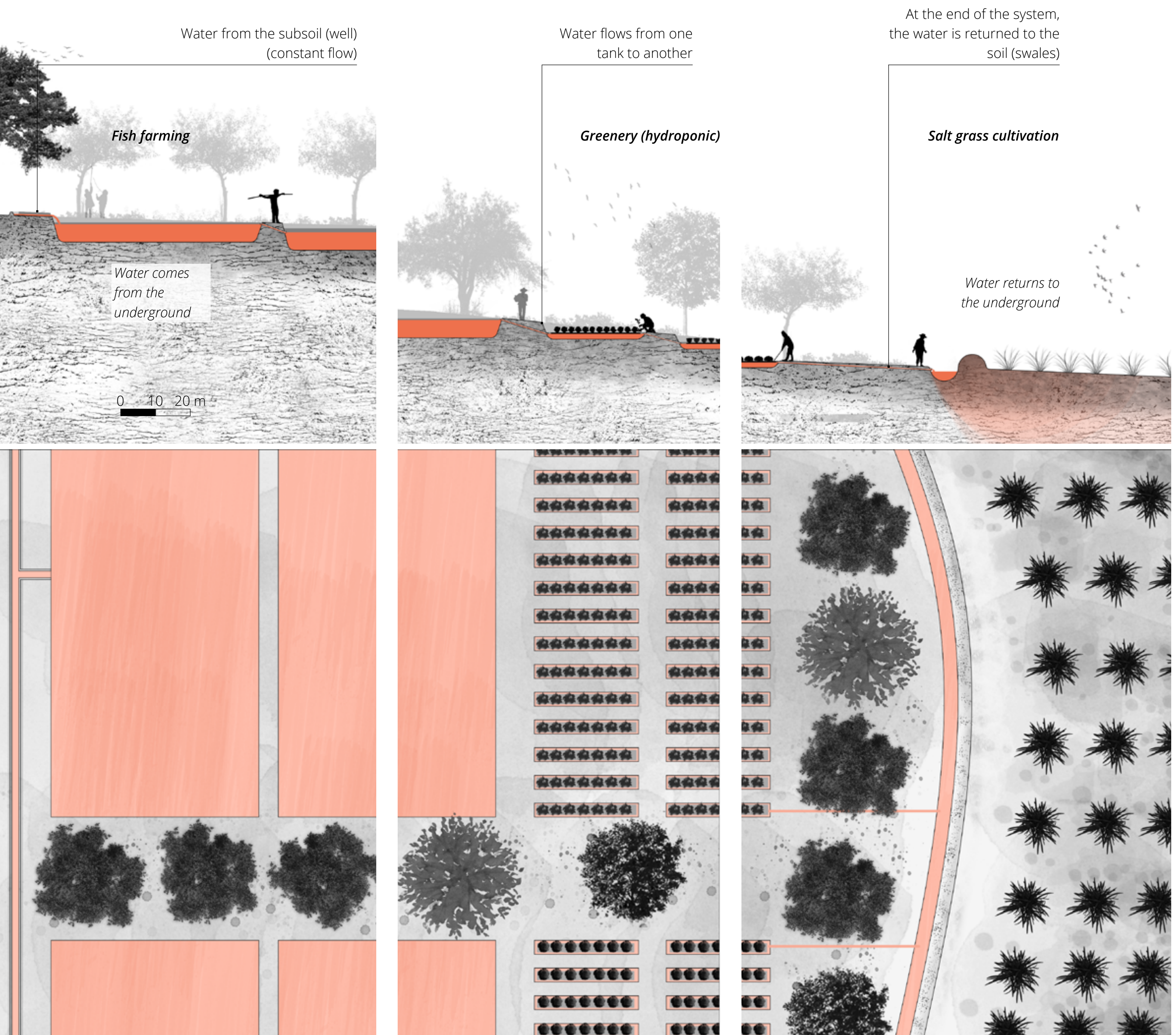


Image 6.33: Materialization of the underground dam well at different seasons.



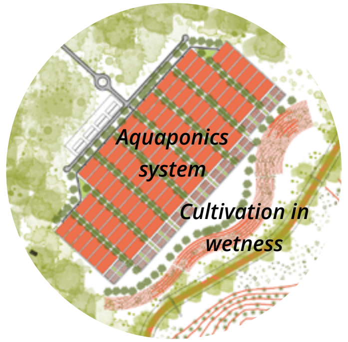


Image 6.34: Aquaponics system: underground water, tilapia fish farming, hydroponic greenery, salt-grass cultivation.

Underground water aquaponics system

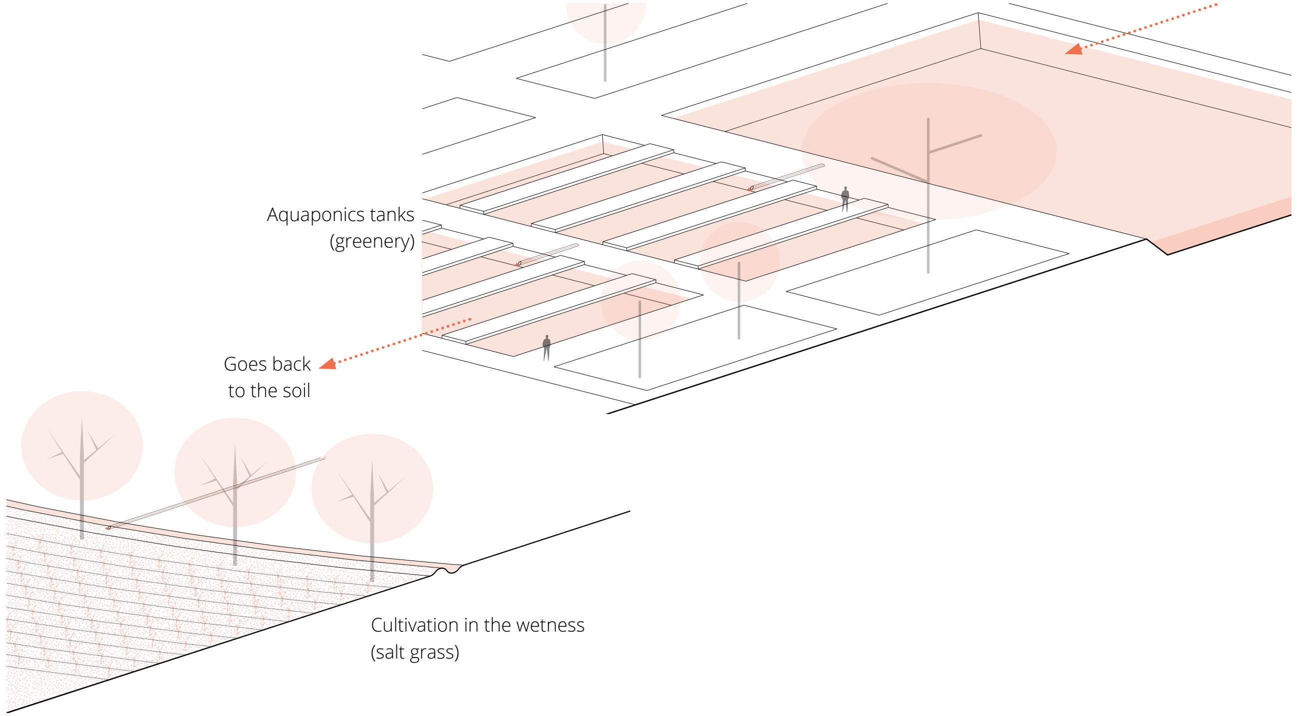
The designed aquaponics system aims to take advantage of the inhabitants' knowledge regarding tilapia fish farming and the production of goods using its derivatives. Once the production of tilapia in cages at Castanhão was extinguished, a system with excavated tanks was designed, by using underground water.

The underground water extracted by the well flows through a narrow channel to the excavated tanks. The water then passes from one tank to another through pipes. After flowing through all the aquaculture (fish) tanks, the water flows into the hydroponic tanks. The greenery grown in this sector consumes excess organic matter in the water (due to fish food). Only after this natural purification process, water is released into the soil in swales. The area after swales, therefore, has access to wetness all year round, and is therefore suitable for new crops, such as salt grass cultivation. (image 6.34)

The transfer of water between the tanks occurs by gravity, without the use of electrical energy. However, water pumping equipment may be required to extract water from the subsoil.

The diagram below shows the components of the **Underground water aquaponics system** and how wetness flows through them.

Underground water aquaculture system



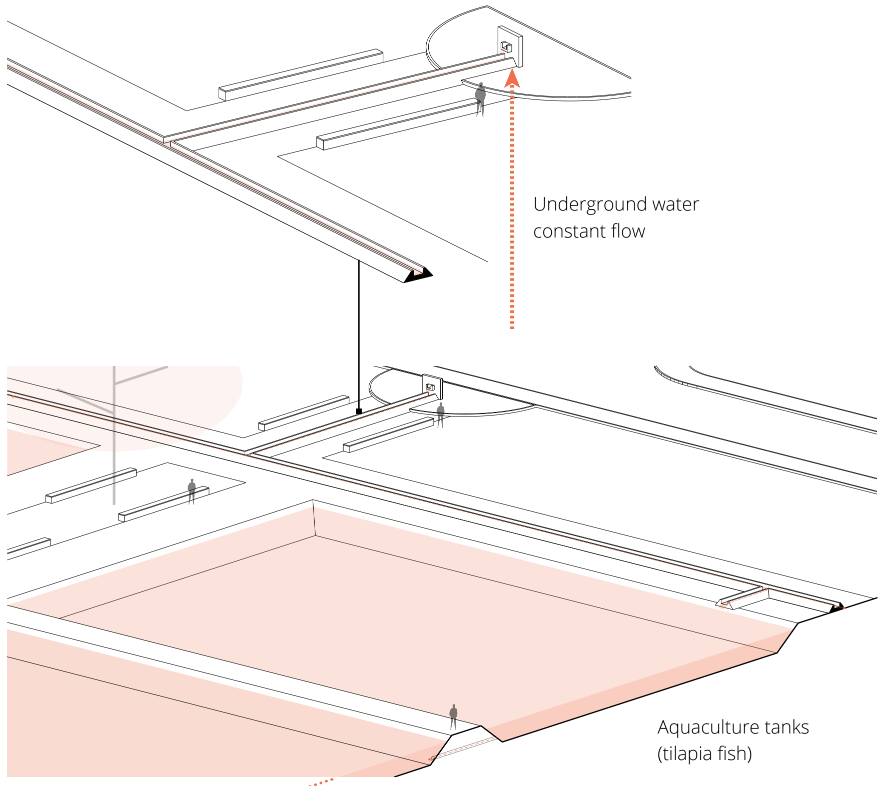


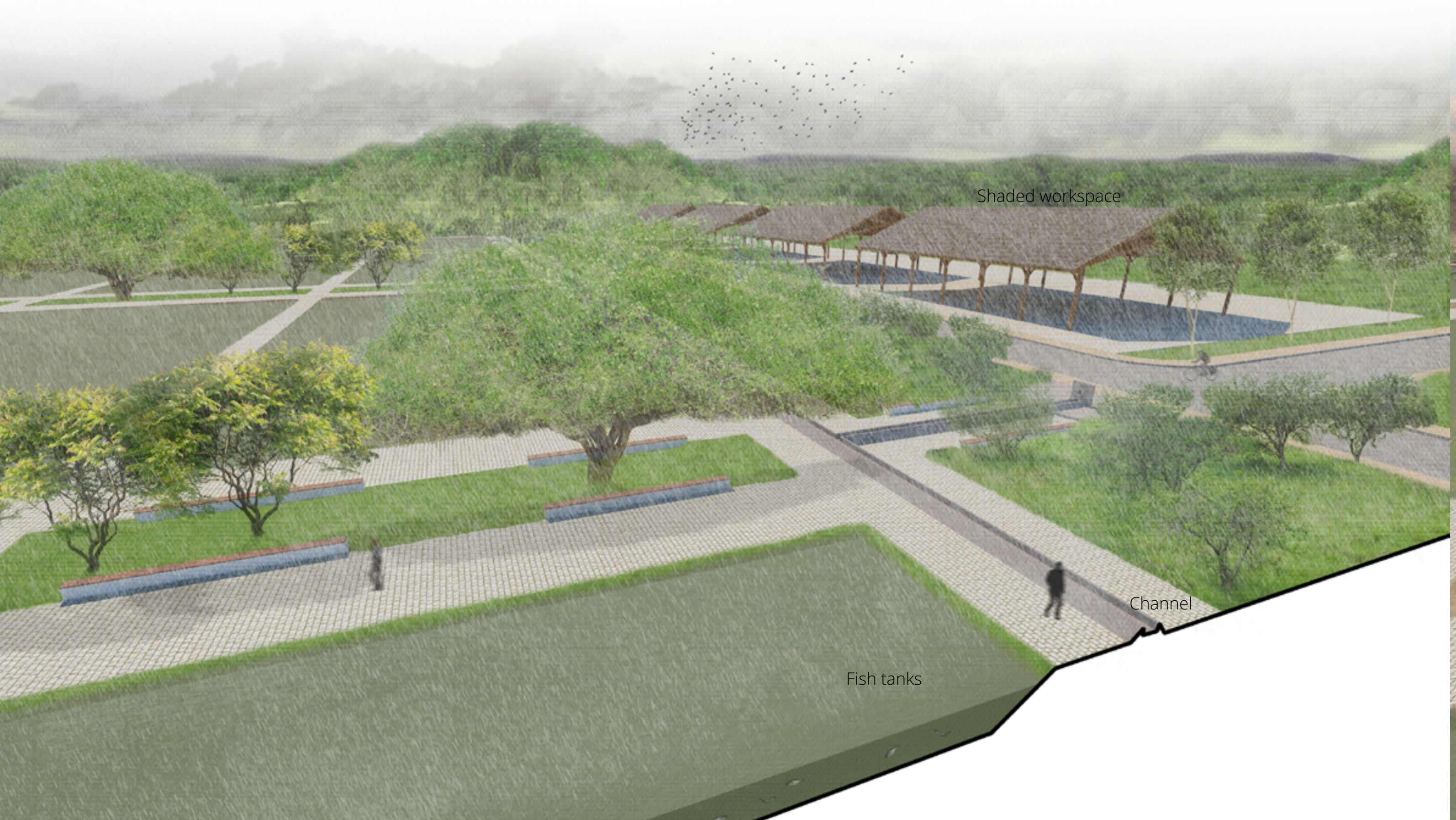
Image 6.35: Wetness and components at Underground water aquaponics system.

Between the tanks, green areas were designed. The insertion of vegetation between the tanks contributes to the creation of a micro-climate, reducing the global temperature and the evaporation of water from the tanks.

In addition, fruit trees, native to the caatinga, were specified. As tilapia fish is omnivorous, the fruits of these trees can complement the fish's diet.

Underground water aquaponics

Rainy season



Underground water aquaponics

Dry season

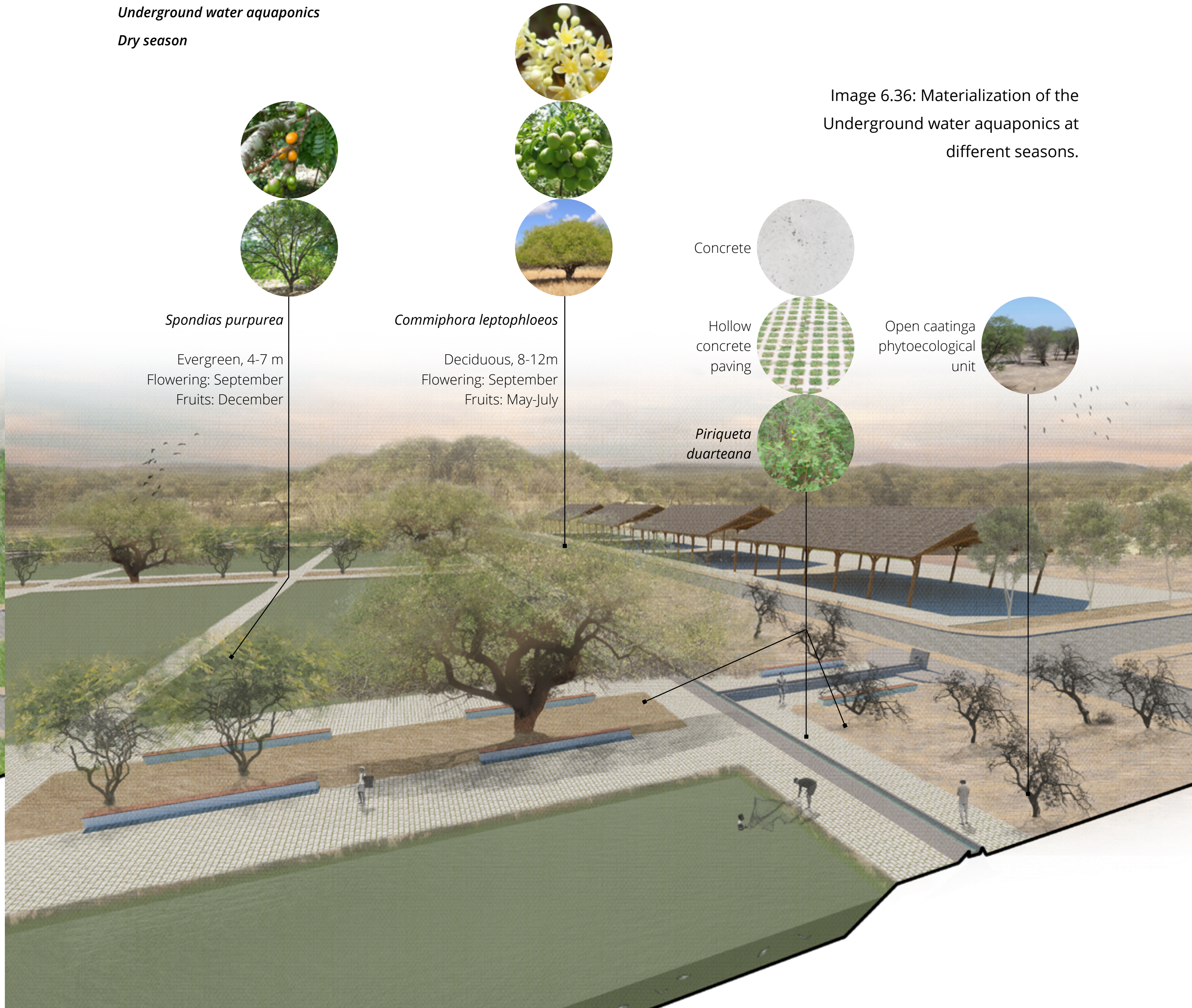


Image 6.36: Materialization of the Underground water aquaponics at different seasons.

Image 6.37: Water, ecology and production flows in Jaguaribara after implementing the design strategies. (rainy periods)

Design x flows

The following images illustrates the parallel between water, ecology and production flows after implementing the proposed design strategies at the local scale. Informations are given for rainy (image 6.37) and dry periods. (image 6.38)

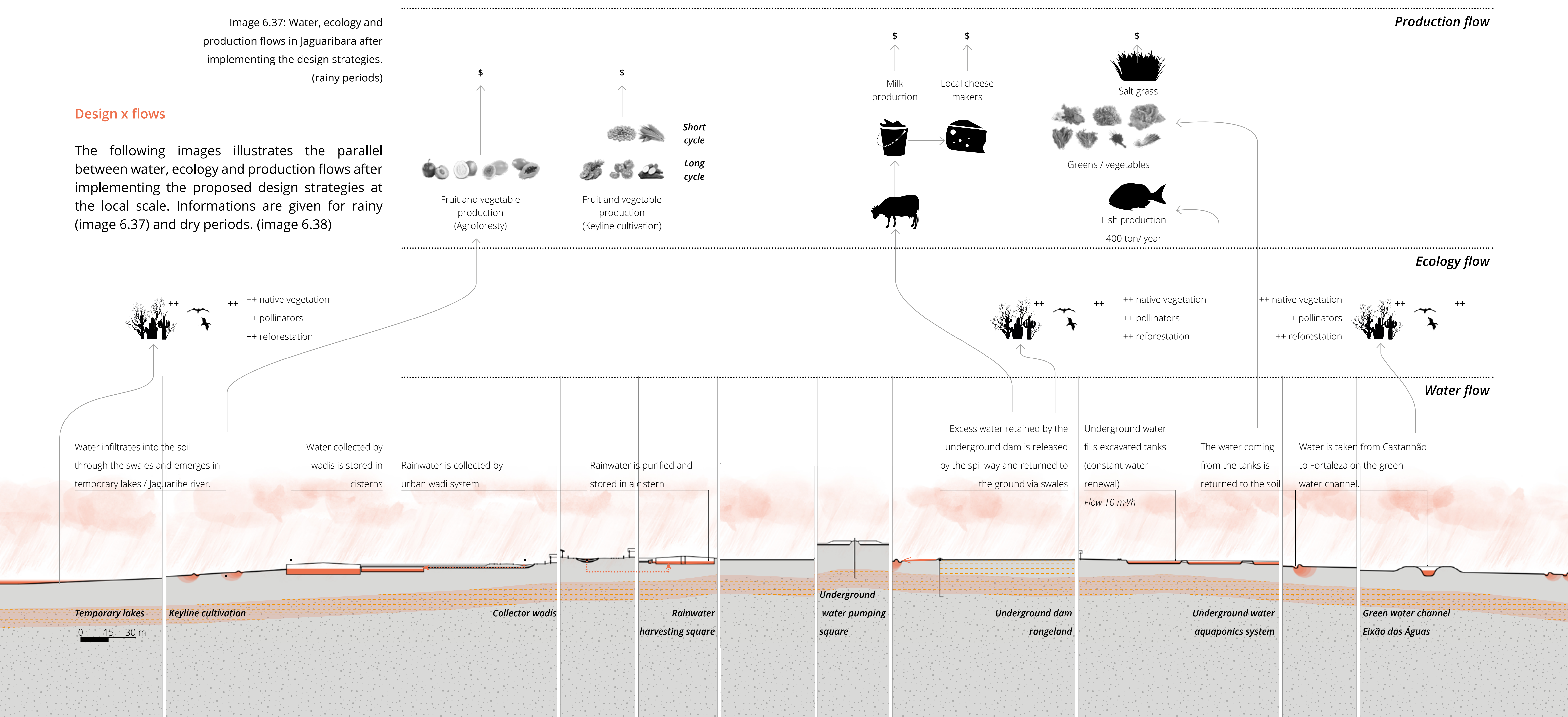
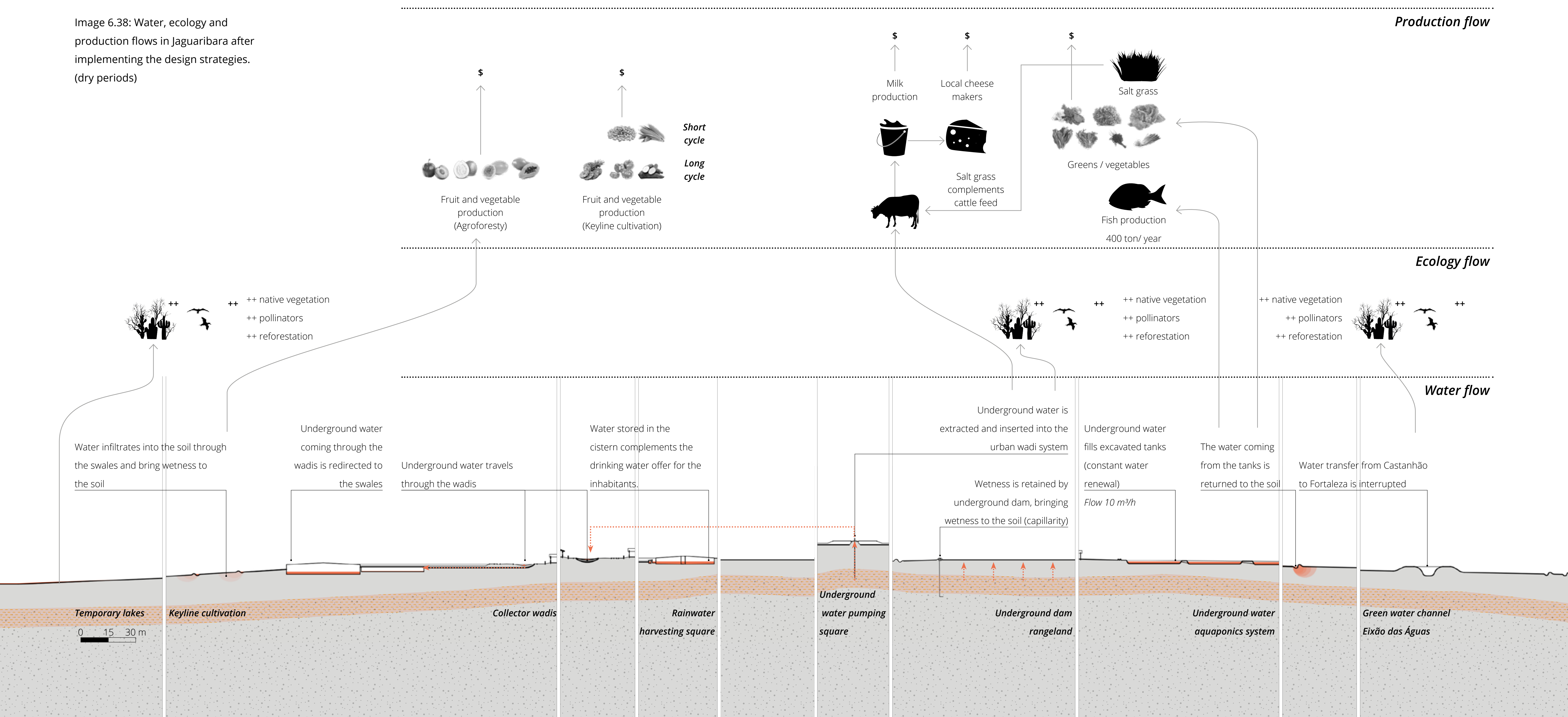


Image 6.38: Water, ecology and production flows in Jaguaribara after implementing the design strategies. (dry periods)



Water calender

To understand how the proposed design strategies respond to water variability throughout the year, a round water calendar was created. For this purpose, it was used the rainfall data from 2019 (regular year) and 2012 (dry year). In addition, it was also added information regarding productive activities, associated with the proposed design strategies. (image 6.39)

The linear calendar, on the other hand, presents information about available water and water use over the years. This was made to simulate the ability of design strategies to ensure wetness in the short and medium term. For this, it was considered rainfall data between 2002 and 2019. (image 6.40)

These data are important to understand the extent to which the design strategies proposed for Jaguaribara provide autonomy to the community.

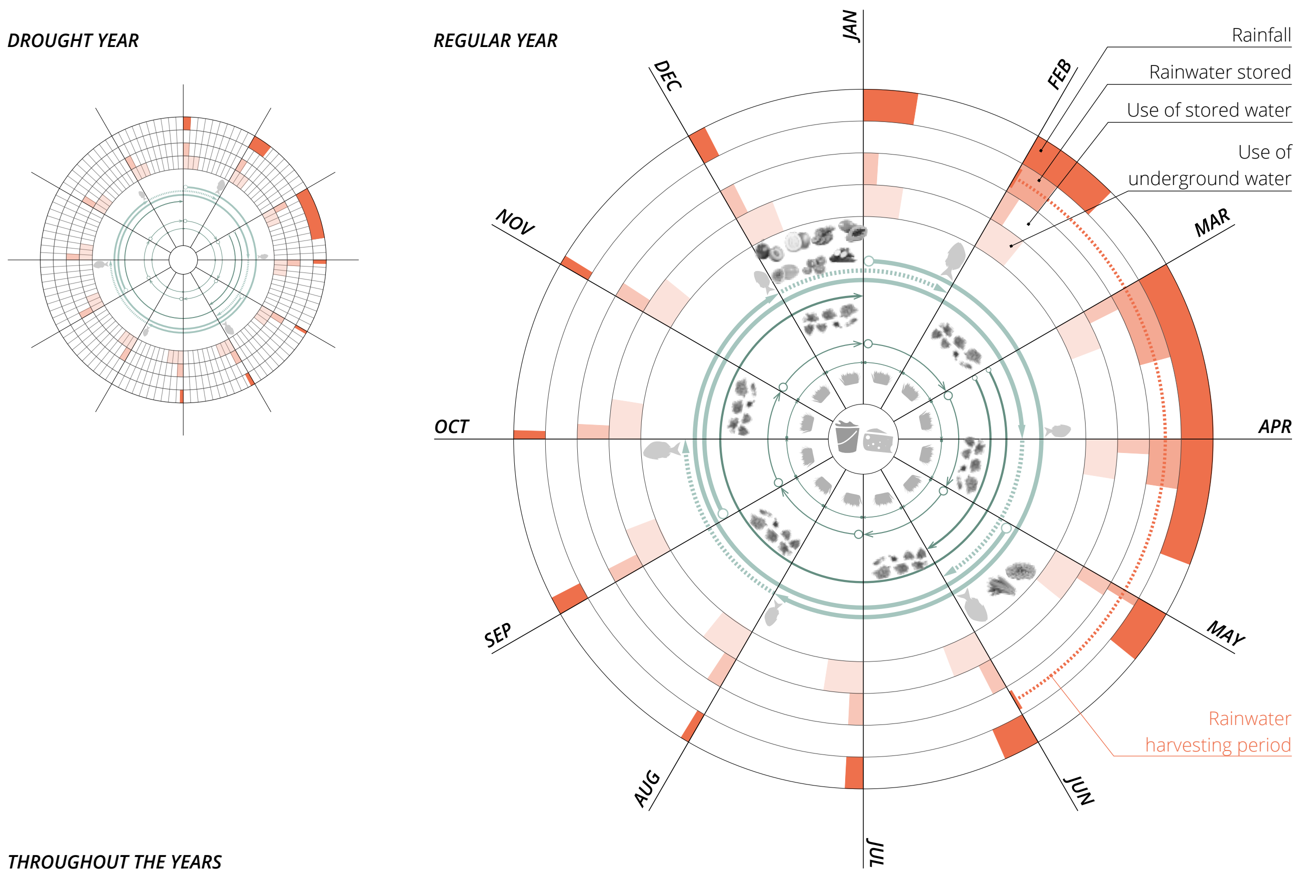


Image 6.39: Round water calender: wetness x harvesting x production over time.

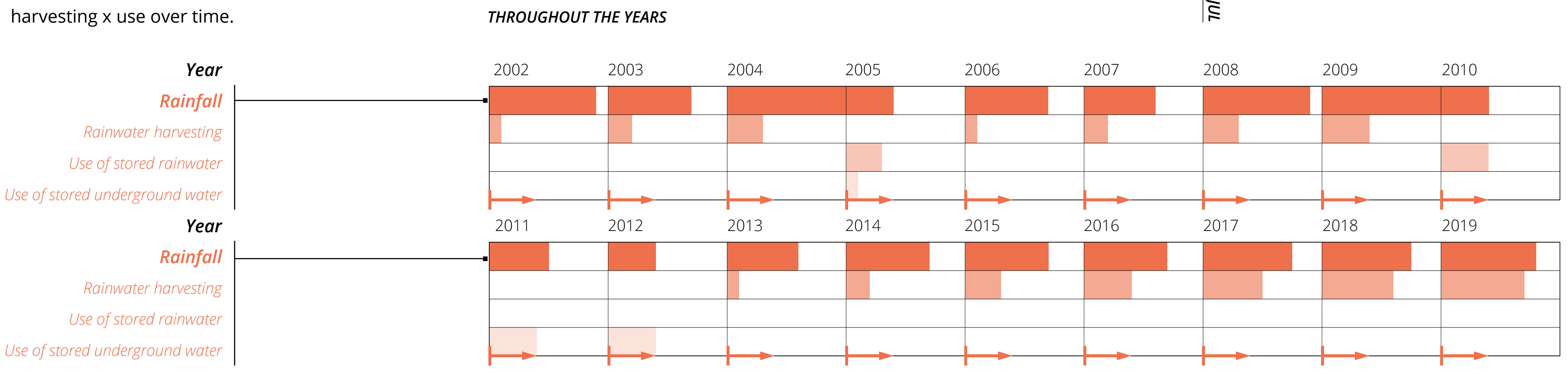


Image 6.40: Linear water calender: water harvesting x use over time.

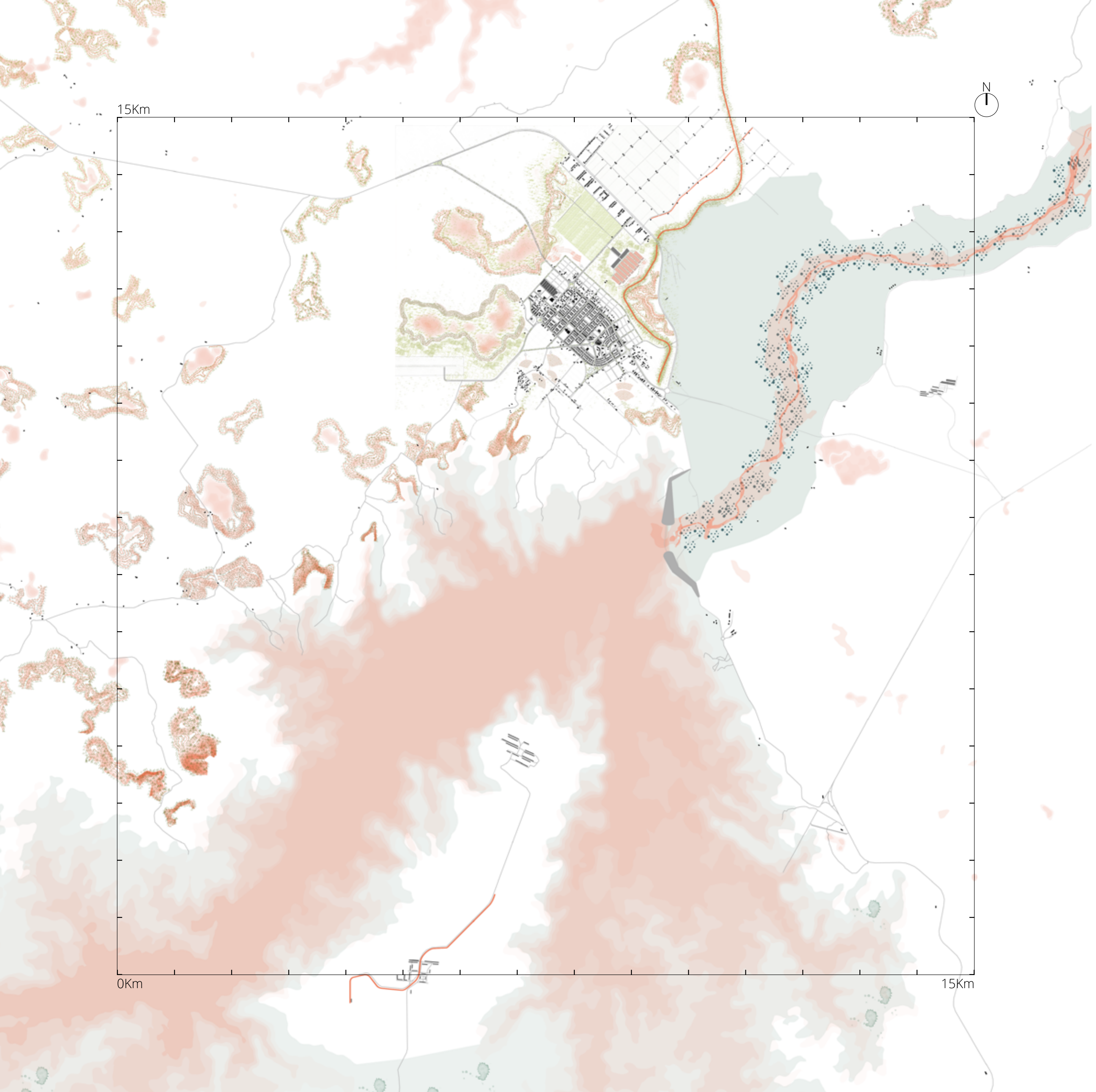


Image 6.41: Recovery of the caatinga and soil creation through swales: protection of water from evaporation, expansion of groundwater recharge and water retention by vegetation.

Swales + caatinga reforestation

Greenification water channel *Eixão das Águas*

Riparian buffer

Expansion of the ecological area of the Castanhão

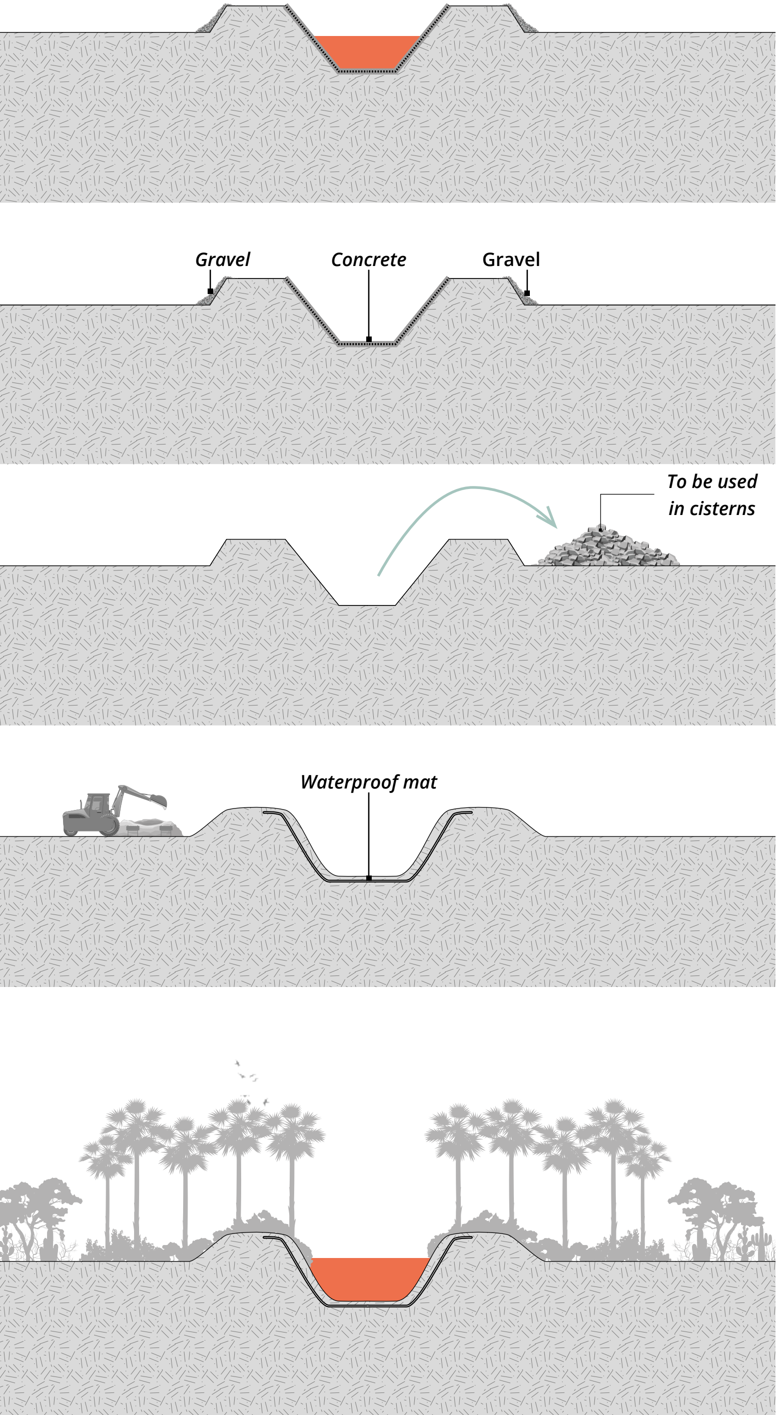
6.3 METROPOLITAN SCALE

At the metropolitan scale, the design strategies focus on promoting the protection of water from evaporation and the recharging of groundwater.

This is proposed through four actions, which work together: 1) creation of a swales system in the north-west portion of the study area; 2) greenification of the water channel *Eixão das Águas; 3)* expansion of the environmental protection area of the Jaguaribe river and recovery of riparian forest (riparian buffer); 4) expansion of the Castanhão ecological area and reforestation of the reservoir edges. (image 6.41)

Swales system

The swales system corresponds to a set of parallel lines of swales and mounds, as shown on the local scale. These would be carved around the "temporary lakes", as well as across the thalwegs. This would increase the overall groundwater recharge, by, reducing evaporation losses and surface runoff. At the centre of this system, it is promoted the natural succession in the wetlands, as explained earlier.



Current situation. Concrete slabs hold water to prevent infiltration. Gravel on the sides of the channel.

Step 1:
Water flow interrupted between Castanhão dam and Fortaleza.

Step 2:
Material removal: concrete and gravel. This material must be reused for the construction of cisterns.

Step 3:
Earthwork (softer profile) + installation of waterproof mat + addition of fertile soil layer.

Step 4:
Reforestation (species of riparian forest, pioneers and intermediate stages). Over time, pollinators spread the seeds and the water channel becomes a starting point for the reforestation of the caatinga.

Image 6.42: Phases of the greenification process of the water channel (*Eixão das Águas*)

Image 6.43: *Eixão das Águas* construction process in 2012: excavation (top), installation of concrete slabs (middle), channel in use (bottom)
Source: HIDRO.CE (2020)

Greenification of *Eixão das Águas*

The greenification of the *Eixão das Águas* aims to protect the transported waters from evaporation. In addition, the green channel makes it possible to interrupt the transposition of water to the coast during the dry season. Currently, this is not possible, as the concrete channels crack with the absence of water. (image 6.43)

The greenification process of the *Eixão das Águas* water channel begins with the temporary water blockage, followed by removal of the concrete slabs of the water channel. The removed concrete can be crushed and reused for the construction of cisterns, adopted in the local scale strategies. Afterwards, it is necessary to flatten and compact the exposed soil and cover it with a geotextile blanket waterproofed with carnauba wax.

After that, the soil rich in organic matter must be added. This can be taken from the dredging of rivers (made regularly in Ceará). Finally, pioneer species of riparian forest would be planted, as well as dicots of secondary stages. Over time, the vegetation will follow the natural succession, imitating riparian forest. (image 6.42)

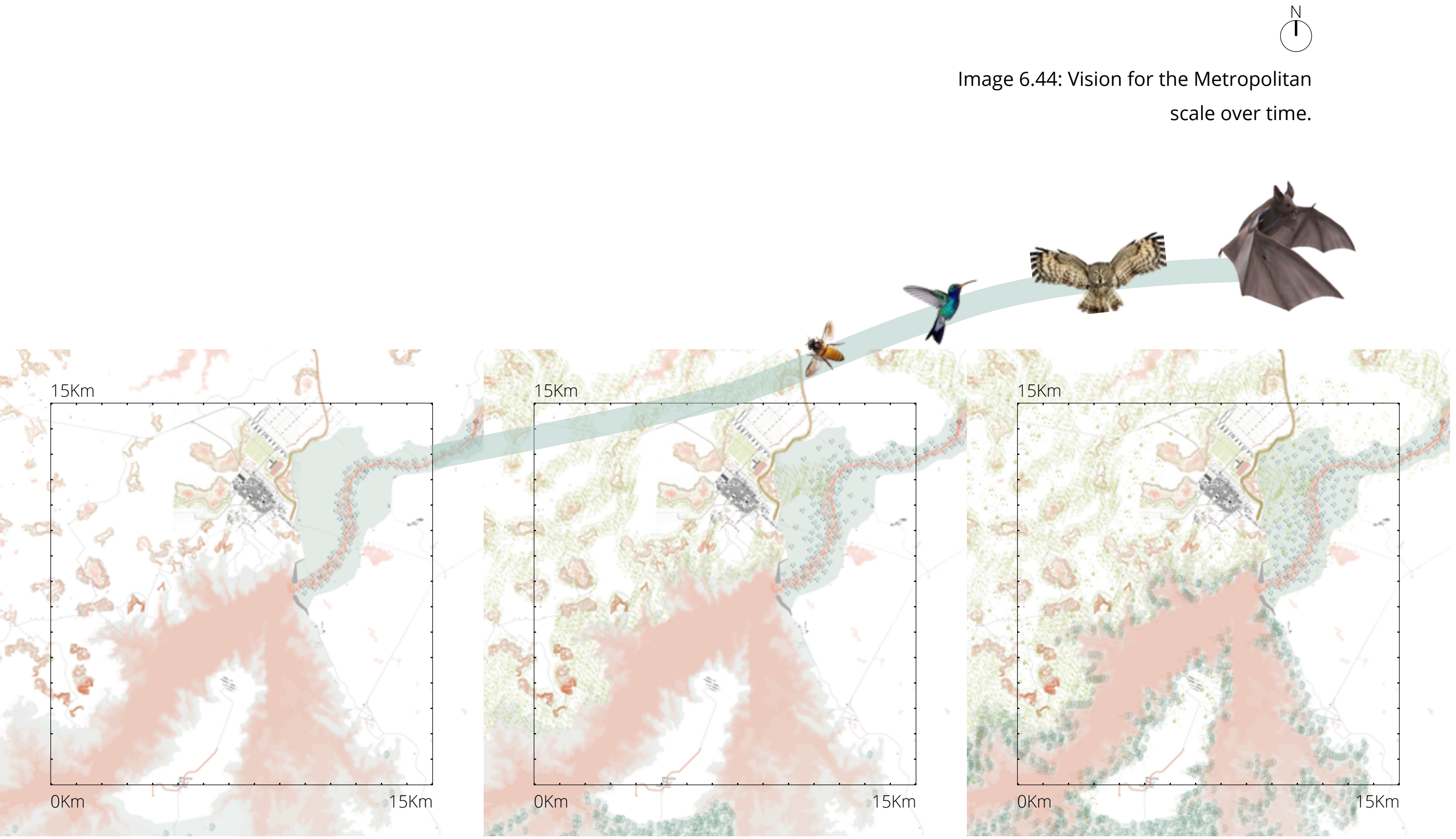


Image 6.44: Vision for the Metropolitan scale over time.

Riparian buffer

The creation of the riparian buffer expands and formalizes the protection area of the Jaguaribe river, promoting the recovery of riparian forest and protecting the water body. Therefore, it is necessary to remove the buildings and to plant pioneer species and secondary stage dicots throughout this area.

Castanhão ecological reserve

Finally, this strategy is based on expanding the ecological reserve of Castanhão to the entire edge of the reservoir. In this area, reforestation would then be carried out, planting pioneers and second-stage specimens of the open caatinga.

Metropolitan scale over time

The image on the right shows how the combination of the strategies proposed for the metropolitan scale would evolve over time.

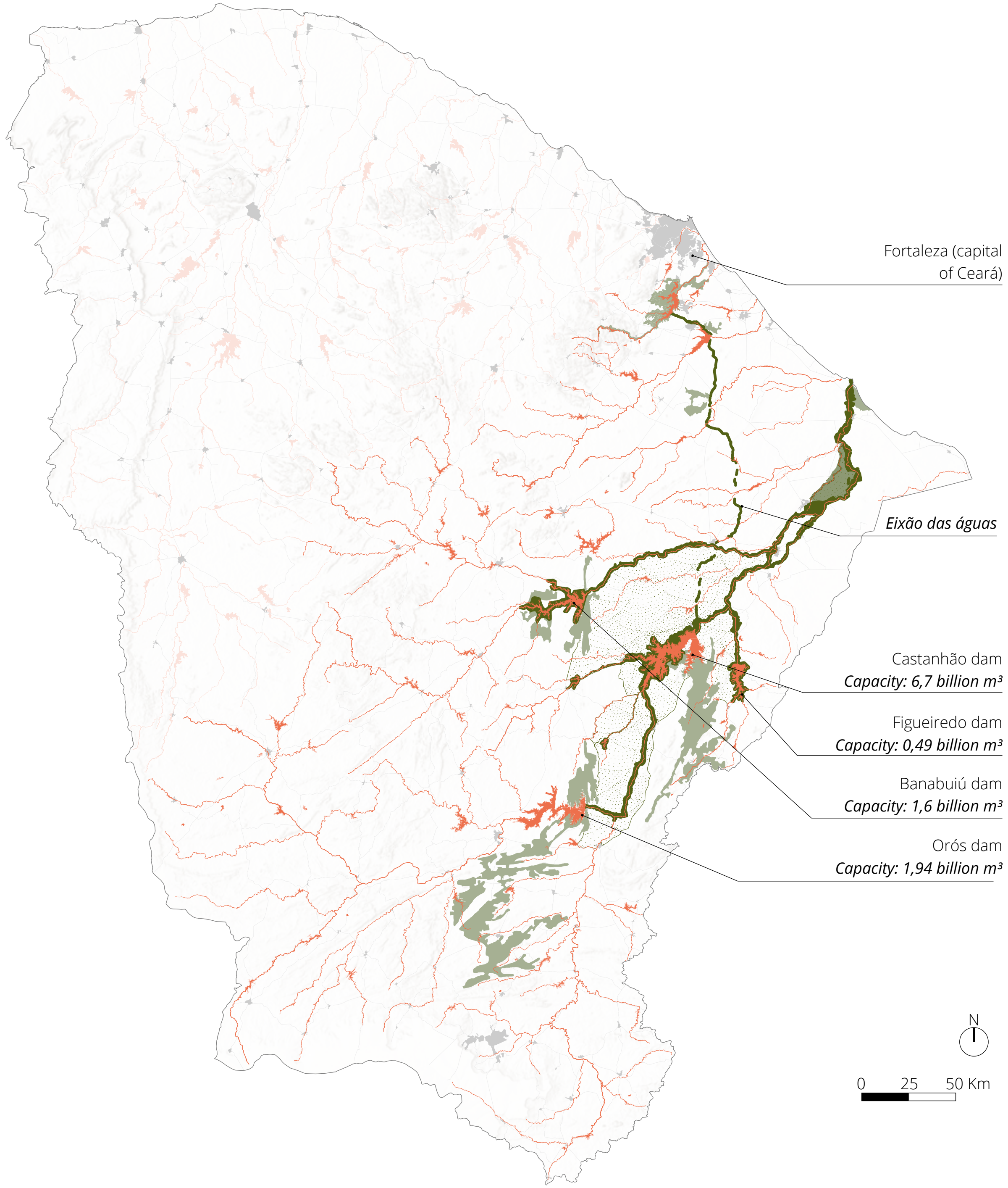


Image 6.45: Vision for the regional scale: greenification of water channel, riparian forest buffer, caatinga vegetation recovery.

6.4 REGIONAL SCALE

The design strategy at the regional scale proposes to expand the idea of water and soil protection to the scale of Ceará and the Jaguaribe river watershed.

In addition to expanding the riparian buffer and the greenification of *Eixão das Águas*, areas were identified in which soil and vegetation recovery are more urgent. These areas are prone to desertification and correspond, as discovered in the analysis phase, to rangelands and agro-extractivism (carnauba / shrimp farming).

In these areas, it is necessary to reduce soil erosion and promote reforestation. The specific strategy to be applied should be chosen after an in-depth analysis of each location. (image 6.45)

The shape given to the intervention area is based on the region's land use. The image on the next page illustrates how this shape was given.

Greenification of water channel (*Eixão das águas*)
Riparian buffer
Areas for recovery of native forest (caatinga)
Riparian forest recovery areas (carnauba).
Existing green areas
Water
Urban areas

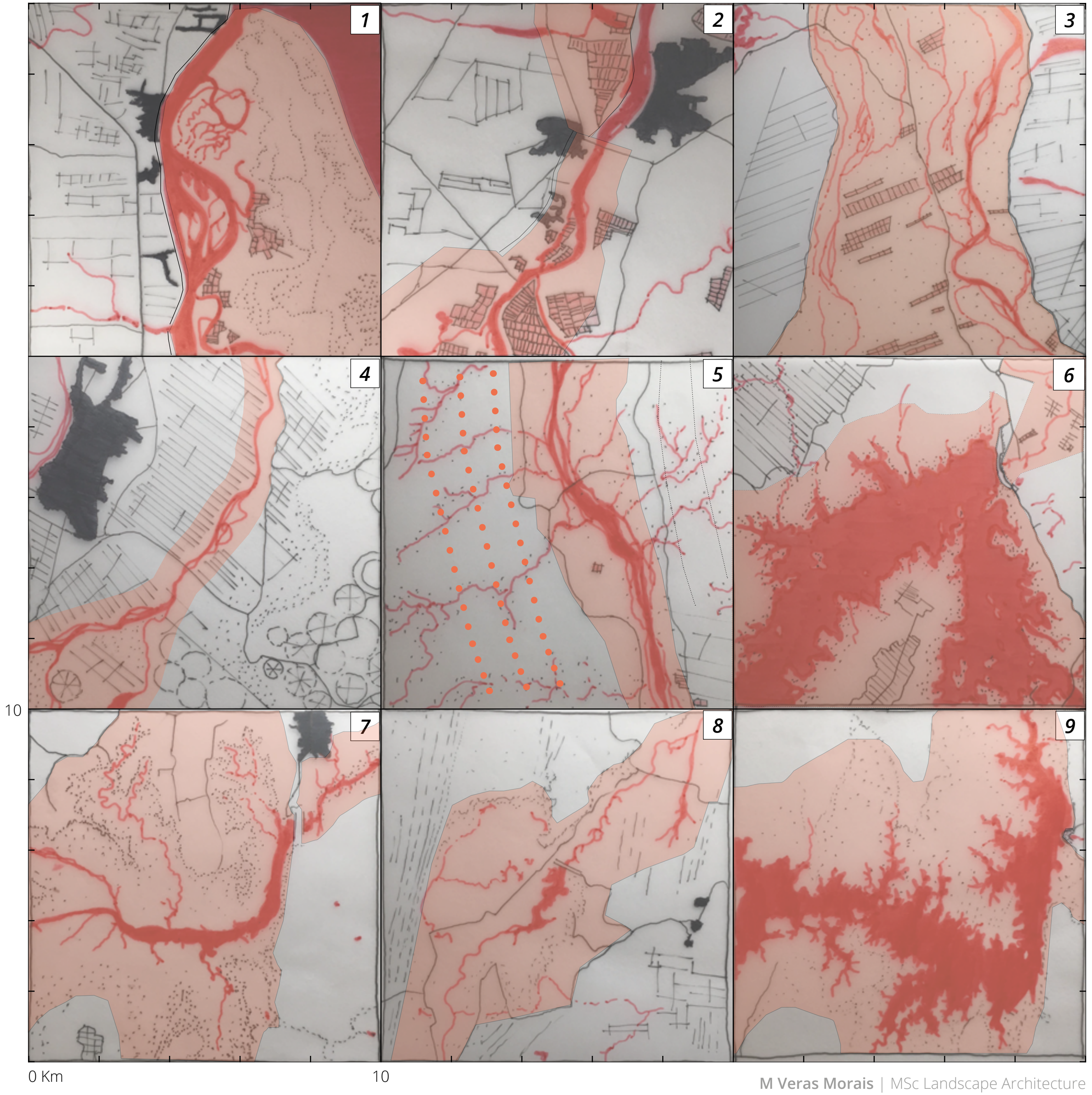


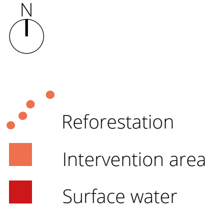
Image 6.46: Zoom-ins riparian buffer and vegetation recovery

In urban occupation areas, the idea is to delimit a linear urban park, to guarantee a soft edge for the Jaguaribe river (1).

In the areas that concentrate the industries of shrimp farming (2) or irrigated agriculture, (4), it is proposed a buffer from the margins to recovery of the riparian forest.

In the rangelands, an association between riparian buffer and reforestation of the caatinga is proposed (5).

Finally, the drawings (6), (7), (8) and (9) show the ecological reserves created around the dams in order to protect the stored water. (image 6.46)



6.5 PLANNING AND STAKEHOLDERS

The following image shows how the participation of stakeholders would take place throughout the process of implementing and operationalizing the proposed design strategies.

The following image shows how participation of inhabitants, society, as well as the other stakeholders in general would take place throughout the process of implementing and operationalizing of the proposed design strategies.

For that, it was reflected on the financing, the public administration bodies and ONGs involved, as well as how society and, mainly, the inhabitants, could be involved in the process. This is important to ensure the democratization of water management in the establishment of a wetness retention landscape.

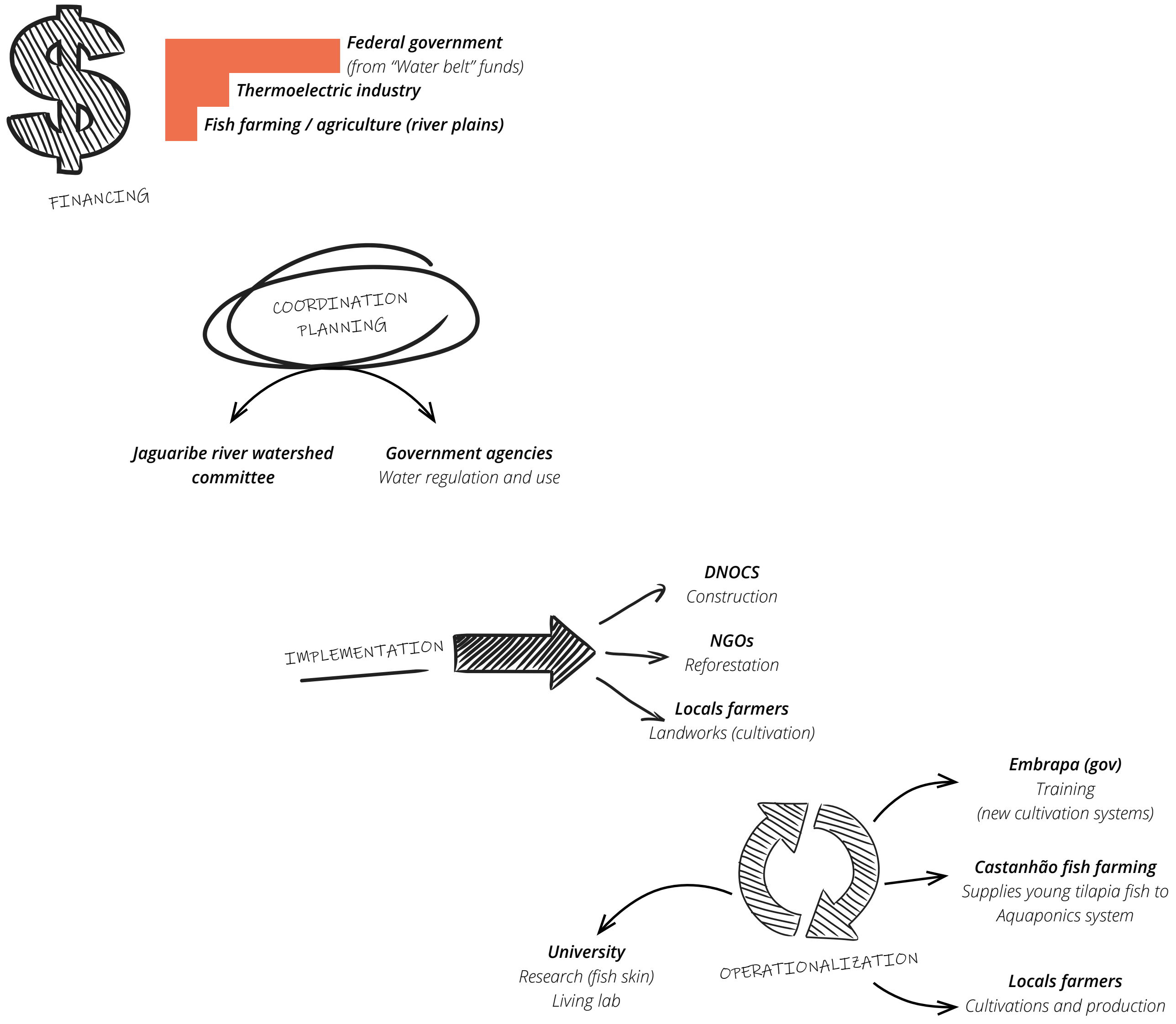


Image 6.47: Stakeholders in the financing, implementation and operationalization of the proposal.

Overview of design strategies from the Rainwater harvesting square lookout: Castanhão in the background, Keyline cultivation area and Wadi street.

CONCLUSION

This last chapter begins with discussion and assessment of the design strategies. After that, it presents final considerations, in which the questions and objectives of this research are brought back and discussed in the light of the results. Finally, a reflection on the research and the design process is presented, followed by the acknowledgements.

7. CONCLUSION

7.1 SYNTHESIS AND DISCUSSION

The wetness retention landscape in Jaguaribara

At this point, we take a step back to make a visualization of the system created from the combination of design strategies.

The diagrams on the following pages show the relationship between the strategies with respect to the wetness flow. This visualization is done for both wet and dry seasons and only for strategies applied at the local scale. (image 7.1-2)

These strategies, although they can be applied in isolation (both in Jaguaribara and in isolation), can also be associated in order to constitute a wetness system.

In the case of the proposal for Jaguaribara, it was decided to associate the Urban wadi system with the Keyline cultivation.

This was done because the capture of water by the wadis allows more than just storing that water to be extracted manually. So, it was possible to think of a flow that, while being more fluid, does not lose its vernacular character - something that was an ambition of this work.

The other two strategies, Underground dam rangeland and Underground water aquaponics, sought to work with underground water in a circular way.

In both cases, the used wetness is returned to the soil after passing through the production system, so that no wetness is wasted. That's because excess wetness in the Underground water rangeland escapes through the spillway. Similarly, when water from Underground water aquaponics passes through all tanks if it is returned to the soil, there is a growing area to absorb that available wetness.

In general, it is understood that the use of wetness in the landscape is done in such a way as to promote the maximum benefits for the community, granting it productive autonomy.

In addition, a parallel was also made between the landscape of Jaguaribara today and after the application of the strategies. (image 7.3-4)

This comparison is made based on the quality of the landscape, in terms of experience and recreational character.

It is possible to notice that the spaces created by the proposal allow one to feel the effects of wetness on the landscape. In the materialization studies, we tried to work sometimes with contrasts (i.e. experience along the underground dam), sometimes with different levels of humidity (i.e. opening the visuals inside the dense caatinga, through the keyline cultivation, until the wetland in the area of natural succession). Changes in the landscape during the rainy and dry seasons were also studied, which was done for all four strategies.

Thus, it is concluded that the strategies have a strong landscape value, which seeks to bring inhabitants closer to the wetness in the landscape, creating different experiences and generating spaces with high recreational potential.

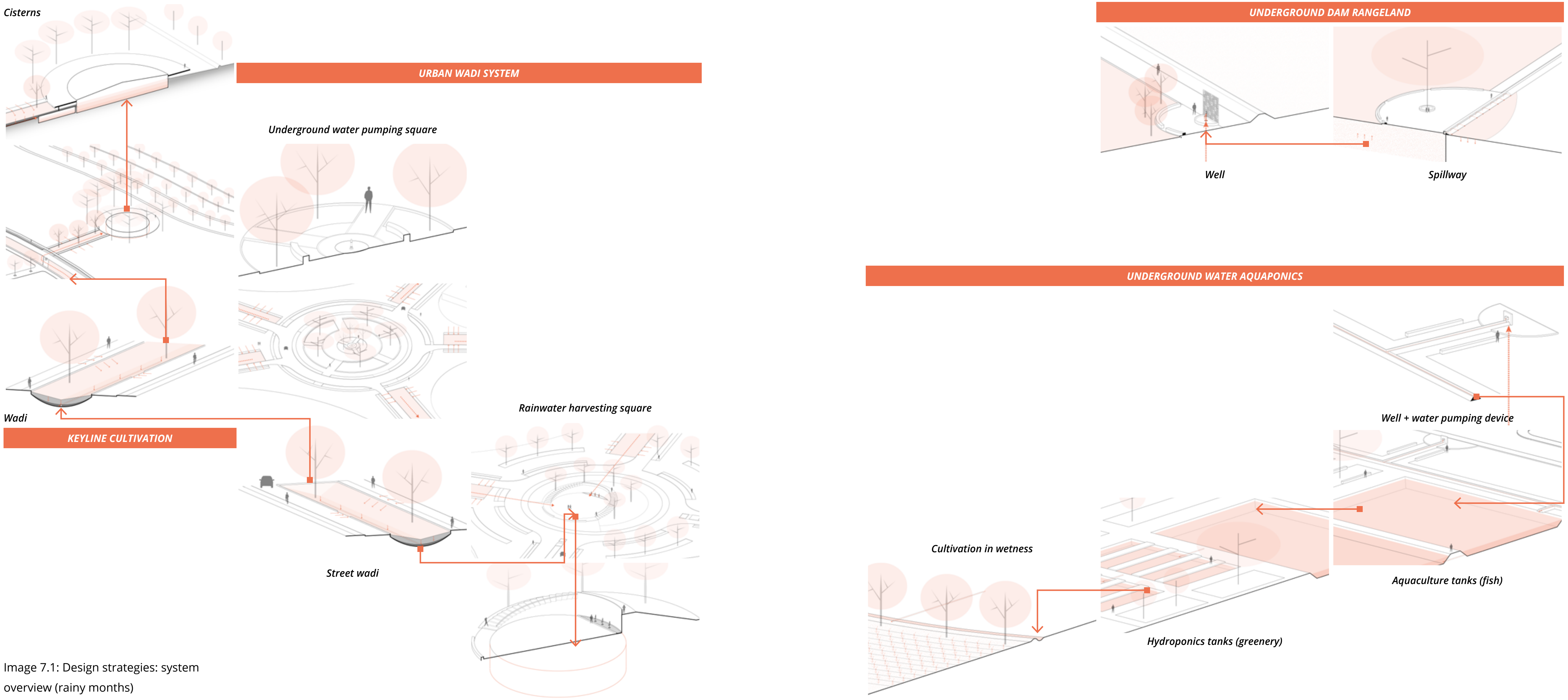


Image 7.1: Design strategies: system overview (rainy months)

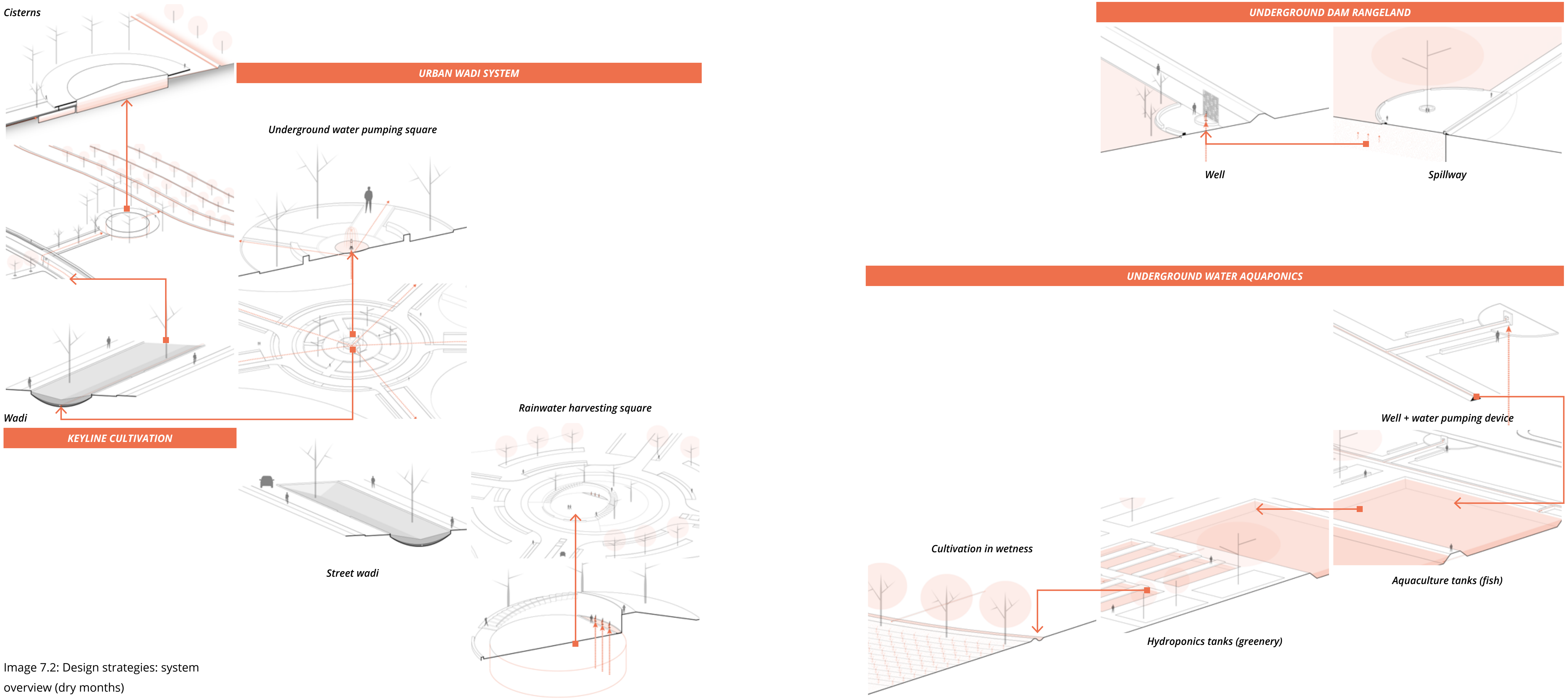


Image 7.2: Design strategies: system overview (dry months)

Image 7.3: Current landscape of Jaguaribara: urban area and productive landscapes.

URBAN AREA

30 m streets

Roundabouts

Housing water storage

PRODUCTIVE LANDSCAPE

Farming in empty lots

Rangelands

Irrigated farming

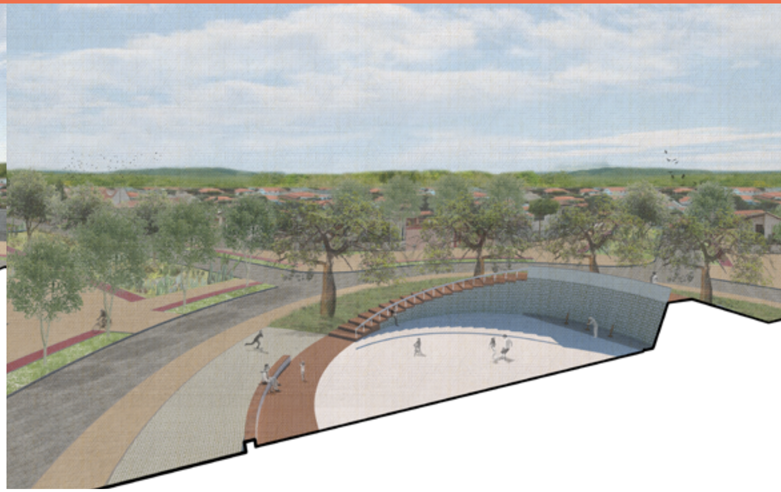
Aquaculture

Image 7.4: Design strategies: spatiality and materialization

URBAN AREA

Wadi streets

Underground water pumping square



Rainwater harvesting square

PRODUCTIVE LANDSCAPE

Keyline cultivation

Underground dam - spillway

Underground dam rangeland

Aquaculture

Design strategies assessment

After presenting the design strategies to transform Jaguaribara into a wetness retention landscape, as well as the effects of applying the strategies at different scales, it is necessary to carry out an assessment of these strategies.

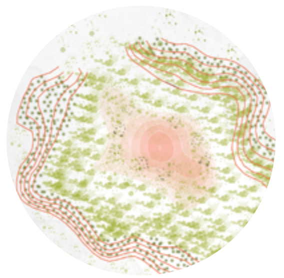
The objective is to read the qualitative character of the strategies in relation to each other, in order to prepare them to be reinterpreted and adapted before being applied in other areas of the Brazilian semiarid.

This assessment was done considering the multiple objectives of each strategy and the areas in which they would be best applied. In this sense, ten objectives were identified: **1) Rainwater harvesting; 2) water table recharging; 3) exploration of underground water; 4) expansion of vegetation covering / soil protection; 5) reduce / prevent soil erosion; 6) promote productive activity using water in a systemic manner; 7) protect water from evaporation loss; 8) reforestation of native vegetation; 9) water reserve for human consumption; 10) water use / drought awareness.**

Regarding the application areas, six possibilities were identified: **A) urban area; B) productive landscapes; C) rangelands; D) natural water bodies; E) artificial water bodies; F) natural areas.**

The design strategies evaluated here correspond to those presented for the different scales, as listed: **a) urban wadi system; b) keyline cultivation; c) underground dam rangeland; d) underground water aquaponics; e) swales system; f) greenification of water channel; g) riparian buffer.**

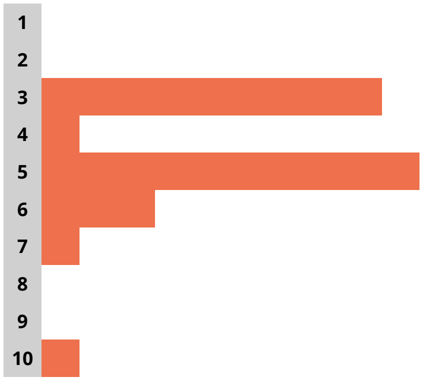
Finally, the summary tables with the assessment of the seven design strategies can be checked on the following pages, considering the objectives and areas of implementation.

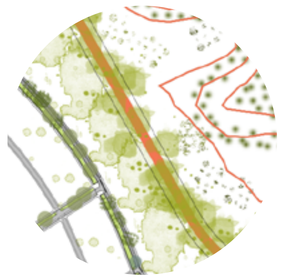


SWALES SYSTEM

APPLICATION AREAS: C - F

OBJECTIVES:

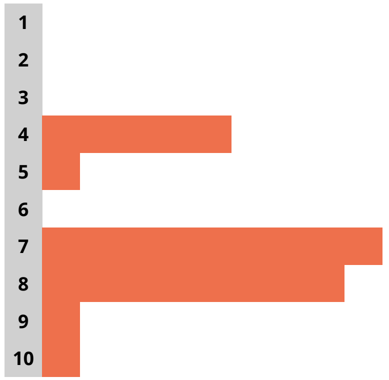




GREENIFICATION OF WATER CHANNEL

APPLICATION AREAS: E

OBJECTIVES:



RIPARIAN BUFFER

APPLICATION AREAS: D

OBJECTIVES:

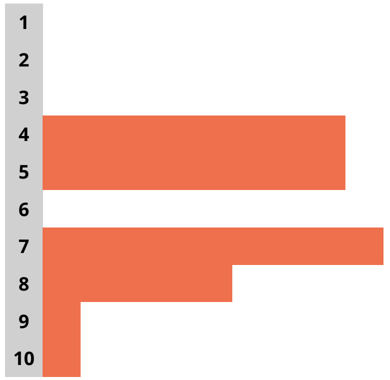
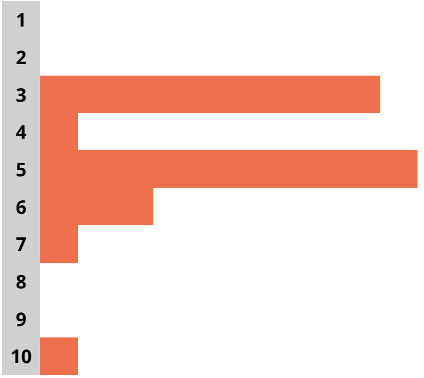


Image 7.5: Design strategies assessment table (metropolitan and regional scale)

UNDERGROUND WATER AQUAPONICS

APPLICATION AREAS: **B**

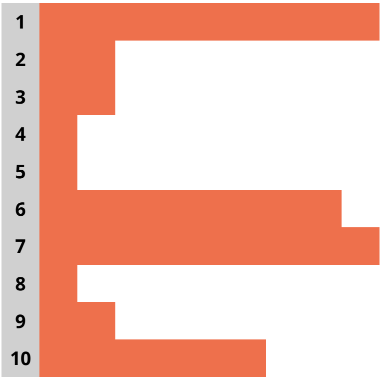
OBJECTIVES:

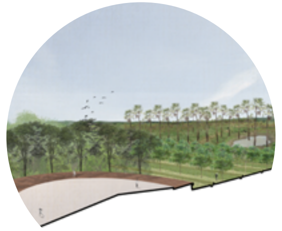


URBAN WADI SYSTEM

APPLICATION AREAS: **A**

OBJECTIVES:





KEYLINE CULTIVATION

APPLICATION AREAS: **B**

OBJECTIVES:

UNDERGROUND DAM RANGELAND

APPLICATION AREAS: **B - C**

OBJECTIVES:

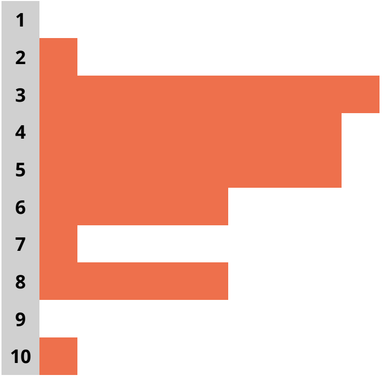


Image 7.6: Design strategies assessment table (local scale)

7.2 FINAL CONSIDERATIONS

The present work started from the understanding that the current water system in the study area is unsustainable and has not been shown to be adequately efficient in making the territory under the semiarid climate resilient to periods of drought. This is because the actions implemented seek to secure water from rivers so that they do not get lost in the ocean, while distributing this water throughout the territory. However, the greatest water loss that occurs in the territory is through evaporation and the transport of water through open channels culminates in water loss in the process. In addition, at the local school, in Jaguaribara, we identified the negative aspects that current practices can bring to the inhabitants in different areas, but especially social and economic.

From the definition of the problem, the hypothesis of this work arose; that it was possible to improve the water system by holding the wet in the landscape, protecting it from evaporation and decentralizing water storage through actions carried out on a local scale.

After that, the following research question was posed: **how to improve the water management in Jaguaribara, considering the relationship between inhabitants and landscape?** To answer this question, an analysis was made of the physical characteristics of the landscape at its interface with the water, in order to carry out a mapping of the water, from the local scale to a larger scale. In addition, it was studied how water was used by the inhabitants, to complete the panorama of water in the region. Finally, design strategies were proposed that aim to insure water in the region, combining engineering and nature-based solutions, in consideration of the inhabitants and the caatinga biome.

Two other specific questions were also asked, the first being: **how can the redesign of the water flow, by retaining wetness, benefit the local community?** This question is closely linked to the study of water use in Jaguaribara and the understanding of how much the water supply influences the city's economic production. By proposing strategies that link water retention in the landscape with Jaguaribara's productive practices, it is guaranteed that the application of the strategies will bring benefits to the community, in addition to guaranteeing the human right to water.

The second specific question is the following: **how can an integrative approach of engineering, landscape and social aspects reshape the territory?** This question was answered by the result of the work itself. The proposed design strategies, almost in their totality, incorporate engineering solutions to the nature-base solutions. In addition, they were solutions completely based on the lifestyle of the inhabitants of Jaguaribara, having as one of the objectives the promotion of a drought-resistant community, which incorporates the mentioned social aspects.

In addition, this research aimed primarily **to develop design strategies regarding the water flow to be applied in Jaguaribara.** This was, therefore, the focus of design strategies at the local and regional scale. In addition, two specific objectives were defined, the first of which was **to redesign the water flow in a systemic manner, using local sources and reducing the need for water transport**. It is considered that this objective was achieved, considering that the design strategies worked on the decentralization of water storage, with the minimum transport of water on the local scale; the transportation was carried out, whenever possible by underground routes, eliminating the problem of water loss through evaporation and the other problems caused by the long water channels existing today.

Finally, the second specific objective was to work on the access to water as a tool to encourage conscious use of water and strengthen the sense of community. This objective was achieved through the establishment of a water calendar, which links the water supply in the region to production practices and human consumption. The calendar also included simulations in years of drought to build a city resistant to water scarcity. In addition, collective access points to water in the city were added as a means of linking public access to rainwater and the subsoil to the sense of community. This community notion is also reflected in the fact that the proposed practices only have effects if the population is involved in the entire process, highlighting the role of each inhabitant in ensuring the water retention landscape in Jaguaribara.

7.3 REFLECTION

Graduation studio and lab

The ***Flowscapes Graduation Studio*** proposes to discuss 'infrastructure as landscape' and 'landscape as infrastructure', considering different scales that interrelate with each other and, at the same time, to a topic of considerable relevance today. In addition, it is proposed to work on the interfaces between architecture, urbanism, engineering, as well as spatial and environmental planning.

In this sense, it is considered that the theme of this work follows the proposal of the graduation studio, considering that it proposes to discuss water scarcity; a theme that brings social, cultural and economic consequences to the affected areas, at the same time that it is a growing concern globally, in view of the effects arising from climate change. Furthermore, the proposed design strategies combine solutions involving elements of the landscape (nature-based solutions) and engineering, culminating in spatial configurations, focusing on economic and social development and environmental recovery.

This research is conducted within the ***Graduation Lab Circular Water Stories - water systems worldwide, multifunctional structures of cultivation***, due to my interest in water systems as starting points of liveable (urban) landscapes, especially in the context of low water availability. Understanding the transforming power of water, I was driven by the challenge of changing the semiarid reality of Ceará and the social injustices using elements of the landscape.

Societal relevance

The relevance of this research lies in different scales: within the semiarid context (especially in an underdeveloped country, such as Brazil), in the professional field and the global scientific community.

Considering the context of the semiarid climate, it is important to note first that semiarid regions can be found on every continent. Each has its particularity, history, culture, modes of production and biome. However, the issue of low water availability unites these regions around the same issue.

Therefore, studying ways to design with wetness, and later deriving principles from a case study, provides design inputs for water solutions different regions of the world.

In addition, systems based on dams and waterways have been used worldwide throughout the history of mankind. Thus, studies on the humanization, naturalization and optimization of this kind of system can benefit communities in several other contexts.

Within the professional context, it is important to emphasize that practices guided by democratic concepts are relatively new in the field of landscape architecture. Thus, design exercises that seek to reflect the democratization of landscape is of great relevance to inspire professionals in the field to be agents of landscape transformation around the world.

Finally, for the scientific community on a global scale, the research theme reflects a major concern of our times regarding the future. Low water availability is a growing concern in more and more places around the world and has attracted professionals from different areas.

Due to climate change, what was previously only a concern of arid climate regions has become a reality in places where previously the availability of freshwater was not a concern. Therefore, it is necessary to change the mindset as to how we think the flow of water on the landscape scale before we are all out of water.

Chosen (design)methodology

This work follows the Research Through Design (RTD) strategy, as means of seeking the most efficient alternative to the proposed problem through design. In this sense, the strategy proved to be quite adequate because it allowed that different design strategies were proposed for the establishment of a wetness retention landscape in the study area. More than arriving at a single design proposal for the study area, the strategies approach allowed to reflect on the countless possibilities of combining engineering and nature-based solutions to retain wetness in the semiarid region.

However, as a weak side of the chosen methodology, it is necessary to mention that it encourages the carrying out of numerous exploration in search of new solutions to compose the design strategies, which ends up, naturally, demanding a lot of development time. Thus, it was necessary to choose to detail only the strategies on a local scale, in view of the impossibility of detailing the other scales during the ten months intended for this work.

Generalization of results

Another issue, also linked to the methodology choice to a certain extent, is the generalization of the proposed design strategies. The initial intention of this research was that, after the design strategies were established in the different scales, design principles were derived, so that they could be applied throughout the Brazilian semiarid region. However, proposed design strategies were highly specific to the site. Thus, to continue with the initial intention, one of the two alternatives would have to be chosen: 1) to study in depth all the different areas of the Brazilian semiarid region in order to define the best strategies for each specific location, in addition to adapting these strategies or 2) that the derived design principles were very general, leaving room for them to be reinterpreted and applied to each location in future works.

The first option was not possible to be carried out within the time established for this research. The second option, on the other hand, because they were excessively generic, they could fall into the error of considering that all locations in the Brazilian semiarid are similar to Ceará, just because they are under the same climate regime. Thus, there was a fear the design principles would constitute "top-down" decisions, like so many others taken by the government throughout the history of Ceará.

Thus, a third way was chosen, in which the derivation of design principles is avoided and, instead, an assessment of the design strategies is carried out so that they constitute a didactic presentation of strategies' potential, so that they are evaluated by those who are interested in applying these strategies in other locations in the Brazilian semiarid region. In this sense, the conclusion of this work prepares the design strategies so that they can be applied in other areas, understanding it will be necessary to study in depth the regions and adapt the proposals to local conditions in order to achieve a design which is site specific.

Ethical issues

During the course of this research I was always attentive to the ethical and moral issues that arose. Firstly, when choosing the water scarcity in the Brazilian semiarid as the theme, as well as the problems arising from recurrent droughts, I knew that I was working in a landscape with political, economic and social clashes.

Political because many of the decisions involving the management of water resources in the state of Ceará (as well as in the whole country) stop by party ideologies and come up against bureaucratic processes. The situation in the Brazilian semiarid region is often popularly referred to as the "drought industry", since many politicians use the region's water deficiencies in their speeches, supporting only solutions that bring their own benefit, while leaving the population without autonomy and hostage to the political system itself.

In addition, economic issues permeate practically all adopted solutions so far, which always seek to act against water scarcity only to burst the economic development of the state as a whole, instead of seeking to guarantee the human right to water, creating an autocratic landscape.

Finally, social issues are linked to the fact that the work involves working with an extremely vulnerable population for which much has already been promised and little has been accomplished. The inhabitants of Jaguaribara, in particular, had already been used by countless studies in the national territory of different fields: history, heritage, social and economic sciences, psychology, journalism and even engineering. They are, therefore, tired of being used for academic purposes without a tangible return to the community.

So, I knew that, when facing this problem and coming up against these issues (which are far beyond my reach as a professional in landscape architecture) I would have to: 1) undress from the pre-established political concepts and positions (which are many, considering that I was born and raised, as well as graduated in architecture and urbanism in Ceará); 2) seek a balance between the state's economic reality and social justice related to water security and other humanitarian issues; 3) understand my limitations in actually helping the population and at the same time having collect the required data for the development of this research.

This last point required me, as a researcher, sensitivity and ethics to clarify the people interviewed about the purpose of this research and how the data provided would be used, always respecting the space and the emotions of those involved, even when they were only slightly uncomfortable, although they did not express. This is because, due to their humility and low education, many of them did not refuse to open their doors and share their experiences, even though they often reported illegal issues. That is why it is necessary for the researcher to understand that a socially vulnerable society can be easily exploited, as they not even understand their rights - and more, never putting themselves in the position of exploiter. It is necessary to have full respect for people's history and to treat the data provided with total esteem, without making promises that are unlikely to be kept.

Challenges of data collection

During the field visit, carried out in January 2020, it was required prior planning to collect as much data as possible in the short time available. As the research was being conducted from the Netherlands, while the study area is located in a humble and remote region of Ceará, it was a challenge to contact those who would be interviewed in advance: technical difficulties on completing and international call; some of the contacts were out of date; it was often difficult for reach the contact due to time-zone difference between countries. So, I expanded the list of possible contacts and tried to speak to them as soon as I landed in Brazil.

As a result, I was only able to schedule one of the interviews, with the DNOCS representative, supervisor of the Castanhão dam. When I arrived at the place and talked to him, I got the contact of the other interviewees from the productive communities. The interviewees from the city itself were approached throughout my days in Jaguaribara, and they were kind enough to open their homes with sympathy and humility, allowing the proper development of this research.

Another relevant issue to mention is that the visit was scheduled for the beginning of the rainy season, as there was an expectation that it would be possible to monitor on the spot the agricultural practices and water collection that happens during that period. Unfortunately, the rainy season started a little later that year and had not yet started when the time. Therefore, the information was given only by the interviewees.

Researching in times of pandemic

These were certainly quite different and challenging months, not just for the university but for the whole world. With the corona virus outbreak, we find ourselves limited and being led to adapt to proceed with the planned activities as much as possible.

One of the limiting issues was the amount of field visits. Ideally, at least two visits should be made, one in the rainy season and one in the dry season. The first visit was made in January, when the virus was already reaching the European continent. Shortly afterwards, it reached Brazil - and would do so strongly later, with Ceará being one of the Brazilian states most affected by the pandemic.

In addition, the university itself had to suspend its on-site activities and we found ourselves without access to their physical infrastructure, as well as having to conduct sessions with the mentors by video-conference. I believe that the entire team of teachers sought to make this process as easy as possible, being flexible in this regard. Apart from that, online mentoring requires preparation in advance. So the master students also had to adapt to the "new normal".

Furthermore, it is valid to admit that maintaining social isolation during the time of greatest design production has been psychologically challenging. Especially added to the concern we have with our families and friends, so distant from us in this difficult time, while undergoing so many trials. However, I understand that every master's student, professor and university employee, as well as every person living in this historic moment of humanity, has faced his own monsters and I have deep respect for all my colleagues and mentors for staying active and optimistic in this time of pandemic.

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Furthermore, I am deeply grateful to those who went to great lengths to assist me during the field research: Fernando Pimentel de Andrade (and the DNOCS family), José Martins Gonçalves Neto and all the residents of Jaguaribara who shared their stories and knowledge with me.

In addition, I need to thank my parents, Iolanda and Vitor, and my husband Pedro, who were by my side during the field research, keeping me safe, taking pictures and sharing their experience of living in the semiarid region of Ceará.

Ultimately, I will cherish the time shared with those who made this whole process more enjoyable: my sisters Aline and Raquel, my good friend Viviane Furtado, Naeema Ali, Tanvi Gupta, Emma Kannekens and all the great friends I have made in TU Delft.

Muito obrigada.

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