RIPPLES OF RESILIENCE

A SYMBIOTIC PATHWAY DESIGN STRATEGY FOR THE WATER SYSTEM TRANSITION TO COMBAT WATER SCARCITY AND DESERTIFICATION IN THE SEGURA RIVER BASIN, SPAIN.

DELFT UNIVERSITY OF TECHNOLOGY
MSC ARCHITECTURE, URBANISM
AND BUILDING SCIENCES
MADE BY
SANNE VAN REES

GRADUATION STUDIO REPORT

METROPOLITAN ECOLOGY OF PLACES SERIES

RIPPLES OF RESILIENCE

Sanne van Rees

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Thank you all.

ABSTRACT

Water scarcity is a growing issue in Europe, driven by the overexploitation of natural resources for anthropogenic activities, intensified by global pressures, and exacerbated by climate change. This has resulted in environmental degradation in many regions, including desertification and an increased risk of flooding. These symptoms signal a disrupted relationship between humans and nature and emphasise the need to transition towards a more socio-ecologically resilient water system. However, designing for systemic change remains challenging, as existing frameworks often fail to bridge theoretical concepts and practical implementation across interconnected spatial and temporal layers.

This thesis addresses this gap by developing a symbiotic systemic design strategy for the water transition in the Segura River Basin, an arid region marked by intensive agricultural production and structural water scarcity. Through a research-by-design process, this study integrates the concept of symbiosis with a systemic design approach.

The outputs include: (1) a methodology for symbiotic strategic design of water system transitions, (2) a pattern language of symbiotic design interventions, and (3) a regional symbiotic strategy for the Segura River Basin. The results show that a symbiotic systemic design framework can effectively connect complex systems theory to actionable design strategies and policy-making. Therefore, this research offers inspiration for researchers, designers, and decision-makers to collaboratively develop context-specific, symbiotic solutions to integrated systemic problems, moving collectively towards a socio-ecologically resilient future.

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PERSONAL MOTIVATION

As an urbanist, I am interested in researching problems related to (a lack of) resilience towards climate change or other problems that are created by the way we as humans exploit the earth and its resources. Climate change is an urgent issue, and to be able to adapt to it, there is a global need for awareness and action on all scales. I believe that many small changes can have a significant impact. By working together, instead of following personal interests, desirable outcomes for all can be created. Because of these reasons, I like to work interdisciplinarily on and through multiple scales to find circular, environmentally friendly, ánd socially just solutions for a more sustainable future.

Spain as a country has always intrigued me because of the beautiful landscape, interesting architecture, warm and sunny climate, and the people's hospitality. As a kid, we used to visit Catalonia yearly to see my parents' friends who lived there. I remember how magical those moments on the beach were: with white sand too hot to walk on and the refreshing, clear blue sea, without jellyfish. Even my relationship with rain changed completely when I was in Spain. Back at home, it would mean staying inside, but in Spain, I used to dance in the backyard whenever it stormed, happy with the refreshing water.

One day, we visited this enormous water park with slides everywhere. Back then, it seemed like paradise. Even now, amid the water scarcity situation and surrounding areas desertifying, some of these regional water parks are still operative. Additionally, more and more golf courses and tourist resorts with private pools are being built. How come we use our precious water in such an irresponsible way?

"¿A qué estamos renunciando en nombre del progreso?"

Fin de Temporada, Leonor Martín Taibo, AFFR 08/10/2024

The quote is from a movie I watched with the graduation studio of MEP during the Architecture Film Festival in Rotterdam last October, which highlights these waterparks that are now abandoned all over the Iberian Peninsula, indicating that a certain period has passed. The film reflects on this idyllic time and asks us how we could have used our precious vital resource so irrationally. A new paradigm has emerged where we acknowledge the precious value of nature's resources and their limited availability. However, in daily practice, common knowledge of how to change our behaviour is still lacking.

Figure 1. Abandoned waterpark (Lake Dolores). Source: (Davis, 2020)

Figure 2. Flamingos above Mar Menor. Source: made by author.

THESIS TOPIC

The topic of this thesis is water scarcity. The subject arose because of an interest in urgent problems related to climate change adaptation and the restoration of natural areas scarred by human overexploitation of natural resources. As water is one of the primary resources for life on earth, both for humans and for flora and fauna, and because the water system is worldwide highly affected by climate change, the focus of this thesis is aimed towards disturbances in the water system. Looking at Europe's context, water scarcity and flooding are noticeable and intensifying, urgent problems. Often, the two issues go hand-in-hand: long periods of drought cause water scarcity, and heavy periods of (unexpected) rainfall cause flooding in the same area. This phenomenon is no coincidence, and can be prevented or mitigated if structural changes occur in the way we as humans interact with our natural environment.

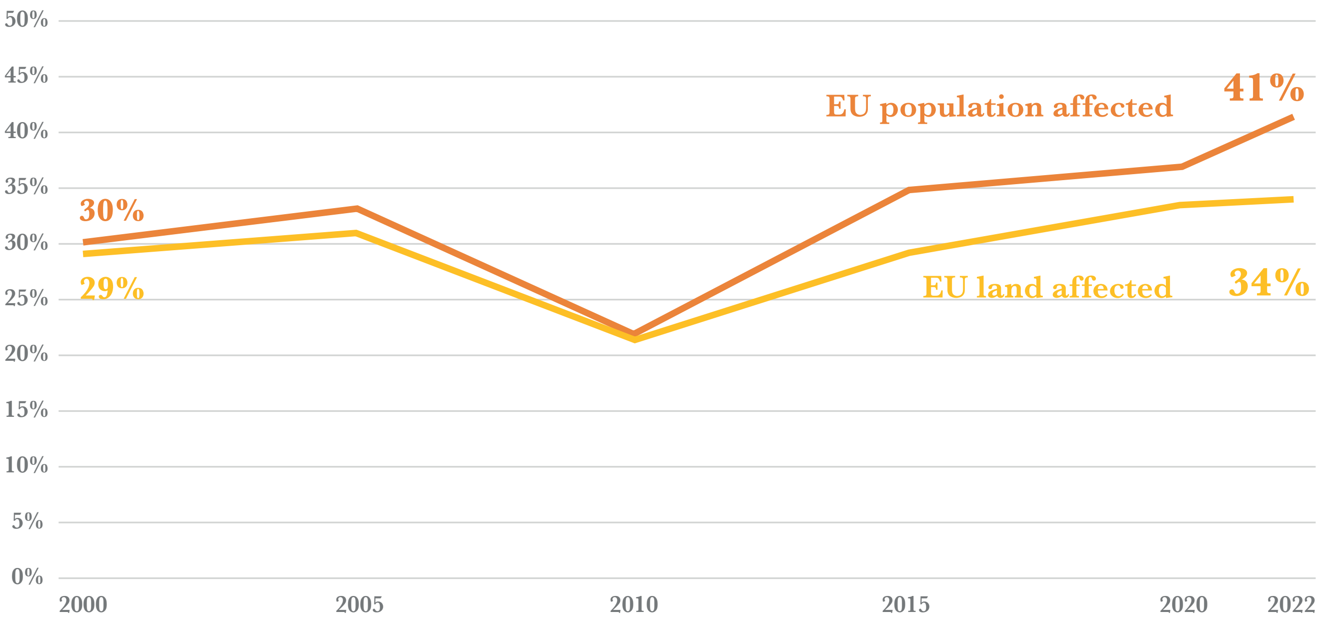


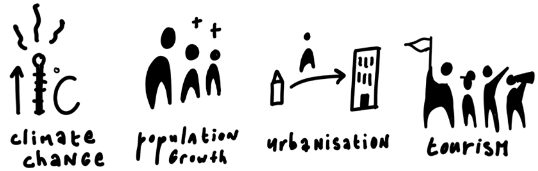
Figure 3. Area and population affected during at least one quarter of the year by water scarcity conditions in the EU. Source: (EEA,2025).

INTRODUCTION

WATER SCARCITY

Availability of and access to resources is becoming increasingly important in the globalised world we live in today. The capitalist approach that characterises this globalisation, in the form of continuous overexploitation of natural resources for economic growth and human development, is challenging environmental-, and therefore human well-being. The United Nations (n.d.) pointed out that water is a finite resource in this growing demand. Water demands are exceeding supply in many places on the world and almost two thirds of the world's population experience severe water scarcity for at least one month each year (UNICEF, n.d.). Water scarcity is a problem all over the world, not only in desert countries. In 2022, 34% of the European Union territory was affected by water scarcity for at least one season (see Figure 3, EEA, 2025).

According to a report by the European Commission, the long-term imbalance resulting from water demand exceeding available renewable water resources is an increasing issue in the EU (European Commission & PRESTA IV, 2020). The duration and intensity of water scarcity is expected to increase with global warming, especially in already water scarce areas in southern Europe. In the EU, currently 52 million people are living in water scarce regions, which is about 11% of the population (European Commission & PRESTA IV, 2020). In the Mediterranean, the duration of water stress periods can exceed 5 months, as shown in Figure 4, based on data from the European Commission and PRESTA IV (2020).



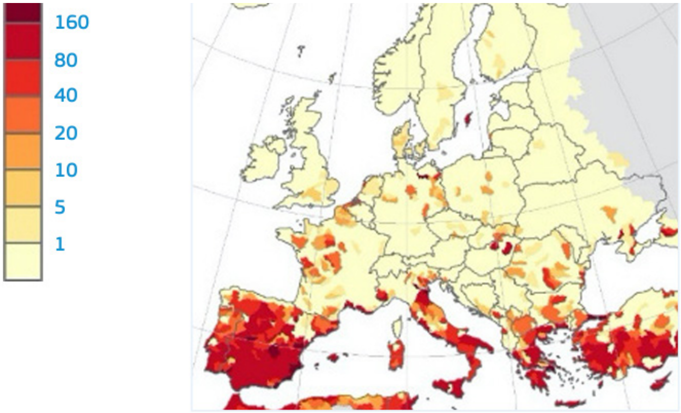


Figure 4. Number of water scarcity days per year, retrieved from (European Commission & PRESTA IV, 2020).

Water scarcity is a relative concept, as the amount of water that can be accessed physically is constantly varying with changing demand and supply. Therefore, water can be scarce for many reasons. While climate is an important factor for the availability of water, the problem of water scarcity is often a man-made phenomenon. Next to the accelerating increase of water demand, inadequate water supply infrastructure, pollution of the available water or poor water management that fails to balance all water needs, are known causes (UN, n.d.).

Despite growing awareness of the climate crisis and environmental degradation, extractivist industries and practices stay at the core of empowering economies and societies (Ciccantell, 2000). As a response, the European Union has set new regulations for the restoration of ecosystems and sustainable water management, including a focus on non-conventional water sources. The Water Framework Directive requires Member States to promote the sustainable use and long-term protection of available water resources (EU, 2000; Directive 2000/60/EC).

OVEREXPLOITATION OF WATER RESOURCES

Due to water shortages, overexploitation of water resources is taking place in the regions where demand exceeds available supply. Water overexploitation is defined as a situation in which the abstraction rate of an aquifer is higher than its recharge rate.As recharge happens usually when it rains, this is a seasonal phenomenon. Figure 5 shows water overexploitation in 2014 per river basin in Europe for the summer season and the winter season, based on the EEA indicator of freshwater resources (Zal et al., 2017).

WATER AVAILABILITY

Climate change is making it worse. With hydrological variability and natural disasters increasing, water availability is expected to drop further in the nearby future.

Hydrological variability refers to the fluctuations in the availability and distribution of water in a given region over time, which can occur on different time frames or scales and is influenced by many factors. These factors include on the one hand natural drivers (natural variability) such as climate systems, geographic features and seasonal cycles that are influenced by climate change in the form of changed precipitation patterns, evaporation rates and temperature changes. On the other hand, human activities such as land-use changes, perception of water, mismanagement and overextraction of water resources, can also have an effect on these patterns (human-induced variability). Hydrological variability is particularly significant in semi-arid regions, where water resources are highly sensitive to both natural climatic changes and anthropogenic pressures.

Additionally, drought is exacerbated by climate change, and is causing temperatures and evaporation rates to rise. Decreased water availability disrupts natural ecosystems, leading to loss of biodiversity and reduced soil quality. These effects are creating problems such as reductions in food production, infertile soils, declined biodiversity, a

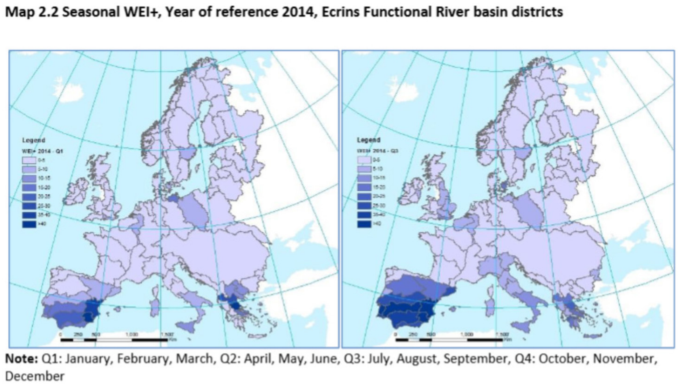


Figure 5. Seasonal water exploitation index (WEI+). Top: Q3, months July, August, September. Bottom: Q1, months January, February, March. Source: (Zal et al., 2017).

decrease in natural resilience and reduced water quality, for instance due to salinisation of groundwater. Prolonged droughts due to climate change and overuse of resources are interconnected drivers of these cascading effects.

Climate change is expected to have a greater impact on Spain, compared to other European countries (Lázaro-Touza & López-Gunn, 2014). Because of climate change, national water resources are projected to drop by 28-40% by 2050, as stated by CEDEX (2017). With the expected 3°C warming, Spain will be the country with the biggest increase in people living in water stressed areas (over 7 million people more than present) (European Commission & PRESTA IV, 2020). Among OECD countries, Spain already has the third-highest level of water stress. In July 2023, water reserves were the lowest in thirty years, at an average of 40% and 9 million people were faced with water limitations (Lassman, 2024).

For these reasons, this thesis examines the critical situation of water scarcity in Spain.

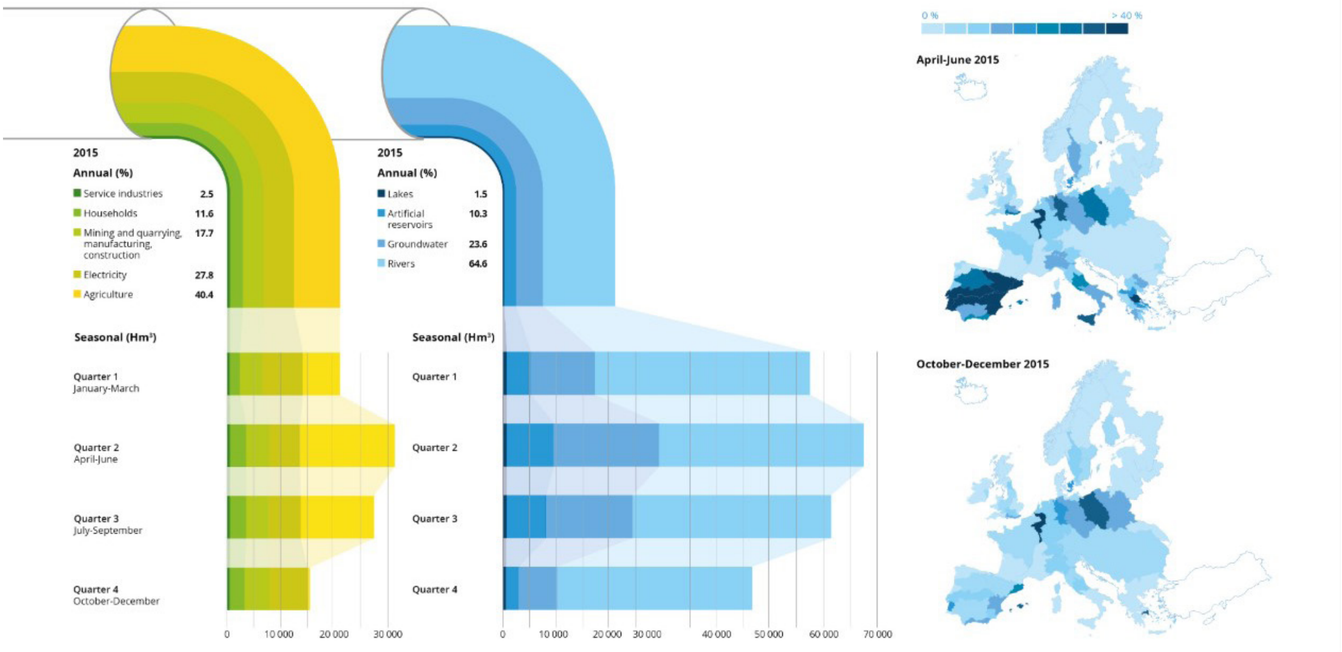


Figure 6. Seasonal green and blue water consumption by industry in the EU for 2015. Source: (EEA, 2025)

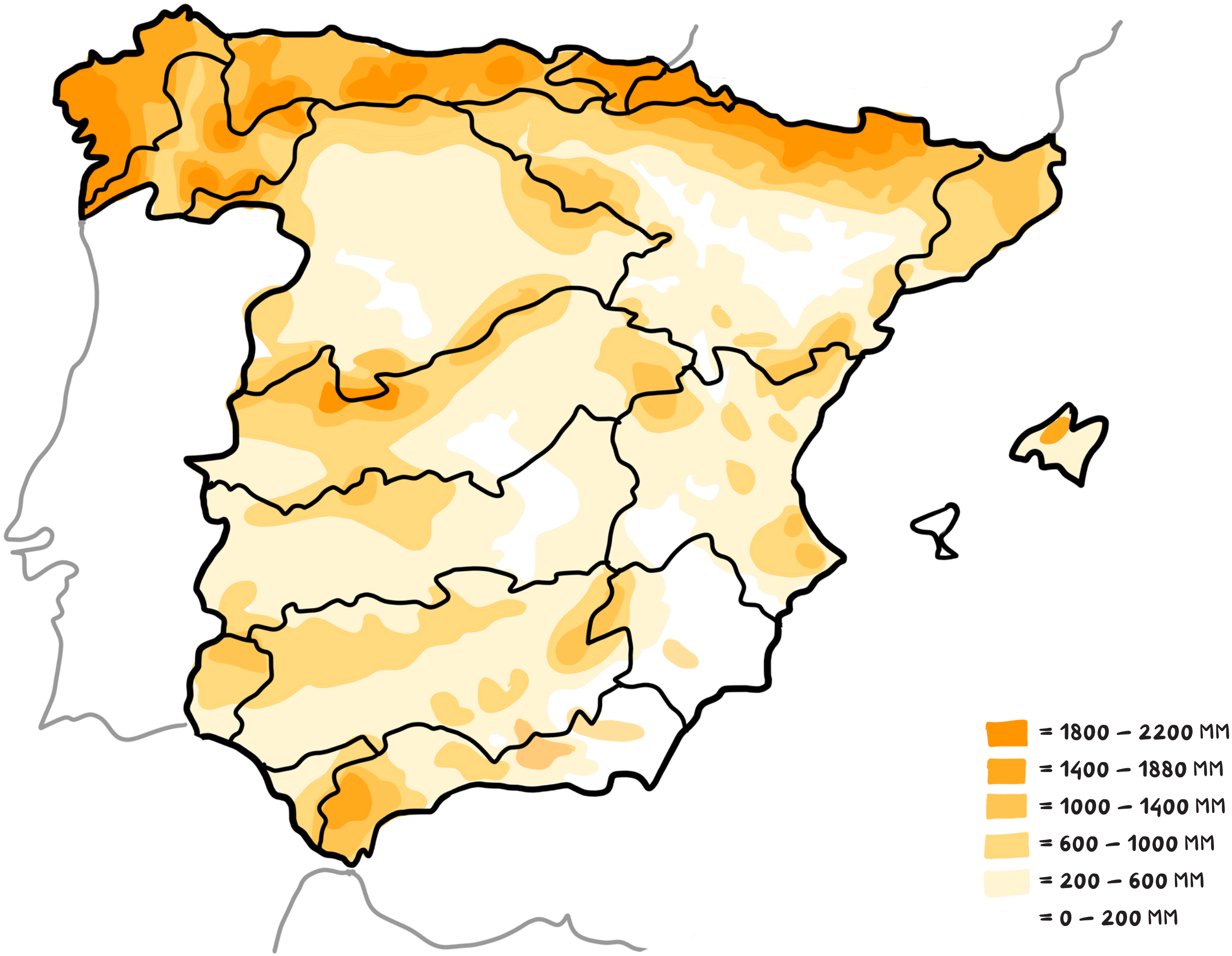


Figure 7. Precipitation map Spain. Source: made by author, based on (Rodriguez-Sanchez & Sarabia-Sánchez, 2020)

PROBLEM FIELD

INTRODUCTION TO THE PROBLEM

Water stress in Spain is created by a combination of drought (low water availability) and overexploitation of freshwater resources.

Spain is facing a growing crisis of water stress and scarcity, driven by a combination of natural water shortages, increase in demand due to urbanisation, tourism and the production economy, overexploitation of available water resources, and the increasing effects of climate change. Additionally, a lack of water is putting the country at risk of desertification.

In this paragraph, the problems related to water scarcity in Spain are presented.

DESERTIFICATION

A lack of water is putting the country at risk of desertification. Spain is mentioned to be the European country that is most likely to suffer from desertification (Puigdefábregas, 1995).

With 74% of the country's territory already at risk of desertification, and 90% of those regions classified as "high" or "very high" risk, the situation in Spain is stated as critical (We are Water, 2022).

Desertification is a form of land degradation in drylands, that has economic, social and environmental consequences (ECA, 2018; Hagemann, 2018). It is defined by the United Nations as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD, 1994). It can cause health problems, poverty and biodiversity decline, but also demographic and economic consequences as people can be forced to move away from those areas (ECA, 2018).

Land Degradation is the phenomenon to cause a reduction or loss in biological or economic productivity, biodiversity and ecosystem services, which is generally caused by human activity (ECA, 2018). Productivity, land cover, soil erosion or soil organic carbon can be used to assess land degradation. The concept of *land degradation neutrality* is defined by the UNCCD (1994) as "a state whereby the amount and quality of land resources, necessary to support ecosystem functions and services and enhance food security, remains stable or increases within specified temporal and spatial scales and ecosystems."

According to the National action programs (NAPs) for the United Nations Convention to Combat Desertification (UNCCD, 2008), 74% of Spain's territory is at risk of desertification and 18% is at high risk of becoming irreversibly desertified. The regions of Murcia, Valencia and the Canary Islands are the most concerning areas, with a "high" or "very high" risk of desertification across 90% of the territory (Valdivia, 2019).

As desertification causes a reduction of infiltration into the soil, a greater surface flow is created during rain events. Excess water cannot be discharged, leading to flash floods during extreme rainfall events. Climate change increases hydrological variability and therefore the chance of these rain events to happen. Soil degradation in turn, leads to vegetation loss, which causes erosion and intensifies the disastrous effects of floods.

The latest World Atlas of Desertification (WAD), recognises the complex nature of desertification and looks at the problem through the concept of convergence of evidence.

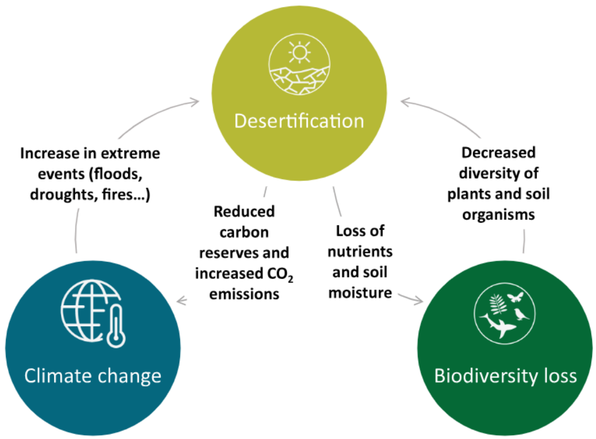


Figure 8. Relationship between desertification, biodiversity loss and climate change. Source: (ECA, n.d.).

In total, 14 global change issues, divided into socioeconomic and bio-physical factors are used to identify desertification hotspots. These factors include for instance decreasing rainfall, growth of irrigated area and changes in population. Places where multiple of these issues overlap, are identified as probably susceptible to desertification. However, to understand the situation, local conditions are critical to take into account (Martínez-Valderrama et al., 2022).

In 2008, The Spanish National Action Program (PAND), identified five desertification landscapes within the country, by using socio-economic and climatic information. By understanding the drivers of the phenomenon, design solutions can be created and preventive measures can redirect the future before land degradation happens (Martínez-Valderrama et al., 2022). However, an action plan against dersertification was lacking at the time and the pre-identified locations of land degradation are indeed dersertifying today. Recently, the Spanish government declared a situation of climate and environmental emergency, which requires a new strategy to combat desertification.

RISING WATER DEMAND

Agriculture and tourism are the main water demanding sectors in the country (CruzPérez et al., 2020). Agriculture is the sector with the biggest water footprint globally (Hoekstra et. al, 2011). Next to this, it is the sector that is most likely to feel the effects of climate change and increased water scarcity. Spain is the third country in the European Union with the highest proportion of irrigable area, and one third of all irrigated land in the EU is located in Spain (Lázaro-Touza & López-Gunn, 2014, Lopez-Gunn et. al, 2012). In 2023, the amount of irrigated land consisted of 3,5 million hectares (MITECO, 2023).

According to the OECD, the global availability of water for irrigation is expected to decrease as a result of the increase in other uses and sectors (OECD, 2012). Tourism is already outcompeting the agriculture sector for water, as a significant share of the renewable water sources available is used to satisfy tourism needs (Auernheimer & González, 2003, Gossling et al., 2012). In 2018, Spain had 82,8 million tourists visiting the country, compared to the national population of 46,6 million at the time (INE, 2019). Therefore, not only the agriculture sector is threatened by the water demand of the tourists, also the residents themselves experience an inflation, as tourist's water consumption is different from resident's water use (Gossling et al., 2012, Toth et al., 2018).

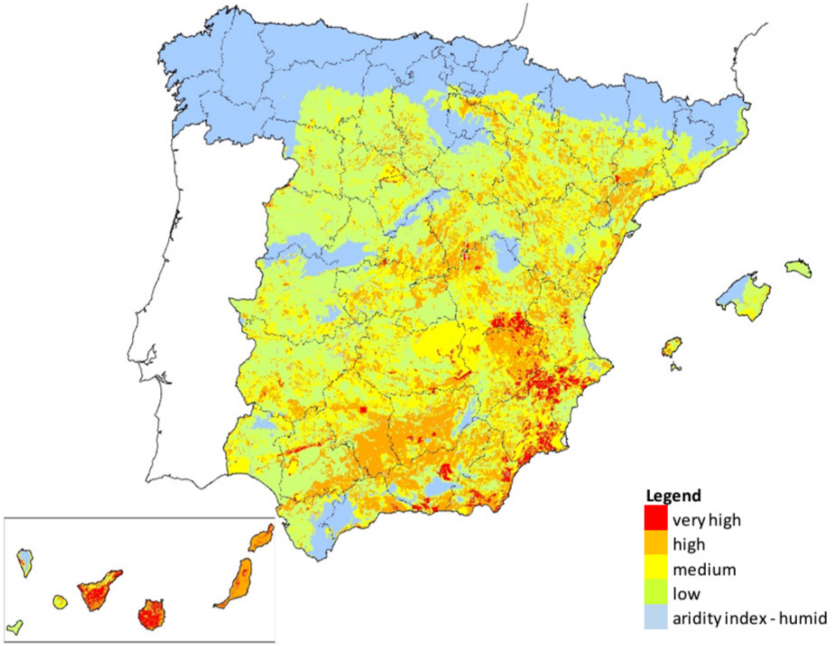


Figure 9. Risk of Desertification in Spain (2008). Source: (MITECO, 2008).

According to a report from UNESCO published in 2019, the level of water use is expected to increase with 20-30% globally, with a growth rate of 1% per year due to population growth, socio-economic development and changes in consumption patterns (WWAP, 2019).

As tourists visit the country mostly during the summer months, the increase in water demand happens during the dry season, intensifying the water shortage further in the form of peak demands.

SPAIN'S WATER MANAGEMENT CHALLENGES

Since the 21st century, water management in Spain is coping with new issues to address due to internal changes and external factors. National changes include the change in perception of water and the environmental concerns of an urban and service-oriented economy, the movement of stakeholder empowerment and the political regionalisation of water management (Fornés et al., 2021). External drivers are climate change, new regulations by the EU Water Framework Directive and mass tourism that brings strong seasonal fluctuations in water demand. According to Teodoro Estrela, water director from the Ministry of Ecological Transition and Demographic Challenge, the hydrological regime in Spain is extremely irregular and the balance between water resources, demands and environmental needs is very fragile (Estrela & Ministry for Ecological Transition and Demographic Challenge, 2023). Balancing demands in a socially just way is becoming increasingly difficult when resources are becoming more and more scarce and demand accelerates. Water in Spain is already a political commodity, causing socio-political conflict among basins and water using sectors.

During the Hydraulic Paradigm of the last century, water management in Spain evolved around huge infrastructures of inter-basin water transfers, allocating water all across the country to provide the dryer areas with freshwater, mainly for the economic profit of irrigated agriculture. Since the 21st century, there has been a governance shift, towards a more multidimensional water management (Fornés et al., 2021). It includes new water sources such as desalination, re-use and managed aquifer recharge, trying to address the demands of an urban and service-based economy. Social equity and environmental justice are topics that are newly arising, especially considering the water transfers that are operative in the country, transferring freshwater from one basin to another. In this period, the political value of water intensified, because elected politicians appreciated the value of powerful hydraulic system with access to and control over water in electoral terms (Lopez-Gunn, 2009). Therefore, water has strategic importance in socio-ecological tensions and territorial identity, more so than traditional left or right politics, which is referred to as the 'political returns' on water (Lopez-Gunn, 2009). Because of the multilevel electoral system and the characteristic of water to flow across borders, tensions appear in political representation, particularly for national parties (Lopez-Gunn, 2009). With the water governance decentralising in the country, the question arises who should determine the most relevant management problems (Thiel et al., 2011). Water management strategies remain driven by economic growth and profit, as a result of an economic paradigm in the previous century. Unsustainable irrigation practises are subsidised and prioritised over environmental preservation, causing socio-ecological conflict and ecosystem decline.

Due to this economic focus in water management, the implementation of climate change adaptation and ecological restoration and preservation strategies is another important issue. Rules set by the Water Framework Directive (WFD) about the restoration of the ecological flow of rivers are not met and land degradation continues. As desertification characterises a point of no return, preventive measures must be taken. There are currently several action plans that are relevant to combating desertification, such as the Common Agricultural Policy, the EU Forest Strategy and the EU Strategy on adaptation to climate change. However, desertification is not the main focus of those strategies and the European Court of Auditors (ECA) has pointed out in its report 'Combating desertification in the EU', the risk of desertification in the EU is not effectively and efficiently addressed, as the steps taken lack coherence and a shared vision in the EU about how land degradation neutrality will be achieved by 2030 is lacking (ECA, 2018). Therefore, developing legal frameworks for desertification and land degradation is necessary.

According to the Spanish ecological organisation Ecologistas en Acción, urbanisation, tourism and industry are the core of the problem. They demand a reconversion of the Spanish economy and advocate for infrastructure network and land use reformations (Revista, 2007). The WWF report 'Chronicle of a drought foretold' however, highlights that unsustainable water extraction, use and management in Spain are the main causes of water scarcity and desertification in the country (WWF España, 2019). In areas where there is not enough water available in rivers and reservoirs, more intensive use is made of groundwater, including illegal consumption through more than half a million estimated illegal wells. The WWF therefore enforces the need to convert to an irrigation model that focusses on quality instead of quantity, as overexploitation of water resources by the agriculture sector is causing depletion of groundwater bodies, pollution and ecosystem decline (Valdivia, 2019).

Additionally, restrictions on water use and measures against pollution, overexploitation in the form of illegal drillings and fair water prices are needed. Household water costs less than €2/m3 on average in Spain, adding up to less than 0,9% of household expenses, both among the lowest rates in the EU. Irrigators pay around €0.02-0.1 / m3, as irrigation water is highly subsidised. As Lassman (2024) points out, "if tariffs increase, raising awareness on the cost of water scarcity is needed for social buy-in". Social acceptance needs to be created in order for demand reducing measures to work. However, data on water in Spain is only fragmented available and incomplete and stakeholders are rarely involved in the decision-making process, leading to a lack of social acceptance (Lassman, 2024).

Furthermore, a shift is taking place from relying on freshwater sources to the current focus of the Spanish government, which is on increasing non-conventional water supply. This transition is happing since the last decade, but is facing challenges as lack of social acceptance and funding. Desalination is promoted as the solution to the water shortages, but the AGUA program of 2004: a plan to build 34 desalination plants and to double national wastewater reuse by 2008, was cancelled due to a lack of funding. Additionally, the EU Water Framework Directive puts an emphasis on the importance of reusing water and has created new rules to which EU countries must comply. Reusing wastewater is an important tool to improve water security, not only for mitigating water scarcity, but also for the adaptation to climate change and facilitating the implementation of a circular and sustainable economy (Voulvoulis, 2018). However, the use of reused water in Spain has been limited to the agriculture and industry sector and urban cleaning services, and in 2016, only 10% of the regenerated water was reused (López-Ruiz & González-Gómez, 2023). In 2018, the national government was fined for not complying to the EU WFD rules. The situation calls for a stronger emphasis on non-conventional water sources though water governance, as well as more detailed and long-term planning for the financial aspect of it.

Especially near the Mediterranean coast, a continuity of unsustainable agriculture practices, accelerating tourism and increasing drought periods combined are creating severe conditions of water scarcity and desertification.

The Segura River Basin, in particular, suffers from extreme water shortages due to its semi-arid climate, unsustainable agricultural practices, and increasing demands for water in tourism and urban areas, and is therefore the chosen study location of this research.

CONCLUSION: CHALLENGES OF THE WATER SYSTEM

The hydrological regime in Spain is extremely irregular and the balance between water resources, demands and environmental needs is very fragile. This situation is aggravated by climate change and an increase in demand for water due to a growth in irrigated agricultural land and tourism. Overexploitation of water resources is causing a disrupted balance of the water cycle, causing many problems for the economy and human well-being, as well as the ecosystem, as it is leading to desertification. These effects are intensified by climate change, and water scarcity is increasing. In order to be able to adapt to a water scarce future, sustainability measures addressing these issues need to be taken.

Recently, there has been a shift in focus of the government from water reallocation via inter-basin transfers to ecological restoration and increasing the water supply through non-conventional water sources (desalinated water and reuse). But the regulations set by the EU are not yet met and this transition has led water to become an economic asset in Spanish politics, driving socio-political tensions and inter-basin conflicts (Lopez-Gunn, 2009).

At the core of this problem lie multiple socio-ecological issues, that are deeply rooted in the socio-political context. These issues and their interrelatedness are currently under-explored when examining the problem of water scarcity of a territory. This makes the challenge to design, plan for and manage a more sustainable water flow in water scarce regions extremely difficult.

The aim of this research is to address this research gap of sustainability planning in water scarce regions, by examining the water system and its context in a holistic way, in order to find integral solutions that contribute to a balanced water system and sustainable future.

The focus area of this thesis is the Segura River Basin in Southeast Spain, where socio-political and socio-ecological issues prevail and hydrological conditions, exacerbated by climate change and economic processes, together shape a condition of severe water scarcity. The output of this thesis is a regional spatial strategy for a resilient water system in the Segura River Basin. However, the scope of the research extends beyond the spatial implications of the water cycle, and critiques the current water consumption patterns and the capitalistic approach to economic growth focussed on extractivism, in a broader context.

The specific focus of this thesis is the transition of the agriculture and water management sectors, as unsustainable irrigation practices and poor water management strategies are at the core of the disruption of the water cycle in the studied region.

With hydrological variability increasing due to climate change, the situation calls for better water management strategies that include more water rations, storage, water use regulations, efficiency, and perhaps a spatial reorganisation that includes different land uses. To be able to address the conflicting demands, a holistic analysis and design approach is needed, where the water system is examined as a whole of socio-ecological, socio-political and economic relations. Hereby, addressing issues on the supply and demand side of the water shortage, across sectors, administrative boundaries and scales, is crucial. The imbalance of the water system cannot be solved alone by redesigning the region spatially, rules and measures to change unsustainable practises and human behaviour are needed. In order for these measures to work, social acceptance has to be achieved (Lassman, 2024). In addition to this, citizens and stakeholders need to be included in the decision-making process, to be able to integrate the needs and wishes of each stakeholder in a just way.

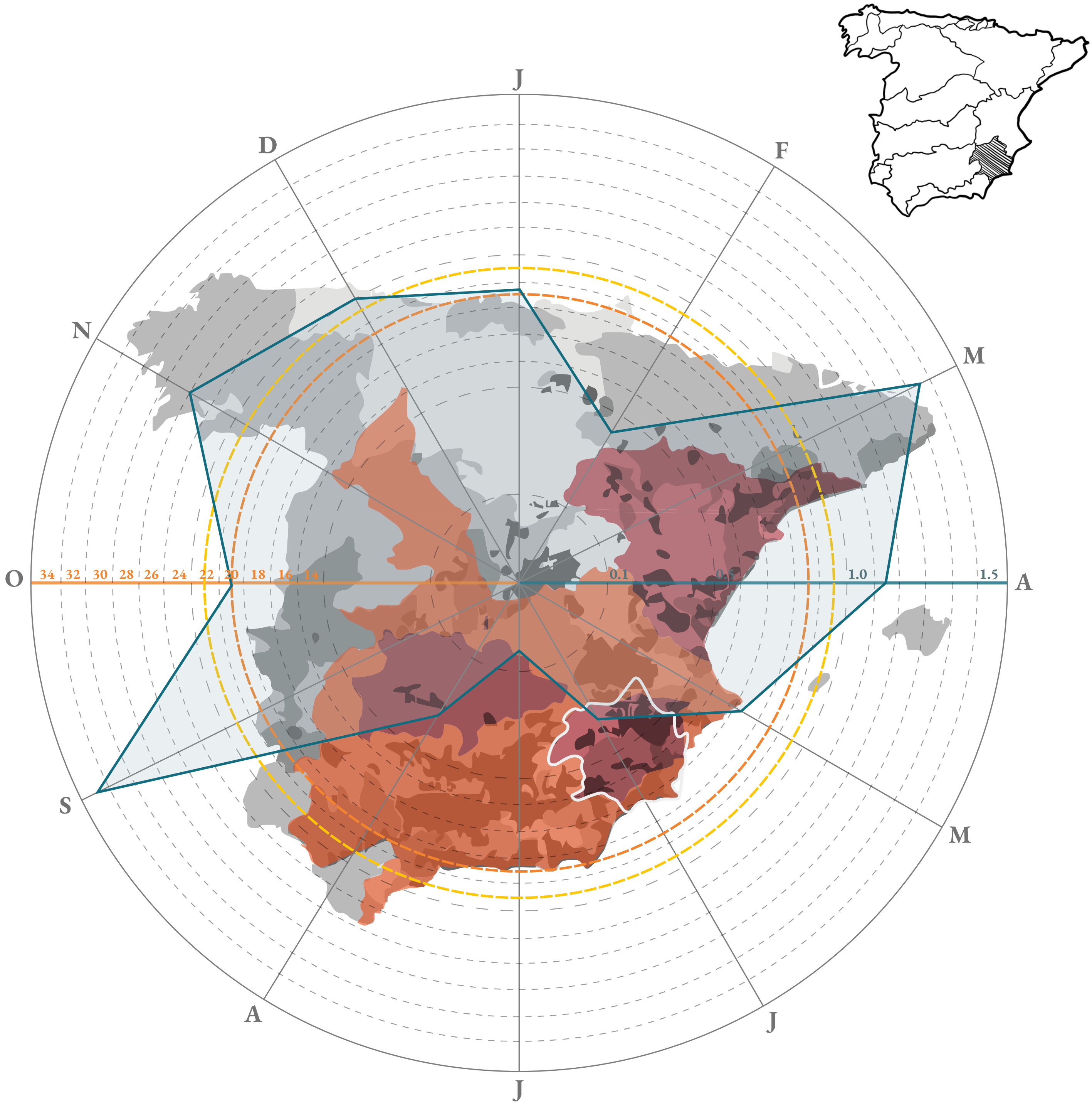


Figure 10. Conditions of the SRB within Spain, made by author, based on data by CHS, EEA and WWF.

= low risk of desertification

= medium risk of desertification

= high risk of desertification

= already arid regions

= Segura River Basin

= precipitation measurement

= precipitation measurement

Precipitation mm/day

Temperature degrees Celsius

= precipitation measurement
= temperature measurement
= months
= mean yearly temperature Murcia
= mean yearly temperature Spain
= monthly precipitation Murcia

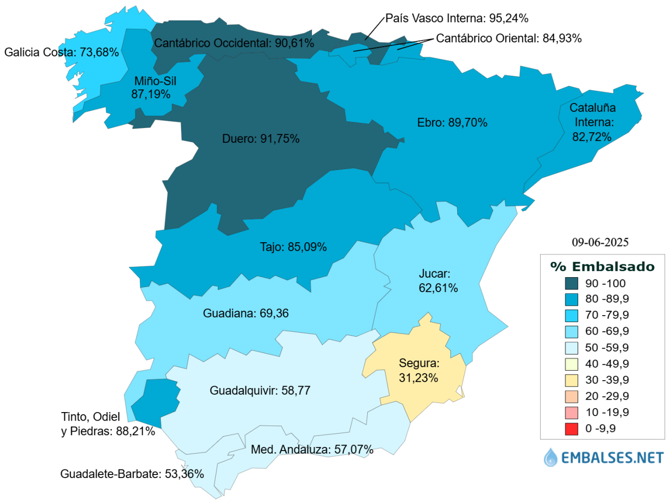


Figure 11. Reservoir availability in spring 2025 per basin in Spain.
Source: retrieved from (AEMET, 2025).

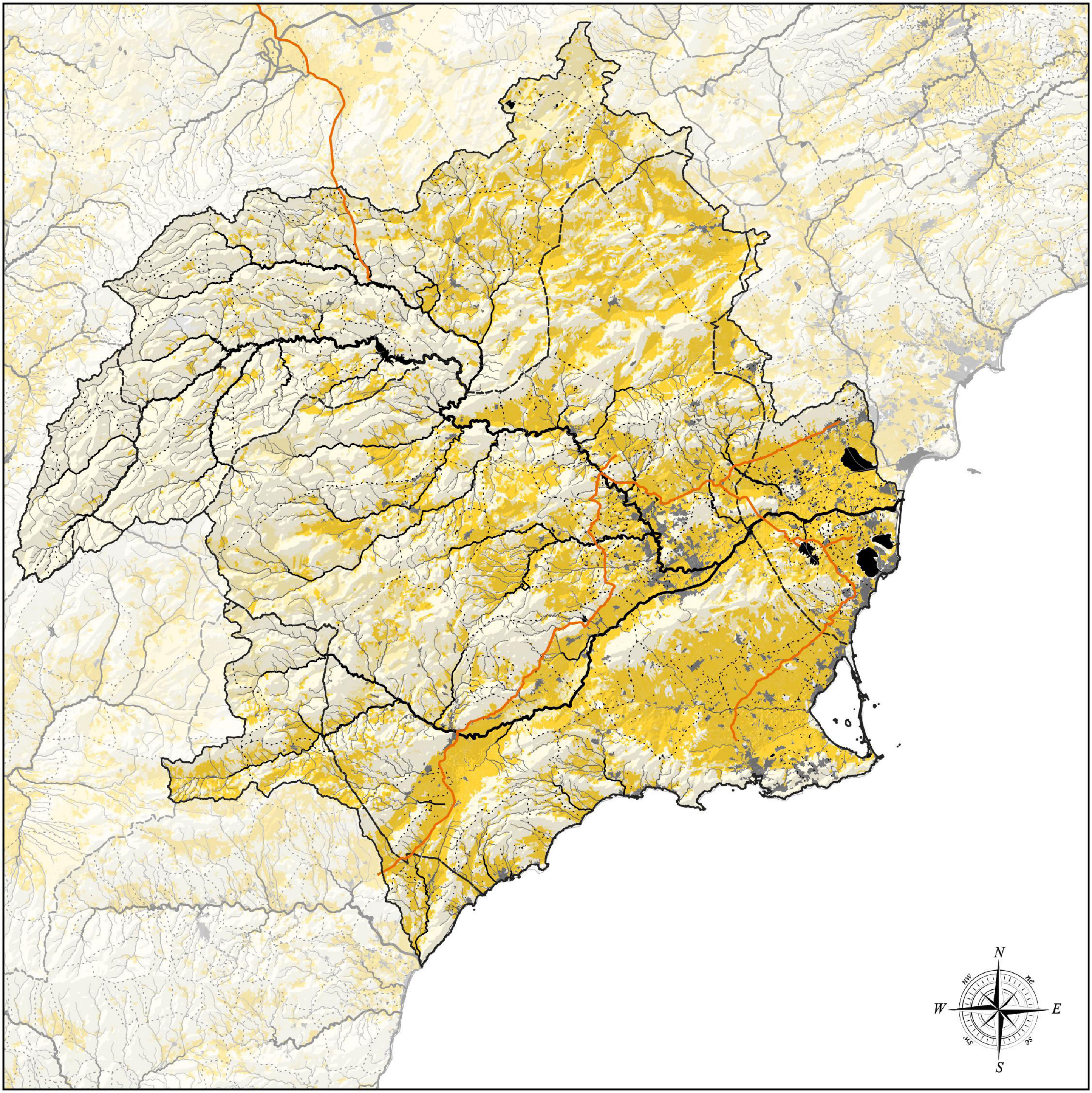
THE BASIN

INTRODUCTION

This thesis examines the critical case of the Segura River Basin (SRB), one of the driest river basins in Europe. The basin is located in Southeast Spain and has a semi-arid Mediterranean climate. It has an average yearly temperature of 23 degrees, which is 3 degrees warmer than the national average. Because of the climatic and geological conditions, the basin has an annual rainfall of just 365 mm, making it the area with the least rainfall in all of Europe (Ministerio de Agricultura, Pesca y Alimentación, 2023).

Water scarcity in the basin has drastically intensified over the last decade, due to climatic changes, increasing water demand and poor water management and governance. Over the recent years, the river's runoff at the mouth has dropped to only 4% (CHS, n.d.). In 2017, water volumes in the basin reached only 14,4% of the basins water storage capacity. The full basin capacity is now at just 23% of what it used to be. Figure 11 shows the current reservoir levels of the different basins in Spain.

Climate change is not the only reason for this, so is a history of overexploitation of water resources and poor water management. The development of irrigation agriculture in the last century has caused continuous overexploitation of



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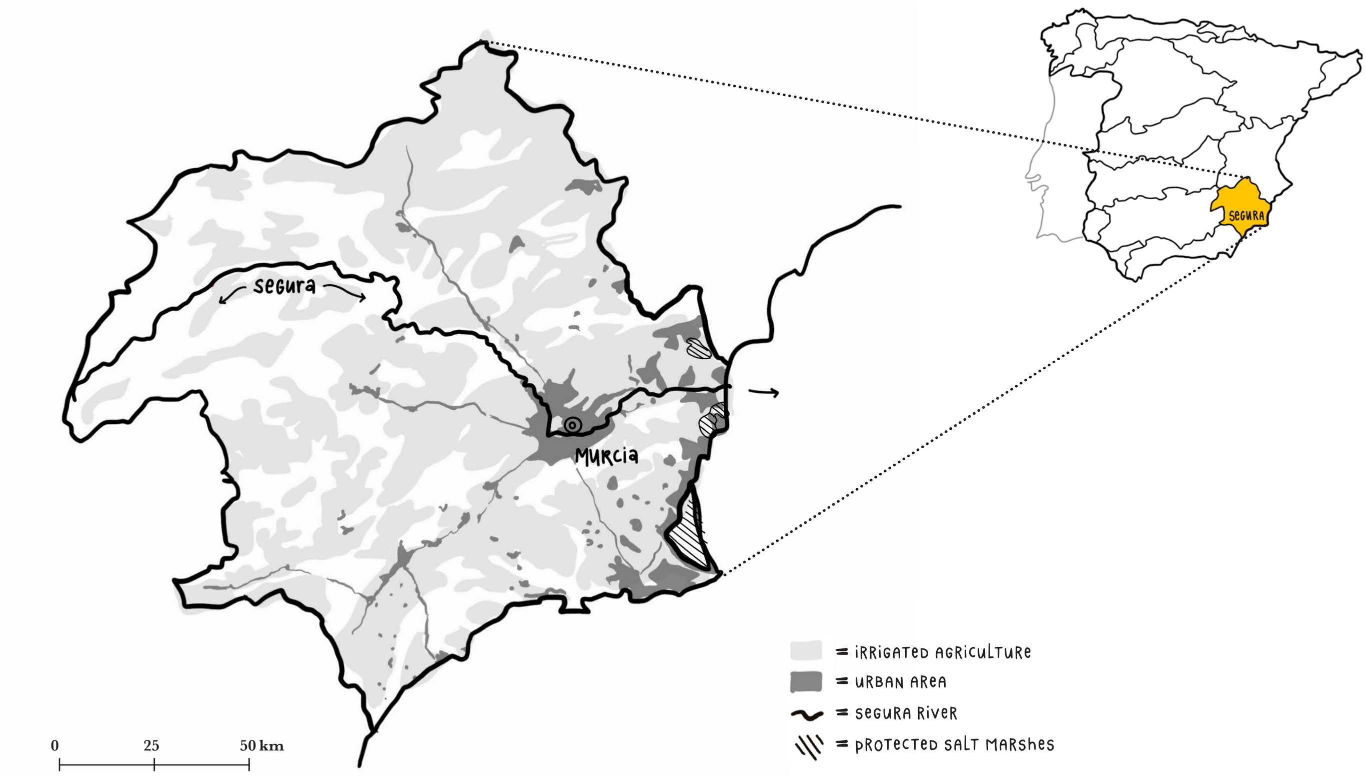


Figure 12. Basin overview. Source: made by author.

water resources and pollution of the landscape, which has led to a degradation of the natural environment and water shortages. The agriculture sector is the biggest economic and water consuming sector, and occupies most of the land use cover. Since the last century, uncontrolled irrigation agriculture expansion for global food production happened. Next to a significant increase in water demand, this has also led to pollution and salinisation of groundwater sources, making groundwater unfit for irrigation and domestic consumption.

TST canal system
Provinces
Inland Water, Segura River Network, Salt Marshes
Land Cover (CLC 2018):
Urban fabric
Permanently irrigated land
Non-irrigated arable land
Sparsely vegetated natural areas, woodlands or mountains
Coastal lagoon

Figure 13. Overview of the SRB, showing agricultural land use. Source: made by author, based on (Corine Land Cover, 2018).

Socio-political tensions are rising, as water becomes more scarce and authorities struggle to fairly allocate resources. The basin is heavily reliant on external water sources through the Tajo-Segura water transfer. However, with decreasing water availability and new regulations for ecosystem restoration, the amount of transferred water has dropped and further restrictions are announced. This causes socio-ecological and socio-political conflicts between the transferring and the accepting basins. A shift in water management has taken place towards desalination practises and the reuse of wastewater. However, the loss of transferred water is not compensated and the goals of non-conventional water supply are not met.

Existing water infrastructures are outdated and urbanisation and tourism increase the pressure on the system further.

Figure 14. Greenhouses in Campo de Cartagena. Source: made by author.

POSITIONING

THEORETIC BACKGROUND

According to Critical Socio-Environmental Theories such as Political Ecology, that examines the interrelatedness of human activities, ecological degradation and systemic inequalities, industrial capitalism separates humans from natural processes. This metabolic rift intensifies resource exploitation and ecological harm.

METABOLIC RIFT THEORY

It is discussed that planetary urbanisation has had an economical focus the last half-century, causing a metabolic rift, where urbanisation is seen solely as agglomeration and city-growth, instead of a socio-metabolic process. Building on the theory of metabolism, this metabolic rift is the concept of estrangement of humans from the metabolism cycle and natural systems in a capitalist society, which is derived from Karl Marx (Marx, 1977).

The natural water cycle is disrupted due to human exploitation for capitalist production of global agricultural exports. This results in the unsustainable extraction and management of natural resources, as well as unsustainable agriculture practices.

The role of the hinterland (non-city operational landscapes) as production sites of the city is forgotten in research about urbanisation, while these operational landscapes keep growing along with planetary urbanisation and now cover 70% of the Earth (Brenner & Katsikis, 2020). Therefore, (urban and regional) developments should be analysed and designed through the lens of Critical Resource Geographies.

CRITICAL RESOURCE GEOGRAPHIES

Critical Resource Geographies is a theoretical lens drawn from Political Ecology, and examines the social construction of extraction and operational landscapes. It discusses the cultural, political and economic context that defines how a resource like water is valued, as well as power dynamics in resource governance, intersections with global processes such as capitalism and socio-environmental conflicts and inequalities.

CAPITALISM AND ECONOMIC GROWTH

According to the Anthropocene Theory, human activity is now the dominant force shaping the Earth's ecosystems and geology and anthropogenic activities (such as overexploitation of resources) drive ecological crises.

According to Paul Crutzen (2002), this new epoch started around 1950, with the industrial revolution, showing intensified impacts of human processes on the planet in several graphs. Critics argue that this new epoch started way earlier, with the emergence of agriculture and settlements (Ellis, nd., Ibañez & Katsikis, 2014). According to Erle C. Ellis (nd.), the Earth is left with a mosaic landscape, where land is either used for agriculture and settlements or left over for ecosystems to be embedded in them.

Even though this theory is criticized a lot on its validity and scientific proof, the inevitable fact that human activity in a globalising and growing economy has polluting and depleting effects on the natural environment cannot be overlooked. To grasp the full complexity of human processes on the Earth, more in-depth analysis that is context (social, spatial, economic, political) and flow related and has a time component, is needed.

The Capitalocene is a critical response to the Anthropocene Theory, stating that capitalism in itself is the reason for the ecological crises (Brenner & Katsikis, 2020). The theory examines how economic systems focussed on profit, growth, and exploitation disrupt natural cycles and create socio-ecological imbalances. According to Moore (2015), the problem of crisis arises through the relation between the zone of commodification and reproduction. Capital surplus rising and ecological surplus declining are intertwined in this capitalist world. As Marx's reasoning states: "the rate of profit is inversely proportional to the value of the raw materials" (Marx, 1977, Moore, 2015).

To decrease the accumulation of costs in order to maintain the trend of (economic) growth, humans find new ways of imposing order on new spaces and find new ways of unpaid labour, leading to increased capitalised relations of human and non-human reproduction. Because the mass of accumulated capital tends to rise faster than the appropriation of unpaid labour, the ecological surplus declines (Moore, 2015). Due to automation and digitalisation, production and circulation of operational landscapes becomes more capital intensive and less labour intensive (Sanz & Katsikis, 2024). This emphasises the metabolic rift and the inherited dichotomy between society and nature, where "technology is the means to conquer nature & society is a homogenised agent" (Lecture: Katsikis, 2024c). This is visible in production landscapes of intensive agriculture, such as the Segura River Basin in Spain, where the little water that is available, is extracted from nature and used to the maximum for human commodification and profit. This comes at the cost of the natural environment, which is vital for human well-being, left helpless and depleted.

THE RIGHTS OF NATURE

For several decades, a paradigm shift is taking place, realising the importance of preserving and maintaining natural ecosystems for planetary health and human well-being. However, with conflicting land use demands from different sectors, pressures from a globalised and growing population, and laws protecting anthropogenic and polluting activities, giving a voice to nature's needs and implementing the measures is still a challenge.

To combat this problem, the concept of the Rights of Nature emerged. The Rights of Nature is a legal, as well as a philosophical concept that acknowledges systems and natural ecosystems as legal entities to hold legal rights, such as humans and organisations. It challenges the traditional view of nature as a resource for human needs by acknowledging nature's intrinsic value (GARN, 2025). According to the concept, people have legal authority and responsibility to enforce those rights on behalf of the ecosystem. By implementing this concept, neglected natural areas and ecosystems can be represented by local communities, environmental activists and NGO's in a legal manner, where decisions from a top-down perspective have to comply with the law and finally, environmental justice can be met by holding polluters accountable.

CONCLUSION FOR THE SEGURA RIVER BASIN

Applying these theories to the context of the Segura River Basin, it can be concluded that the eco-nomic development related to the Hydraulic Paradigm, and the transition from indigenous prac-tices towards mechanised agriculture, have caused (socio-)ecological deterioration and a meta-bolic rift in the form of a changed relationship with nature. Water is not valued as a critical re-source provided by nature, but as a political and economic commodity, and citizens are often not aware of the severity of water scarcity for both ecosystem health, as human well-being. This paradigm of overexploitation has led to deeply rooted unsustainable (agricultural) practices, which cause an ecological surplus decline and rising socio-political conflicts. A radical reconceptualisa-tion of the hinterlands (the agricultural production land) is needed, where systemic vulnerabilities are taken into account and a shift from global operationalised landscapes towards regional pro-duction sites takes place.

Figure 15.   Pink saline wetland in Torrevieja. Source: made by author.

PROBLEM STATEMENT:

Water scarcity in the Segura River Basin is created and intensified by a continuation of unsustainable agriculture practices, accompanied by poor, compartmentalised water management and a neglect of nature. The basin needs a radical transformation of the water system to achieve socio-ecological resilience and a water-secure future.

Perhaps a study that implements symbiotic design principles to connect the different layers, objectives, sectors, and stakeholders could contribute to a sustainable future water system in the Segura River Basin region.

Figure 16. Bare, desertified agricultural landscape in Campo de Cartagena. Source: made by author.

PROBLEM STATEMENT

There is a problem in arid or semi-arid regions, such as the Segura River Basin in Spain, with water availability and adjusting sustainably to a water-scarce future. Despite the efforts of the Spanish government to use new technologies such as desalination to increase the water supply in the region, a structural water shortage remains in the area. Climate change is causing long periods of extreme drought, resulting in even lower water availability. At the same time, an increase in water demand due to irrigation agriculture expansion, urbanisation, and tourism in the form of seasonal peaks is putting more pressure on the system.

Overexploitation of water resources and drought have caused the mouth of the Segura river to drop to only 4% of its original runoff over the last years (CHS, n.d.), stating the severity of water scarcity. The abundance of water has negatively impacted the citizens and farmers in the area in the form of rising water prices, more restrictions on water use, and a decrease in agricultural produce, affecting the economy of the whole country of Spain. Thus, conflicts about fair water distribution arise because the different sectors compete for the available water. At the same time, the lack of water causes landscape deterioration, declining ecosystem services, and ecological surplus, resulting in a point of no return: desertification.

A possible cause of these problems is the compartmental and centralised water management system resulting from a history of profit-driven national regimes (Fornés et al., 2021; Lopez-Gunn, 2009). A metabolic rift has caused a change in the relationship between humans and nature, resulting in irresponsible, non-resilient, and inefficient water use and management. For instance, managing land use transformations and water systems across different sectors is underexplored, and water scarcity awareness is low. The ecosystem, which is vital for storing freshwater, enhancing its quality, and protecting against floods, is declining. More water than is available in the region is used for unsustainable practices, overexploiting natural resources, and polluting them simultaneously.

The Segura River Basin's challenge of adapting sustainably to a water-scarce future is underpinned by socio-ecological issues that are deeply rooted in the socio-political context. Technological solutions aimed at resource efficiency alone do not solve socio-environmental problems such as water scarcity, as the problem lies in the disturbance of the human-nature relationship. To analyse, plan, and design for a more sustainable future, holistic approaches to address this relationship are needed, accompanied by a changed global mindset towards degrowth.

RESEARCH APPROACH

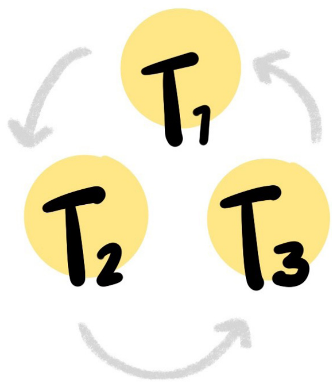
KNOWLEDGE GAP

The main gap addressed with this research is the lack of an actionable, holistic, and cross-disciplinary design framework for the systemic water transition in arid agricultural regions.

Although integrated frameworks such as Integrated Water Resources Management (IWRM) provide important principles for managing water resources holistically, they fail to offer concrete, design-based solutions that operationalise system-wide symbiosis across sectors, scales, spatial systemic layers, and time. In the highly politicised, arid context of the Segura River Basin, where agriculture, ecology, and urban development are interconnected, no design-oriented framework systematically connects these dimensions.

Other methods used to address the problem of water scarcity, such as global strategies and participation frameworks, are too generic for the specific socio-political and environmental context, too short-term focused, and lack the integration of different spatial layers of the water system and a concrete design aspect.

This thesis addresses this gap by developing a regional symbiotic strategy for the water system transition, tailored to the region's context and vision, along with a symbiotic strategic design method for systemic transitions, enabling participatory design across disciplines.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RESEARCH AIMS

RESEARCH GOAL

This research aims to develop a symbiotic strategy for guiding sustainable water system transitions by formulating symbiotic pathways. The strategy outlines how to analyse, identify, select, and combine symbiotic design solutions across sectors, spatial scales, and temporal phases. To support this, a conceptual framework was constructed to define what symbiosis means in this context, which components must be connected, and why these interrelations are essential for achieving a resilient water system.

Focusing on the Segura River Basin, an arid, agriculturally intensive region affected by water scarcity and desertification, the research addresses transitions toward sustainable agriculture, integrated water resources management, ecological restoration, and climate-adaptive urbanisation.

By integrating technological and nature-based solutions, the research proposes a design approach that fosters synergies between anthropogenic activities and natural systems. This symbiotic method seeks to balance short-term demands with long-term resilience, prioritising interventions that simultaneously address multiple challenges across domains, thereby connecting sectors, scales, and goals.

RESEARCH OUTCOME

This research set out to develop a symbiotic design strategy for sustainable water system transitions. In doing so, it produced three interconnected outcomes:

1. A pattern language of symbiotic solutions for the water system transition in arid regions of agricultural production,
2. A regional symbiotic design strategy for the Segura River Basin, and
3. A symbiotic systemic design methodology for territorial systemic transitions.

During the pre-analysis period, it became evident that no existing methodology adequately supported the development of a symbiotic strategy. As a result, the research itself constructed the method required to produce this symbiotic strategy. Through an iterative research-by-design process, a pattern language emerged as a crucial tool, enabling the identification, organisation, and application of interventions that operate across sectors, scales, and timeframes. Its structure facilitates both strategic coherence and flexibility, making it a transferable tool for complex transition contexts.

The pattern language is presented in a separate booklet, which outlines the logic behind each solution, their interdependencies, and guidelines for how they can be applied and adapted in different territorial settings. To test and exemplify its use, the pattern language was applied in the Campo de Cartagena sub-basin, resulting in three scenarios for the future and a strategic design project on a more local scale. This project illustrates the integration of multiple interventions over time, highlighting the symbiotic working of human and natural systems, supported by a phased roadmap and policy recommendations tailored to the socio-ecological dynamics of the region.

PROFESSIONAL RELEVANCE

A radical revisualisation of the water system is needed to start the transition towards a sustainable water system in water-scarce regions affected by climate change. The hinterlands of global food production that have come with globalisation, population growth, and urbanisation have to be reorganised to fit the landscape and natural systems in place. This transition requires a spatial design task and a new paradigm of mindset change. An integral approach across sectors, political borders, disciplines, and different scales is needed, as these systems are intertwined.

As urbanists, our role is to combine sectors and stakeholders, stimulate collaborations and knowledge exchange, and design a balanced system and resilient future. This research sets out to explore how a symbiotic design methodology could support this role.

With the output of this thesis, the intention is to contribute a methodology as a tool that can inspire designers, planners, and decision-makers to identify integrated, multi-benefit interventions. I aim to inspire designers, decision-makers, and stakeholders in the region to shift away from isolated, top-down solutions toward collaborative and adaptive transition pathways, and to see the potential in addressing the problems related to the sustainability transition in a symbiotic way. I hope that my pattern language can be the start of a new design approach, where individual stakeholders are included and symbiotic pathways are found that combine the needs of multiple sectors, without having to choose one solution over the other from a top-down perspective.

SOCIETAL RELEVANCE

A global mindset change starts with individual correction of behaviour, social awareness, and acceptance of the need for change. A balanced relationship with nature is crucial to achieve socio-ecological resilience and ensure quality of life for future generations. Water-related issues due to climate change do not only occur in water-scarce regions, and water scarcity is not always related to visible drought in the landscape. Awareness is the first step to change, and therefore, I believe that knowledge must be shared and stakeholders and communities must be engaged to achieve social acceptance and individual change. With this project, I hope to inspire individuals to think about these global systems in everyday life, to start this change of mindset collectively.

The output of this research can be used as an inspiration for decisions by local and regional authorities within the study basin. Next to this, the pattern language can be distributed amongst different stakeholders in the region to individually or collectively implement solutions and start the transition from a bottom-up perspective. Additionally, this research can inspire sustainable development and resilient planning in other (semi-)arid regions facing water scarcity problems.

SCIENTIFIC RELEVANCE

This research contributes to the growing field of systemic design for sustainability transitions by bridging gaps between spatial design, water governance, and resilience thinking. This is done by developing a research and design-based methodology for symbiotic water system transformation in arid regions of intense agricultural production. While existing frameworks, such as nature-based solutions and Integrated Water Resources Management (IWRM), are well established in water governance, they often lack spatial, design-oriented tools to operationalise systemic change across different domains. Especially in highly politicised and drought-struck regions like the Segura River Basin, actionable design methodologies that integrate the various stakeholders are lacking. By bridging systemic thinking and design practice, this research aims to contribute to the current water transition discourse with a novel approach for symbiotic water system design.

LIMITATIONS

Designing systemic change in complex water systems inherently involves trade-offs, scope boundaries, and uncertainties. This thesis focuses primarily on the agricultural transition within the Segura River Basin and does not fully explore other related domains such as energy or tourism, which could further enrich the symbiotic method. Furthermore, the pattern language and methodological framework developed through this research are shaped by iterative design exploration rather than predefined by theory. As such, further refinement and testing are needed to evaluate their robustness, applicability, and transferability.

HOW COULD SYMBIOTIC SYSTEMIC DESIGN BE USED TO DEVELOP PATHWAYS FOR THE SUSTAINABLE WATER SYSTEM TRANSITION, CONTRIBUTING TO WATER SECURITY AND A SOCIO-ECOLOGICALLY RESILIENT FUTURE FOR THE SEGURA RIVER BASIN?

1 A SYMBIOTIC PATHWAY PATTERN LANGUAGE

2 A REGIONAL SYMBIOTIC DESIGN STRATEGY

3 SYMBIOTIC SYSTEMIC DESIGN METHODOLOGY

SUB QUESTIONS

RQ1.

What elements, processes and interrelations define the water system in the Segura River Basin, and how have governance structures historically influenced its resilience?

RQ2.

What vision for a sustainable future water system in the region can be created from the analysis conclusions?

RQ3.

What symbiotic solutions can contribute to the vision of a socio-ecologically resilient future water system in the region, and how can they be organised according to the vision framework?

RQ4.

How does testing these solutions through sector symbiotic spatial scenarios inform symbiotic pathways for the strategic design of the water system transition?

RQ5.

What strategic projects for a sustainable water system in the region can be derived from comparing the scenarios, and how can they create a symbiotic adaptive pathway?

AIMS

UNDERSTAND the multi-layered current complex adaptive and socio-ecological systems and historic influences that shaped them.

IDENTIFY the problems, goals and leverage points related to the water system in the region, and create a framework for change.

IDENTIFY possible symbiotic solutions for the sustainable transition of the water system in the region &
CREATE an organised and transferable overview.

CREATE a framework for the design of sector symbiotic future scenarios through applying the symbiotic interventions in the region, that informs no-regret measures for the strategy.

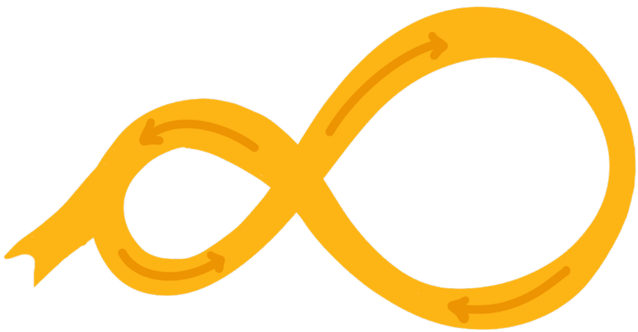
CREATE examples of a symbiotic pathways in the form of spatial design projects that are phased over time, tailored to the local conditions and accompanied by policy recommendations, and aimed at achieving system symbiosis.

RESEARCH QUESTIONS

In this paragraph, the sub-research questions are presented, along with their aims.

The aim of this research is to develop a strategy for symbiotic design of the water system transition. This strategy is created and tested by examining the critical case of the Segura River Basin. Therefore, the research questions and thesis output are tailored to the analysis and design of the study location.

Together, the answers to the sub-reserach questions form a symbiotic design methodology. This will be explained further in the methodology and conclusion chapters.



THEORETICAL FRAMEWORK

SYSTEMS THEORY

Systems theory is the study of organisation per se, where a general system is being understood as a set of interrelated objects and organisation is the form of interdependence of the objects. This theory is used to study systems' components, interactions and feedback loops, to get an understanding of complex systems such as water governance.

SOCIO-ECOLOGICAL SYSTEMS THEORY (SES)

A socio-ecological system is a concept used in analytical approaches, intended to examine the relationship between people and nature. It recognises humans should be seen as a part of, not apart from, nature, and nature as inter-linked to social systems (Berkes & Folke, 1998, Ostrom 2009).

Socio-Ecological Systems Theory examines the interdependence between human societies and ecological systems, emphasizing feedback loops, interconnectivity, and limitations. It is linked to the concept of sustainability and related to the Critical Socio-Environmental Theories by providing an approach to understanding the complexity and management of systems.

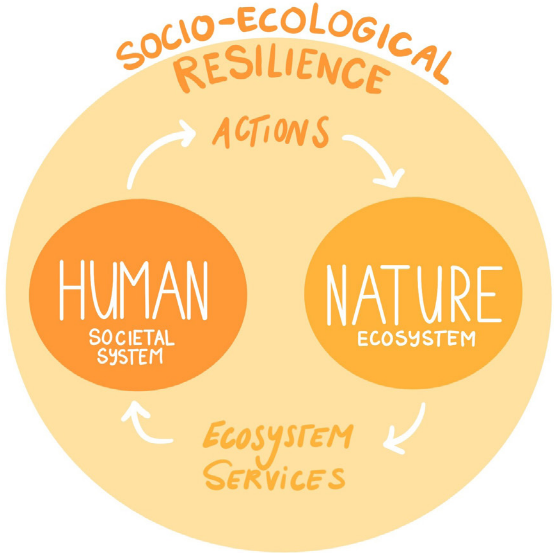


Figure 17. Socio-Ecological System diagram. Source: made by author, based on: (Sanchez, 2019).

COMPLEX ADAPTIVE SYSTEMS THEORY (CAS)

Complex Adaptive Systems (CAS) is a theory as well as a conceptual framework that describes how systems made up of interconnected and interdependent components behave, evolve and adapt over time. It combines global systems and local agents to describe the adaptability of a complex system, where it focusses on the interaction between 1) the agents, and 2) the agents and the environment (Holland, 2006). It provides a theoretical basis for the adaptability of environmental resource allocation and management such as water resource management (Rammel et al., 2006).

In the case of this thesis, the water system is examined holistically, including the natural ecosystem of the river basin, the water governance as a social system and the agriculture industry as a socio-economic system. Together they are seen and described as CAS, because they are shaped by interlinkages between processes and agents, and adapt to changing conditions of the context or within the system.

SOCIO-ECOLOGICAL RESILIENCE (SER)

Socio-ecological resilience is a part of Resilience Theory, developed by Holling (1973). Resilience theory examines the ability of systems to absorb disturbances while maintaining their functions, and is therefore closely related to Systems Theory, in particular to Complex Adaptive Systems theory. Socio-ecological resilience adds to this concept, by focussing on the dynamic interrelations between humans and ecosystems. It emphasizes on adaptability and transformability of systems in response to environmental and socio-economic changes (Walker et al., 2004). This theory is widely used in adaptation management and sustainability planning. Feedback-loops and cross-scale interactions are key principles to designing for long-term resilience (Folke, 2006).

In this research, SER is used as an overarching goal for the analysis and design of the project.

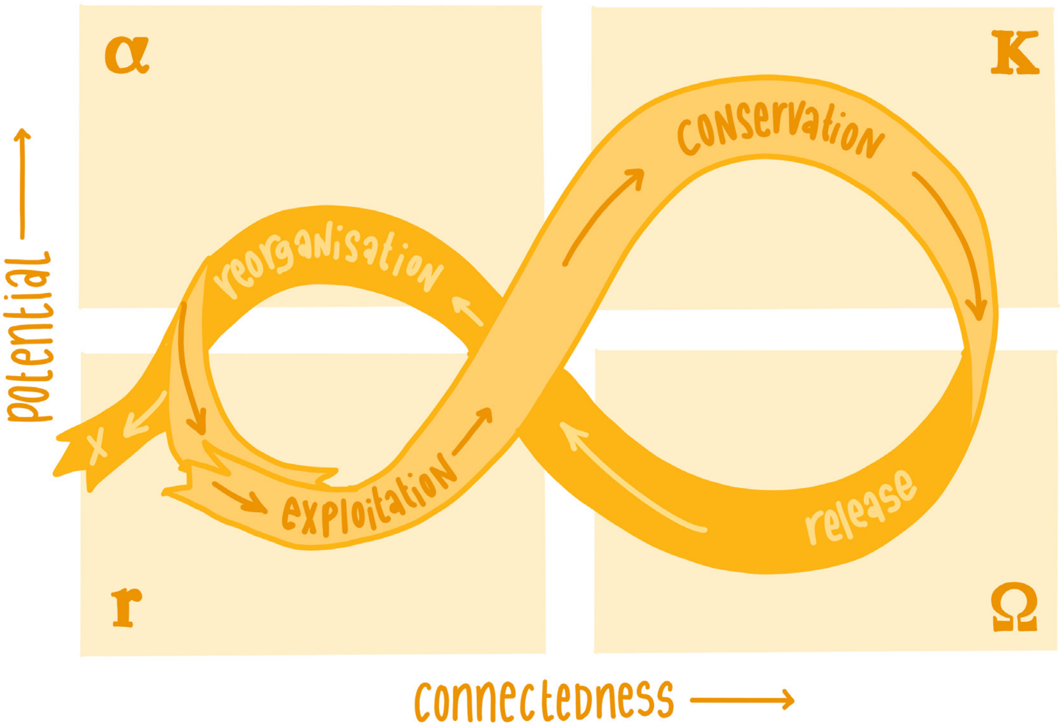


Figure 18. The Adaptice Cycle of the Panarchy Theory. Source: made by author, based on (Gunderson & Holling, 2002).

PANARCHY THEORY

Most systems go through repeated cycles consisting of four phases: fast expansion, conservation, release and reconfiguration, which is described as the adaptive cycle (Gunderson & Holling, 2002). In the Panarchy theory, cross-scale dynamics and adaptive cycles are incorporated, building on resilience and complex adaptive systems theories. It describes the transitioning of the systems through the phases and how process on one scale influence processes on the other. According to Gunderson and Holling (2002), "a significant backloop is unavoidable" unless there is an organised effort to reduce the complexity, release potential, and return to the rapid growth phase or create a very rapid, minimal conservation-to-reorganisation transition.

In the case of this research, the transition discussed is a transition away from a linear water flow where resource extraction and landscape depletion dominate, as a cause of a disrupted relationship between humans and nature. The release phase has triggered a need for reorganisation of the water system.

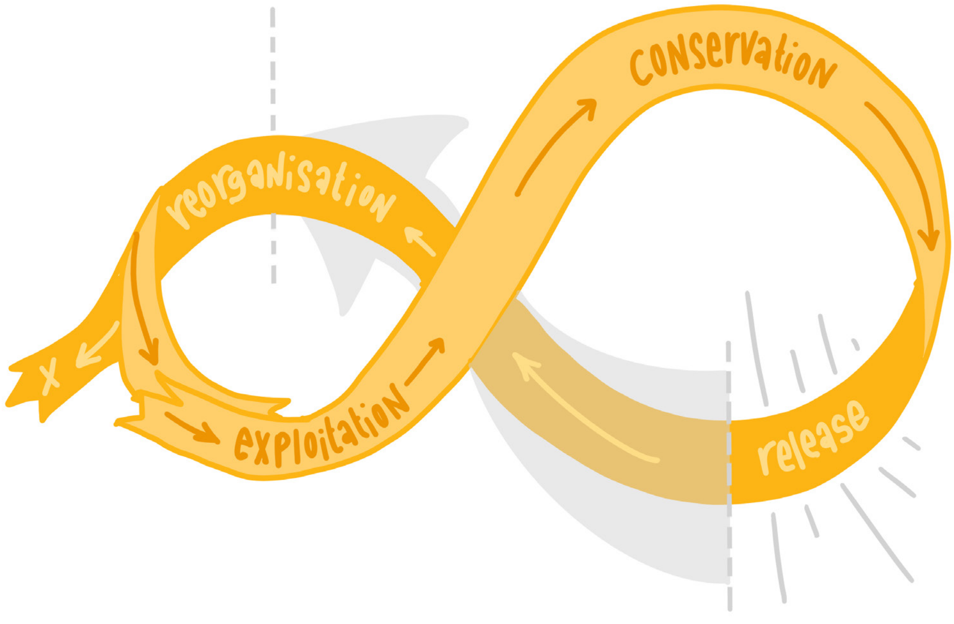


Figure 19. The Adaptice Cycle of the Panarchy Theory, showing the current position of the water system in the SRB. Source: made by author, based on (Gunderson & Holling, 2002).


NA

CONCEPTUAL FRAMEWORK

INTRODUCTION

In this paragraph, the theories used for this research are linked to the broader concepts and methodological approaches that frame the research. Together, they create the conceptual framework.

SYSTEMIC DESIGN (SD)

The main approach used for this research is systemic design. Systemic design is a conceptual framework for understanding complex systems in itself, as well as a method for applying design principles to address systemic changes. It integrates the thinking behind systems theory with the practical approach of design thinking (Jones & Kijima, 2018). It emphasises understanding the broader context in which systems operate and acknowledges the interconnectedness of the systems' components, as well as their unpredictable nature.

As a methodological approach, systemic design includes tools and processes to analyse and intervene in complex systems. It can be used to map systemic relationships and leverage points in the system that could result in sustainable system change. The design process includes phases of divergence and convergence in an iterative process that continuously improves, as a way to understand complexity and create value (Wandl, 2024). The steps are: 1) research the stakeholder network, 2) define the system, 3) map the system, 4) choose leverage points for systemic change, 5) ideate solutions for change, 4) prototype these solutions, 5) test these solutions, and 6) evaluate the results. This research follows a similar approach in the research and design process.

TERRITORIAL METABOLISM (TM)

Territorial metabolism is used in this research as an overarching framework for the analysis and design of the complex adaptive water system. TM as a concept within metabolism describes the flows of materials, energy, and resources through territories and socio-economic systems. By researching a flow, it aims to understand how resources are extracted, transformed, consumed, and discarded within a territory. Additionally, it examines the influence of socio-economic processes on these flows and on ecological processes. According to Erik Swyngedouw (2006), urbanisation processes commodify nature, shaping power relations and socio-environmental injustices. Therefore, the political dimension of urban metabolism is emphasised as crucial for understanding and addressing sustainability, thereby connecting critical socio-environmental theories with territorial metabolism studies. Swyngedouw emphasises that socio-environmental dynamics are often overlooked in studies about metabolism that are highly technical (Swyngedouw, 2006).

Because TM incorporates interdisciplinary perspectives and uses a systemic view of territories as socio-ecological systems, it integrates urban metabolism and socio-ecological metabolism and functions as an approach to analyse how territorial processes influence and are influenced by global environmental challenges such as climate change or water scarcity, as well as sustainable governance and water management within and across territories.

INTEGRATED WATER RESOURCES MANAGEMENT (IWRM)

Additionally, for the management of the water system, the concept and methodological approach of Integrated Water Resources Management (IWRM) is used as a goal. IWRM is a widely accepted framework for water resource management, but also incorporates elements of a methodology for planning and implementing water governance strategies. It emphasizes the coordinated development and management of water, land, and related resources. IWRM is defined by the Global Water Partnership as 'a process which promotes the coordinated development and management of water, land, and related resources to maximize the resultant economic and social welfare without compromising the sustainability of vital ecosystems' (GWP, 2000). Key elements of the concept are; a holistic perspective that considers the entire hydrological cycle and the interconnectedness of natural, social and economic systems, cross-sectoral coordination of water use (including the environment), participatory management that involves stakeholders in decision-making processes to ensure equity and inclusiveness, and the focus of sustainability in the sense of managing water resources in a way that meets current needs without limiting future generations (Agarwal et al., 2000).

It also includes adaptive water management, an approach that recognises the uncertainty and complexity of water systems and focuses on flexible management strategies that can adapt to changing conditions, such as climate change. Another key element of the approach is that it takes the basin scale as the operational unit to understand and assess interconnected links between human and natural systems (Agarwal et al., 2000).

THE NETWORK APPROACH (NA)

The methodological approach called the network approach is used for the analysis and design. The network approach emerged as the Dutch layers approach evolved, which organised spatial planning into three layers (the substratum, networks, and occupation layers) to address spatial challenges (de Hoog et al., 1998). Academics critiqued the Dutch layers approach for oversimplifying the complexity of the layers, where the approach initially classified the substratum as static and socio-political and cultural-historic factors influencing the network and occupation layers were overlooked (Priemus, 2004, 2007; van Schaick & Klaasen, 2011). Additionally, the flow of information related to technologies was not researched enough. Most importantly, the Dutch layers approach did not acknowledge non-linear relationships between the layers. With these critiques of the Dutch layers approach in mind, the network approach was conceptualised (Priemus 2004, 2007).

The approach is used in sustainable resource management and urban planning and aligns with systemic thinking and adaptive planning. The network approach incorporates dynamic interrelations between the layers and focuses on flows and cross-scale interactions, aligning with concepts such as territorial metabolism and socio-ecological systems.

Looking at the problem of water scarcity, the focus of this research is the flow of water. The network approach is applied in this research by dividing the analysis of the water system into three layers: 1) the network layer, 2) the occupation layer, and 3) the substrate layer. The network layer shows the infrastructure network of water supply in the region, mapping the input flows of water. The occupation layer shows how land uses in the form of agricultural (and urban) systems interact with this infrastructure by using the provided water, and with the substrate by releasing the water back into the environment. The substrate layer shows the effects of this relationship and the relationship with the network layer that extracts the water.

A design goal can be connected to every layer of the water system to aim for more sustainable interrelations (see Figure 21). The goal for the occupation layer is sustainable food production. Renewable and circular water use form a goal for the network layer of the water system, and resilient natural landscapes for the substrate layer.

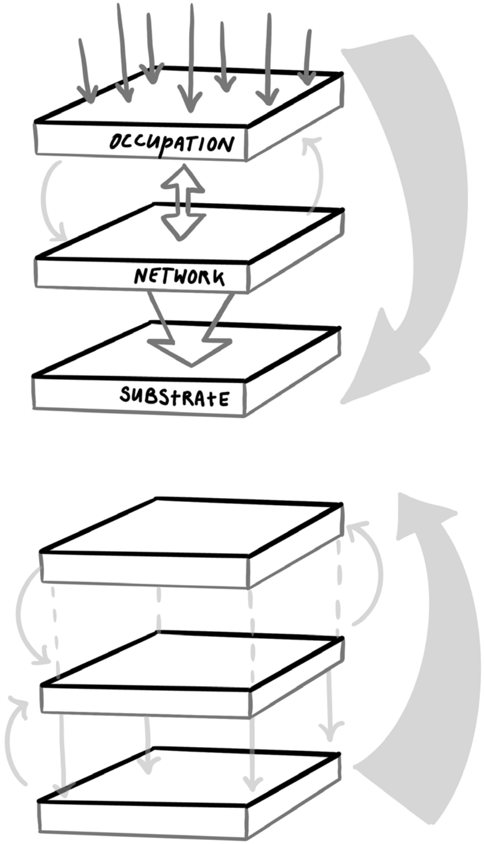


Figure 20. Top: the Dutch Layers Approach, bottom: the Network Approach. Source: made by author, based on (de Hoog et al., 1998 & Priemus, 2004 & 2007).

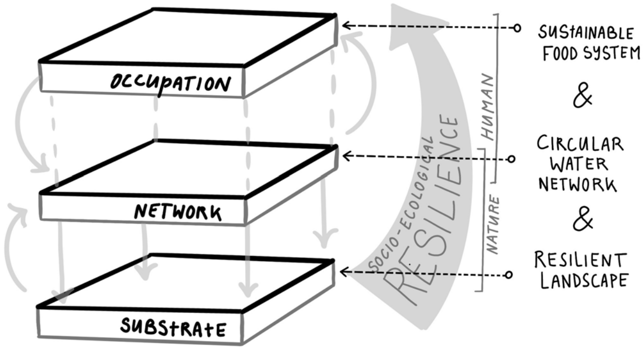


Figure 21. The Network Approach applied to this research. Source: made by author.

SYMBIOSIS AND SYMBIOTIC DESIGN (SD)

The main goal of this research is to achieve symbiosis between human and natural systems. The concept of symbiosis is thereby adapted in the form of symbiotic design, forming the basis of the conceptual framework. The concept of symbiosis originates from biology, focusing on mutually beneficial relationships between organisms. The concept has been adapted in the field of architecture, where symbiotic design is seen as a concept that emphasises the integration and co-evolution of nature and human-built environments (Horn & Proksch, 2022a,b; Olivieri, 2022). The concept of "mutual symbiosis" is applied within broader frameworks of sustainable and regenerative architecture, where it is seen as a system with feedback loops between natural and built environments. Davíd Ruano (2016) defined "Symbiotic design" in his PhD thesis as:

'A practice that recognizes the inseparability of human and natural systems, aiming to design with, rather than against, nature.'

Melissa Poon (among others) applied the concept of symbiosis to design within the field of architecture and investigated the relationship between humans and ecosystems in her PhD thesis "Design for Symbiosis", focusing on fostering harmony between built environments and their natural surroundings. In her approach, symbiotic design emphasizes the integration of technological and biological systems, aligning architectural elements with natural processes to promote mutual benefit and long-term ecological balance (Poon, n.d.).

Combining this concept with systemic design principles, complex adaptive systems theory, socio-ecological resilience theory, and the network approach creates a new conceptual framework for symbiotic systemic design. In this research, symbiotic design is defined as a systemic design approach that addresses and integrates several problems and solutions and the needs of different sectors and disciplines on multiple scales to create a symbiosis between humans and nature.

CONCEPTUAL FRAMEWORK

This research seeks to find a balance within the water system to achieve socio-ecological resilience. The symbiosis concept lies at the center of the interrelation between humans and nature (see Figure 22) and facilitates this balance. In this research, symbiotic design forms the intersection of human (often technical) occupation activities and networks and ecological (landscape, climatic) processes by addressing the water system holistically. It aligns human systems with natural processes, works across scales, and incorporates perspectives from multiple disciplines. Additionally, it integrates socio-ecological and technological systems to create mutually beneficial interactions across water using sectors within the socio-political and territorial context of the region. Therefore, it is a concept used to understand the complex adaptive nature of the water system, the socio-ecological interrelations of the system's components, and a method used for the integral and holistic design of the system's transition.

This research focuses on the three layers of the network approach as the main components of the water network. Therefore, the analysis of the layers has defined the different sectors included in this framework: the agriculture sector, the urban (and tourism) sector, and nature as a sector. By aiming for a symbiosis amongst these sectors, through the implementation of sustainable agriculture, tourism, and integrated water management, socio-ecological resilience is shaped.

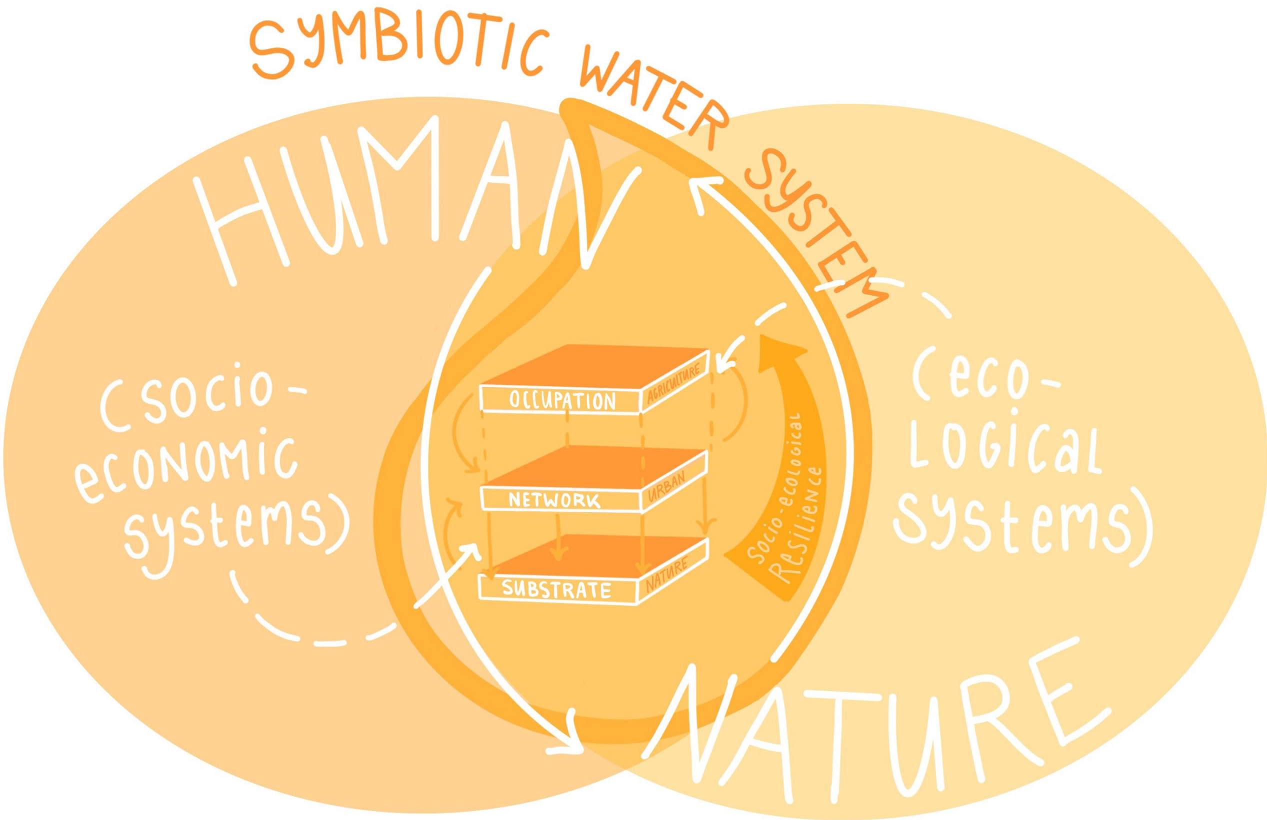


Figure 22. Conceptual framework for a symbiotic water system.
Source: made by author.

METHODOLOGY

INTRODUCTION

For this research, a combination of multiple methods is used, where each method is altered or used to complement the other, in order to create a new method for regional symbiotic strategic design of the water system transition. This method is developed as a holistic approach for strategic design for systemic change in the water system of arid agricultural production regions, while examining the case of the Segura River Basin. The method resulted as an output of a Research by Design (RD) process, which is the overarching method used for the creation of this thesis. The final output of this thesis is a strategy for symbiotic design of the water system transition in the Segura River Basin region, consisting of a symbiotic strategic design suggestion for the region, a pattern language of symbiotic design interventions, and a reproducible method for symbiotic design of a regional strategy for the water system transition in arid regions of agricultural production.

The report is structured in chapters, each of which aims to answer a sub-research question. Together, the answers to the sub-research questions create the final methodology, part of an iterative research-by-design process that incorporates multiple methods.

RESEARCH BY DESIGN (RD)

Research by Design is a method that is led by design practice, exploring knowledge through an iterative design process, rather than testing a pre-defined hypothesis (Cross, 2007). It enables designers to bridge conceptual thinking and design practice (De Jong & Van der Voordt, 2002), to discover systemic relationships, test spatial implications of concepts or ideas, and generate integrative solutions through a creative process (van Dooren et al., 2014). In this thesis, research by design forms the central approach to bridging the conceptual framework of symbiotic design with practical design tools, such as the Pattern Language.

MAIN RQ - SYMBIOTIC REGIONAL DESIGN

The methodology for a symbiotic regional design strategy for the water system transition is created in this research and forms a part of the answer to the main research question:

"How could symbiotic systemic design be used to develop pathways for the sustainable water system transition, contributing to water security and a socio-ecologically resilient future for the Segura River Basin?"

The main methods used to create this methodology are the Pattern Language method (PL), the Dynamic Adaptive Policy Pathways (DAPP), and Research by Design (RD).

The conceptual framework for symbiotic regional design (Figure 22) is used for the design of the strategy. Several layers of symbiotic design, derived from an iterative research by design process, are incorporated to integrate a symbiotic aspect.

SYSTEMIC SYMBIOSIS

The overarching layer of symbiosis is called Systemic Symbiosis. It represents the integration of the theories and methodological approaches presented before, which is shown in the conceptual framework. It refers to the integration of human- and natural processes within the water system to achieve socio-ecological resilience in the form of a mutually beneficial relationship between human and natural well-being. Systemic Symbiosis is achieved when all the layers of the water system work in harmony together and form a resilient system. It is therefore the aim of the thesis' output.

SYMBIOTIC INTERVENTIONS

The second layer of symbiosis is called *Symbiotic Interventions*, and refers to a design principle that is used, where only symbiotic design interventions (interventions that contribute to multiple design objectives at the same time) are chosen for the pattern lanugage and applied in the strategy. The aim of this symbiotic layer is to identify and select the most beneficial interventions, that are supported by various stakeholders.

SECTORAL SYMBIOSIS

The third layer of symbiosis in the framework is *sectoral symbiosis*, which is defined in this research as the aim of designing a balance between the needs of different stakeholders involved in the water system transition. To be able to design for *Sectoral Symbiosis* in the study region of the Segura River Basin, a scenario framework is created on the basis of a stakeholder analysis and the integrated analysis conducted in the analysis chapter. The sectors combined in the scenario framework represent the stakeholders of the region and their conflicting interests.

Each sector would prefer a different set or sequence of symbiotic interventions, and therefore, three scenarios are constructed that each combine the preferred interventions of two of the three sectors. Through the spatial overlapping and comparison of the different scenario outcomes, a set of sector symbiotic interventions is selected for the water system transition in the region. The concept of sectoral symbiosis through scenarios, and the scenario framework, are further explained in the design chapter.

SYMBIOTIC PATHWAY

The final layer of symbiosis is called the *Symbiotic Pathway*, and is aimed at finding a middle ground option for conflicting interventions and points of decision in the adaptive policy pathway system. Originally, whenever an intervention reaches its end date, a switch to another intervention pathway must be made to reach the vision. However, these pathways are often preferred by one sector and would not be chosen by another. With the suggested *Symbiotic Pathway* approach, a different method is proposed, where a synthesis of the possible pathways is aimed for by integrating the different possible interventions of the pathways that can be chosen from, and forming new connections between them. This requires a strong design aspect and a thorough analysis of the possibilities and constraints in the context of the region of implementation.

How the methodological steps of the symbiotic layers come together, is set out in the methodological framework.

METHODOLOGICAL FRAMEWORK

This framework (Figure 23) contains a brief overview of the different methods used, why they are used for this research, and how they are used, by setting out the methodological steps in the form of sub-research questions. Further explanation is given in the various chapters as answers to the sub-research questions.

RQ1 – INTEGRATED ANALYSIS

The main method used for the first sub-research question is an integrated analysis consisting of a spatial and non-spatial part. It includes a combination of sub-methods (see Figure 23), and is aimed at defining and mapping the systems' components and their interrelations, according to the socio-ecological metabolism and complex adaptive systems theories. This is done following the network approach, dividing the system into three layers. For the spatial part of the analysis, a GIS spatial analysis is performed, and satellite and fieldwork observations are used. Synthetic mapping, GIS mapping, and hand-drawing are used as sub-methods to translate information into maps. For the non-spatial part of the integrated analysis, a diachronic analysis, literature study, policy document review, and media analysis are combined in the form of desk research. Additionally, a literature review is conducted to understand the historic water management of Spain and the study region in particular.

RQ2 – VISION MAKING

For the second sub-research question about translating the analysis conclusions to a vision for the region, the method used is vision making.

VISION MAKING (VM)

Vision Making emerged as a method in spatial planning in the late 20th century, as a critique of master planning in blueprints. Hajer and Zonneveld (among others) (2000) emphasised the need for strategic, imaginative visions to guide long-term territorial transformation. The method allows designers to explore desirable futures, shape collective ambitions, and frame complex challenges and uncertainties. It works as an imaginary and communicative tool to shape a common desired goal to which decisions can be coordinated.

Desk research, a policy document review, a literature study, and the synthesis of the analysis are combined to define a vision for a symbiotic future of the water system in the region. The vision consists of three main transitions and several objectives within those transitions, considering the wishes of multiple stakeholders in the analysed region.

RQ3 - PATTERN LANGUAGE

The main method for the design aspect of this research is a pattern language for symbiotic regional design strategies for a socio-ecologically resilient water system in arid regions of agricultural production, tailored to the Segura River Basin region.

PATTERN LANGUAGE (PL)

The Pattern Language method was introduced by Christopher Alexander and others in: A Pattern Language: Towns, Buildings, Construction (1977) and the Timeless Way of Building (1979). Ever since, it has been gaining popularity as a design approach among designers to help understand, communicate, and address the interconnected solutions to multi-layered complex challenges. It bridges the gap between theory and practice and forms a communication tool for participatory design with various stakeholders. The elements of a pattern language are entities called patterns, which present solutions to problems in the system that is addressed. The patterns are ordered in a pattern field according to the connections that can be made between the patterns. Creating the pattern field and selecting the patterns to be included is a subjective design process, which is performed by everyone differently, and is never finished. Christopher Alexander (1977) emphasised the need for a society-wide process where people will gradually become aware of their own languages:

"We believe.... that the languages which people have today are so brutal, and so fragmented, that most people no longer have any language to speak of at all and what they do have is not based on human, or natural considerations."

The output of the third sub-research question forms the basis of the pattern language. First, a precedent study is conducted, in combination with desk research, fieldwork observations, and a literature study. These methods are used to create a list of possible symbiotic interventions for the problems identified in the integrated analysis of the region. Out of this list, a catalogue of symbiotic solutions is created, in the form of a pattern language for symbiotic regional design for the transition of the water system in the region.

RQ4 – SCENARIO BUILDING

Scenario building is used as the main method for the fourth sub-research question.

SCENARIO BUILDING (SB)

Scenario Building is a key method for spatial designers to explore possible futures, considering complex uncertainties. It is developed to enable organisations, planners, and decision-makers to anticipate and prepare for a range of possible futures, to be able to adapt to new conditions and create resilience through uncertainty (Schwartz, 1991). Furthermore, scenario building is argued to form an essential tool for synthesising knowledge and facilitating a creative exploration of alternative futures, to inform adaptive interventions in dynamic environments (van der Heijden, 1996). Considering the complexity of the interrelated layers and conflicting stakeholder perspectives within the water system, developing future scenarios that deal with these uncertainties is crucial to be able to form a symbiotic strategy.

To develop the pattern language further and tailor it to the spatial and non-spatial conditions of the basin, the interventions are tested in three different sector symbiotic scenarios for a sustainable water system in the region. A scenario framework is created to discover symbiotic relationships on all layers of the system and between the different sectors.

RQ5 – STRATEGY MAKING

For the last sub-research question, strategy making and the Dynamic Adaptive Policy Pathways method are used to translate the use of the pattern language into examples of strategic symbiotic design strategies for the water system in areas of sector symbiotic conflict.

STRATEGY MAKING (SM)

Rather than developing a master plan for top-down spatial planning, strategy making enables designers to map out flexible, adaptive pathways toward desired futures (Mintzberg, 1994; Albrechts, 2004). It structures the relationship between short-term interventions and long-term visions, while adapting to changing spatial, political, or ecological conditions. Especially when working on complex systemic transitions, strategy making enables the integration of scales, timeframes, and stakeholder perspectives into an integrated research and design approach (Healey, 2007).

DYNAMIC ADAPTIVE POLICY PATHWAYS (DAPP)

The Dynamic Adaptive Policy Pathways method, designed by Haasnoot and others (2013), is aimed at helping designers and policymakers deal with uncertainties in planning for future decision-making. It proposes different pathways to a desired future, while giving insight into lock-ins and future dependencies of choices and actions. It stimulates planners to consider adaptation of plans over time, and could be used to create the right political circumstances to achieve the desired future goal. The method consists of 10 steps, the main results of which are a catalogue of effective possible actions, adaptation pathways that form sequences of these interventions, preferred pathways within the overview of policy pathways, and a dynamic adaptive policy strategy. Scenario planning is used to test and adjust the intervention catalogue.

In this research, the strategy that is created not only includes policy recommendations, but also spatial interventions. Therefore, the DAPP method is combined with the Pattern Language, where the sequences in pattern choices from the pattern-web form the adaptation pathways.

RQ

"How could **symbiotic systemic design** be used to develop **pathways** for the sustainable **water system transition**, contributing to **water security** and a **socio-ecologically resilient future** for the **Segura River Basin**?"

RQ1.

"What elements, processes and interrelations define the water system in the Segura River Basin, and how have governance structures historically influenced its resilience?"

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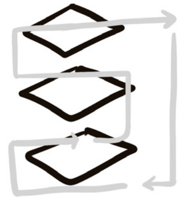
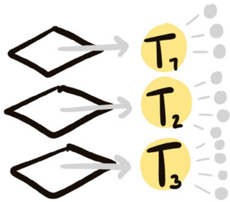


RQ2.

"What vision for a sustainable future water system in the region can be created from the analysis conclusions?"

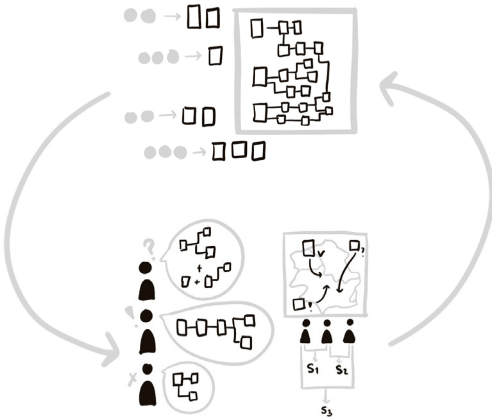
VM PR



RQ3.

"What symbiotic solutions can contribute to the vision of a socio-ecologically resilient future water system in the region, and how can they be organised according to the vision framework?"

PL RD PS



RQ4.

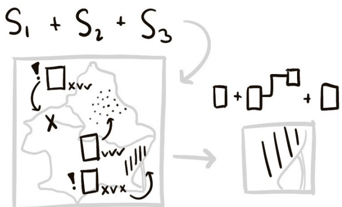
"How does testing these solutions through sector symbiotic spatial scenarios inform symbiotic pathways for the strategic design of the water system transition?"

SB DAPP RD SA

RQ5.

"What strategic projects for a sustainable water system in the region can be derived from comparing the scenarios, and how can they create a symbiotic adaptive pathway?"

SM DAPP RD



OUTCOME:

A systemic overview of the interrelated problems and causes of water scarcity in the basin, identified transitions for systemic change, and leverage points for societal change.

OUTCOME:

A vision for the transition of the water system in the region with design objectives, and a symbiotic design vision framework.

OUTCOME:

A pattern language for symbiotic strategic design of the water system transition in an arid region of agricultural production.

OUTCOME:

Sector symbiotic scenarios for strategic design of the water system in the SRB region, no-regret measures, and conflicting spatial implications of scenario specific interventions.

OUTCOME:

Design experiments of strategic projects that form symbiotic pathways in areas of conflicting spatial implications, including policy recommendations and a phasing of interventions over time. These symbiotic pathways with the no-regret measures combined, form the final regional strategy.

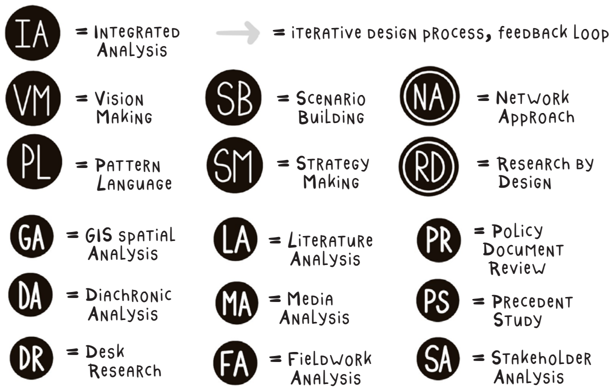


Figure 23. Methodological framework of the thesis research.
Source: made by author.

ANALYSIS OF THE WATER SYSTEM

Figure 24. Image of the TST water supply canal amidst the greenhouse agriculture of Campo de Cartagena. Source: image made by author.

HISTORIC WATER SYSTEM
INTRODUCTION

In this chapter, the history of the water system in the Segura River Basin is set out. To do this, the history of water management, land use changes and overexploitation is examined for the case of the Segura River Basin. This integrated analysis is based on the three identified layers of the network method: the Network layer (water supply infrastructures), the Occupation layer (water demanding land use and the changes over time) and the Substrate layer (the effects of human actions on the natural environment).

Figure 25. Image of the TST water supply infrastructure amidst the greenhouse agriculture of Campo de Cartagena. Source: Made by author.

WATER GOVERNANCE IN SPAIN

A LITERATURE REVIEW

INTRODUCTION

In the first 80 years of the previous century, the agricultural and hydropower sectors drove Spain's water policy. Centralised and state-driven water infrastructures were built without social or environmental concerns.

National water resource governance in Spain has undergone scalar reorganisations throughout history, which have been studied by many (Swyngedouw, 1999; Lopez-Gunn, 2009; Thiel, 2015, Fornés et al., 2021). The EU Water Framework Directive has emphasised the importance of river basin water management, indicating a more polycentric and decentralised approach to water governance. However, especially in the case of Spain, national governance and politics have a high power and influence on water management, and economic uses based on access to water seem to dominate over the ecological state of the waterbodies (Thiel, 2015). Every four years, a new government gets elected democratically, and the political changes influence the plans and focus of national (and thus regional) water management. Usually, socialist governments tend to prioritise environmental sustainability, while conservative governments have supported large-scale infrastructure projects throughout history, with a focus on economic benefits.

Since the 21st century, with the election of a new socialist government, the Spanish governmental strategy based on large-scale inter-basin water transfers as a response to water scarcity has shifted towards an approach that promotes mainly desalinated water and reused water to improve the water supply. This focus on increasing non-conventional water resources is not only to increase water availability, but also a strategy to replace water transfers and avoid controversial socio-ecological, socio-economic, and socio-political issues (López-Ruiz & González-Gómez, 2023).

A historic analysis is needed to understand the socio-political context of water management in Spain. In this paragraph, a timeline of the political history of water management in Spain is presented and discussed through a literature review. The main conclusions are summarised afterwards.

HYDROGRAPHIC CONFEDERATIONS

Spain was one of the first countries in the world to start with river basin management and planning with the creation of river basin agencies in 1926 (Estrela & Ministry for Ecological Transition and Demographic Challenge, 2023). The Hydrographic Confederations (River Basin Authorities) were meant to advance the state-led Hydraulic Mission on a regional scale.

HYDRAULIC MISSION

The Hydraulic Mission started during the period of Regenerationism in the 20th century, a paradigm where water was seen from a modernist perspective as a tool to drive economic growth and development (Fornés et al., 2021; Swyngedouw, 1999). Irrigation agriculture was seen as crucial for Spain's socio-economic development and self-sufficiency in a climate of extremes of droughts and floods. Therefore, in 1888, the state started sponsoring irrigation with subsidies. Social divisions between the rural poor and the elites with rights to water access would be bridged through the modernisation of agriculture by reforming the geographical landscape. The rationale that technology could re-design nature with the construction of canals, dams, and reservoirs was therefore promoted through the state (Lopez-Gunn, 2009; Swyngedouw, 1999). Water scarcity was not seen as a natural, geographical phenomenon, but as a mission to correct the unfair differences between the 'wet' North and the 'dry' South (Lopez-Gunn, 2009; Swyngedouw, 2007).

Regenerationist ideas were implemented with Plan Gasset in 1902 by creating Hydrological Divisions (River Basins) based on natural river boundaries as new power regions. However, this seemed to be more difficult. In 1933, the first water plan of national scale, called the National Plan of Hydrological works, was developed by Lorenzo Pardo (see Figure 28), supported by Indalecio Prieto, the minister for Public Works (water infrastructures). According to the plan, 1.75 million hectares of agricultural land had to be irrigated by constructing 215 dams, canals, and irrigation districts (Lopez-Gunn, 2009). As a part of the Hydraulic Mission, colonisation turned land-inwards in 1939 during the Instituto Nacional de Colonizacion (INC). Villages (289) were created from scratch, and land was given to the people "to colonise and irrigate" in response to the newly built water infrastructures. Furthermore, the INC developed irrigation infrastructures and promoted groundwater use and wetlands drainage (Bosque, 1984).

During the Francoist regime, which was considered a dictatorship by many, the construction of dams and reservoirs continued throughout the whole country to provide hydropower and irrigation water (Fornés et al., 2021; Lopez-Gunn, 2009). Over time, the social objectives (decentralisation of power and participation methods) of the Regenerationist ideals vanished, and the focus on conquering the landscape remained (Lopez-Gunn, 2009). In total, 800 reservoirs were built (in 2000, there were 1200 existing reservoirs). After the economic growth of the 1960s, competition for water escalated due to the increase in agricultural land, urban developments, industrialisation, and tourism (Ibor et al., 2011).

PARADIGM SHIFT

In 1972, the Stockholm meeting on Human Environment was held, which is seen as a turning point in the governance paradigm. It promoted new ways of envisioning state policies, based on the environmentalist movement and enhanced public awareness. Since the 1970s, a public awareness of water as a crucial element of the landscape and ecosystems has slowly emerged due to European influences. This was the start of a new democratic regime. This new regionalist hydraulic paradigm resulted from decentralisation, European (top-down) influences on Spanish water policy, and an increased acknowledged importance of the regional territory, identity, and water control (Lopez-Gunn, 2009).

Figure 26. Ojo dam of the TST. Source: (Meseguer et al., 2018)

The Water Act of 1985 was a turning point in the Spanish water policy (Ibor et al., 2011). It introduced the law that water can be publicly owned. Groundwater also became a public good, and treated wastewater reuse was legally recognised. The confederations (river basin authorities) monitored the water domain, controlled compliance with concessions, and imposed sanctions (Avellà & García Mollá, 2008). As a part of the Water Act of 1985, participatory water management strategies became operative in 1990 through new boards in the river basin agencies: the Government board, the Reservoir board, and the Public Works Commission. In addition, the Water Act involved the obligation to elaborate a National Water Plan.

The 1993 National Hydrological Plan (HNP) of the socialist government included the National Water Balance Integrated System, a revised program of the National Plan of Hydrological Works in 1933 (Blomqvist et. Al, 2005; Lopez-Gunn, 2009). In this plan, all river basins in the Iberian Peninsula were to be connected with a transfer capacity of 4000 Mm3 (see Figure 27). Principles of solidarity formed the HNP: to give water resources to those lacking, thus contributing to the country's wealth, employment, and cohesion; to provide money and subsidies to compensate for the spatial and environmental impacts of the transfers needed. However, due to delays and opposing votes because of new democratic movements, the plan was eventually cancelled.

The National Plan of Sanitation and Water Treatment (PNSD), which was constructed in 1995 (but only approved in 2005), was the start of large-scale water purification, increasing the total volume of treated wastewaters by 0.18 m3 /inhabitant/day (Jodar-Abellan et al., 2019). With a total budget of 11.4 billion euros, 700 wastewater treatment plants were constructed throughout the country (López-Ruiz & González-Gómez, 2023). At the same time, the irrigation of golf courses with regenerated water began. The construction of plants with tanks to reuse water for agriculture in Murcia started already in 1980 (López-Ruiz & González-Gómez, 2023).

In 1996, the White Paper, an analysis of and critique of water resources and water policies in Spain at the time, was presented by the new conservative government called The People's Party (MIMAM, 2000; Lopez-Gunn, 2009). It was intended to improve the information available on water for public discussion and address new models for managing water allocation and demand.

During the Albufeira Convention, Spain and Portugal cooperated to solve water issues through transboundary basins. Furthermore, the First Iberian Congress on Water,

Figure 27. National Hydrological Plan of 1993. Source: (Source: YA Newspaper 19.1.1993), adapted from (Lopez-Gunn, 2009)

Figure 28. Plan of the TST in 1933 Public Works Plan. Source: (Lorenzo-Pardo, 1933), adapted from (Lopez-Gunn, 2009)

held in Zaragoza in 1998, has given rise to a social movement through the New Water Culture (NWC). The NWC aimed for holistic water management: economic, ecological, social, sustainable, equal, and democratic. According to the NWC, water had to be seen as 'life' instead of a 'means of production' (Tabara and Ilhan, 2008, in Lopez-Gunn, 2009). The new democracy was urbanised, and the beauty of the rural Mediterranean landscape was rediscovered. A new liberal state rationale and logic started to question the large water infrastructures, as the technological knowledge had to be justified by participants with power under the democracy (Water Councils, the Parliament, the Senate, and the National Water Council). Questions that arose were, for instance, Who pays? Who benefits? Is the plan economically beneficial, environmentally sustainable, socially justified, and equitable? (Lopez-Gunn, 2009).

The EU Water Framework Directive (WFD) has driven the remodelling of Spain's water management paradigm since the 21st century by striving to re-establish a balance among the three sustainable development aspects. Therefore, it addresses the neglected component of the environment. According to the WFD, EU countries must achieve good water status for all water systems, including groundwater systems, by 2027 (EU 2000/60/EC).

POLITICAL POWER

In 2001, the New National Hydrological Plan was constructed. The new NHP became law within 7 months due to the conservative government of that time. It passed quickly through the different democratic structures, because it included the proposed Ebro transfer of the previous central government as a political return (Albiac et al., 2006, in Lopez-Gunn, 2009). The Ebro transfer was initially planned to move 6% of its annual flow (from that time) from the Ebro River to the Segura River Basin. Additionally, the plan included the construction of more than 100 new dams (McFall, 2002 in: Lopez-Gunn, 2009). Due to the new socialist government of 2004, the transfer proposal from the Ebro to the Segura river was cancelled for technical, economic and environmental reasons, and socio-political conflicts between regions. One of the reasons was that it did not comply with the EU regulations of conservation. A social movement emerged, calling for a New Water Culture against the New National Hydrological plan of 2001, based on restoring the ecological status, demand management, accountability, and participation (Lopez-Gunn, 2009).

NON-CONVENTIONAL WATER SUPPLY

Instead, the desalination program AGUA started: action for water management and use. The program focused on desalination as an alternative to water transfers, and another attempt to address water scarcity. With 621 Mm3 of desalinated water, the Ebro transfer of 1000 Mm3 was to be replaced. Between 2004 and 2008, 34 desalination plants had to be built, and national wastewater reuse had to be more than doubled. Additionally, the plan included demand-management policies such as the reform of water confederations, promoting citizen participation, charging water in accordance with the costs of obtaining and treating water, creating public banks to reallocate historical water rights, and improving management and water quality control (Ibor et al., 2011). Unfortunately, the AGUA program was too expensive, and the water reuse goals were not met because of the economic recession. Additionally, there were a few wet years in Spain during this period, so there was a lack of political interest in funding the desalination program.

The UN Human Rights Commission in 2007 showed concerns about urbanisation and, in particular, the rapidly growing tourism along the Mediterranean coast. At the same time, The Royal Decree (RD), a specific regulation in Spain about the legal framework for water reuse, was set up by several Ministries (The Ministry for the Environment, Agriculture, Food and Fisheries, Public Health and Consumer Affairs), the National Water Council, local authorities and autonomous communities (López-Ruiz & González-Gómez, 2023). The RD defines what should be understood by reuse and distinguishes between treated and regenerated water. Because there were no Europe-wide regulations on the governance of regenerated water, Spain was a pioneer in this. Also in 2007, the National Water Quality Plan: Sanitation and Water Treatment (PNCA) was approved. The PNCA stated that 34% of the total wastewater volume that could be treated in 2015 (1200 hm3/year of the total 3500 hm3/year) would be available for reuse (López-Ruiz & González-Gómez, 2023). However, due to the economic crisis of 2008, most investments were avoided.

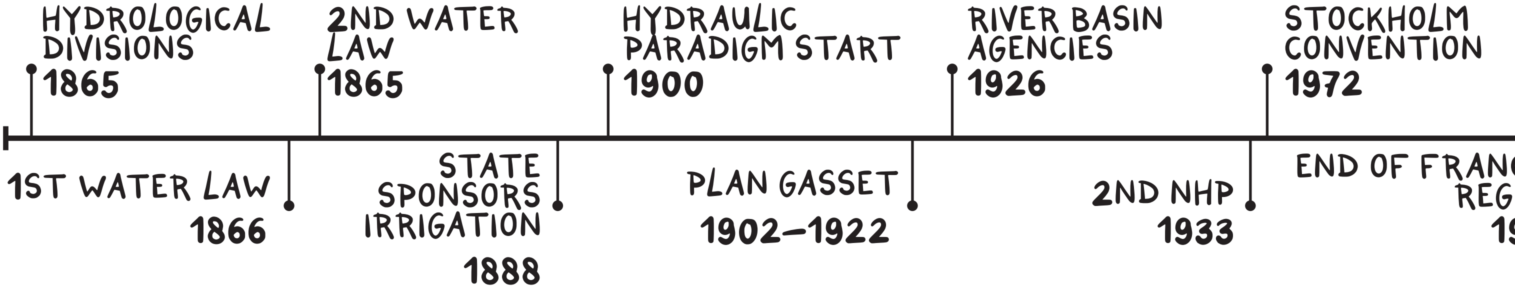
The first cycle of the River Basin Management Plans (RBMPs) from 2009 to 2015 implemented the requirements of the EU WFD. The government's CRECE Plan, launched in 2014, invested in 400 water treatment plants to improve river water quality by purifying waters from city sanitation networks (López-Ruiz & González-Gómez, 2023). The second cycle of the RBMPs from 2015 to 2021 updated water allocation strategies and environmental flow standards. In 2019, the Green Book on Water Governance was launched, a platform to involve locals and improve water management.

The National Water Reuse Plan of 2010 (PNRA) tried to involve the River Basin Organisations and autonomous organisations in implementing infrastructures related to wastewater treatment, storage, and transport of regenerated water. However, regeneration projects were not the government's priority at the time, and the replacement of water transfers with non-conventional water projects largely failed (López-Ruiz & González-Gómez, 2023). In 2018, Spain received a fine from the ECJ for non-compliance with the 1991 Directive on wastewater treatment.

The DSEAR plan (the National Plan for Purification, Sanitation, Efficiency, Saving, and Reuse) was approved in 2021 as an update of the AGUA plan. The plan's main objective was to complete the investment policy necessary to comply with the requirements of the European Commission in the field of sanitation and water purification. The plan includes challenges and proposals for the promotion of reused water. Creating a generation of trust and social acceptance of regenerated and reused water is a crucial component of the plan (General Directorate of Water, 2020a and b, p. 30). To do so, a proposal to carry out a communication campaign to the public about reused water is included, together with a proposal to develop a reuse section on the MITECO website that is accessible to the public. The regulatory and financial framework for reuse is to be improved to remove institutional and financial barriers that limit the use of reused water. Lastly, the pressure on critical water bodies is to be relieved by prioritising reuse actions that aim to achieve a good status in water bodies (Government of Spain, 2021a and b).

In the Circular Economy Action Plan of 2021, the reuse and purification of water are incorporated. A new irrigation policy of the Ministry of Agriculture, Fisheries and Food is included that prioritises funding of projects that allow replacing the extraction of surface or groundwater with regenerated water (López-Ruiz & González-Gómez, 2023). The fifth final provision of Royal Decree-Law 4/2022, of March 15, which adopts urgent measures to support the agricultural sector considering the drought, provides the approval of a "Shock plan for the optimisation of water resources in the Mediterranean basin". This plan promotes non-conventional resources through the use of already existing pipelines and is aimed at keeping the water prices affordable for irrigators (CHS, February 2025).

In May 2023, the government announced an investment of 2.2 billion euros to tackle the drought. 1.4 billion euros were reserved for supporting irrigators and increasing water supply with new infrastructures such as desalination plants. The aim is to double the amount of reused wastewater, in compliance with the Water Law (Lassman, 2024). The Water Law was modified to solve regulatory, financial, and technical barriers related to increasing the volumes of reused wastewater and adapting to the EU regulations (Estrela & Ministry for Ecological Transition and Demographic Challenge, 2023).



CONCLUSION

During the Hydraulic Mission of the last century, water policies to increase water supply for irrigation in the semi-arid Southeast (the region most suitable for irrigation) were the main asset of Spain's economic regeneration (Ibor et al., 2011). Therefore, the previous century formed a paradigm of exploitation and resource allocation for economic profit, characterised by the build-up of large-scale inter-basin water transfer infrastructures.

Since the 21st century, there has been a paradigm shift towards a more multidimensional water governance (Fornés et al., 2021). This governance change is directed towards environmental preservation, efficiency, and water savings. It includes new water sources such as desalination, re-use, and managed aquifer recharge, trying to address the demands of an urban and service-based economy. This requires encompassing social, cultural, economic, ecological, and political transformations with complex interactions (Rotmans, 2005). Social equity and environmental justice are newly arising topics, especially regarding water transfers. These infrastructures are at the top of the political agenda, as socio-ecological conflict is rising due to droughts, an increased awareness of environmental degradation, and the effects of climate change. However, the political value of water has intensified further because elected politicians appreciate the value of powerful hydraulic systems with access to and control over water in electoral terms (Lopez-Gunn, 2009).

Efforts have been made to increase the national water supply, such as desalination and reuse. However, the EU regulations have not been met in Spain due to management challenges, a lack of social acceptance, and a lack of funding.

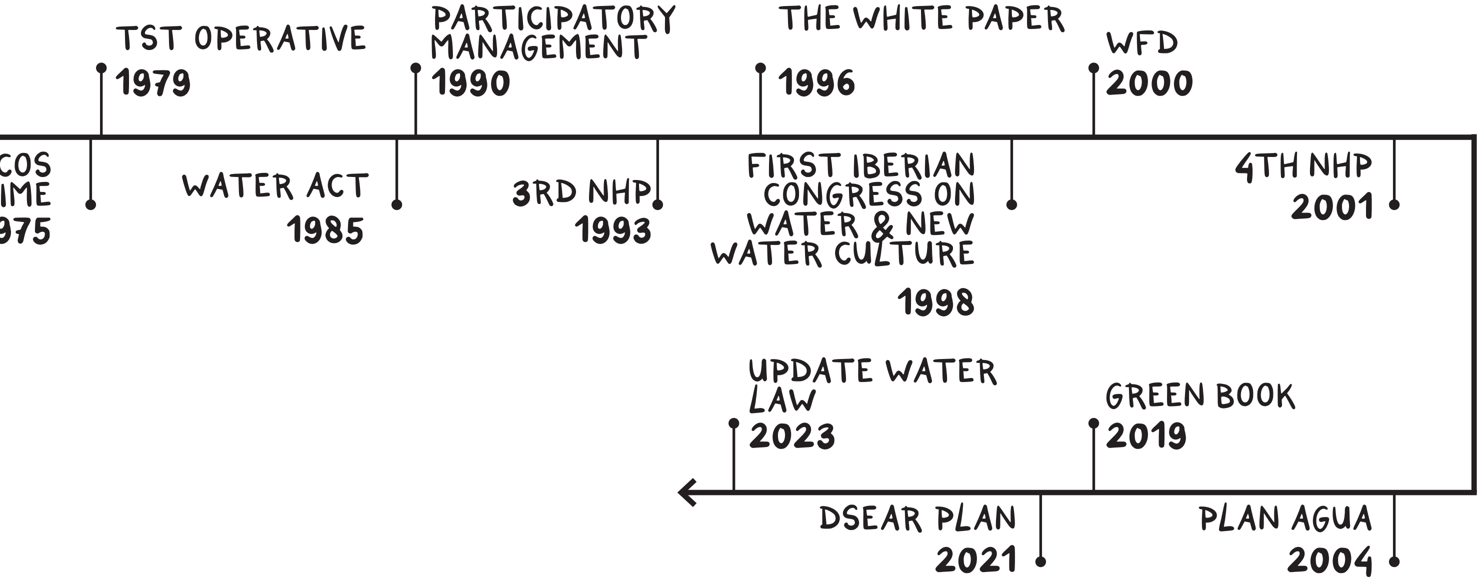


Figure 29. Timeline of historic events in Spanish water governance

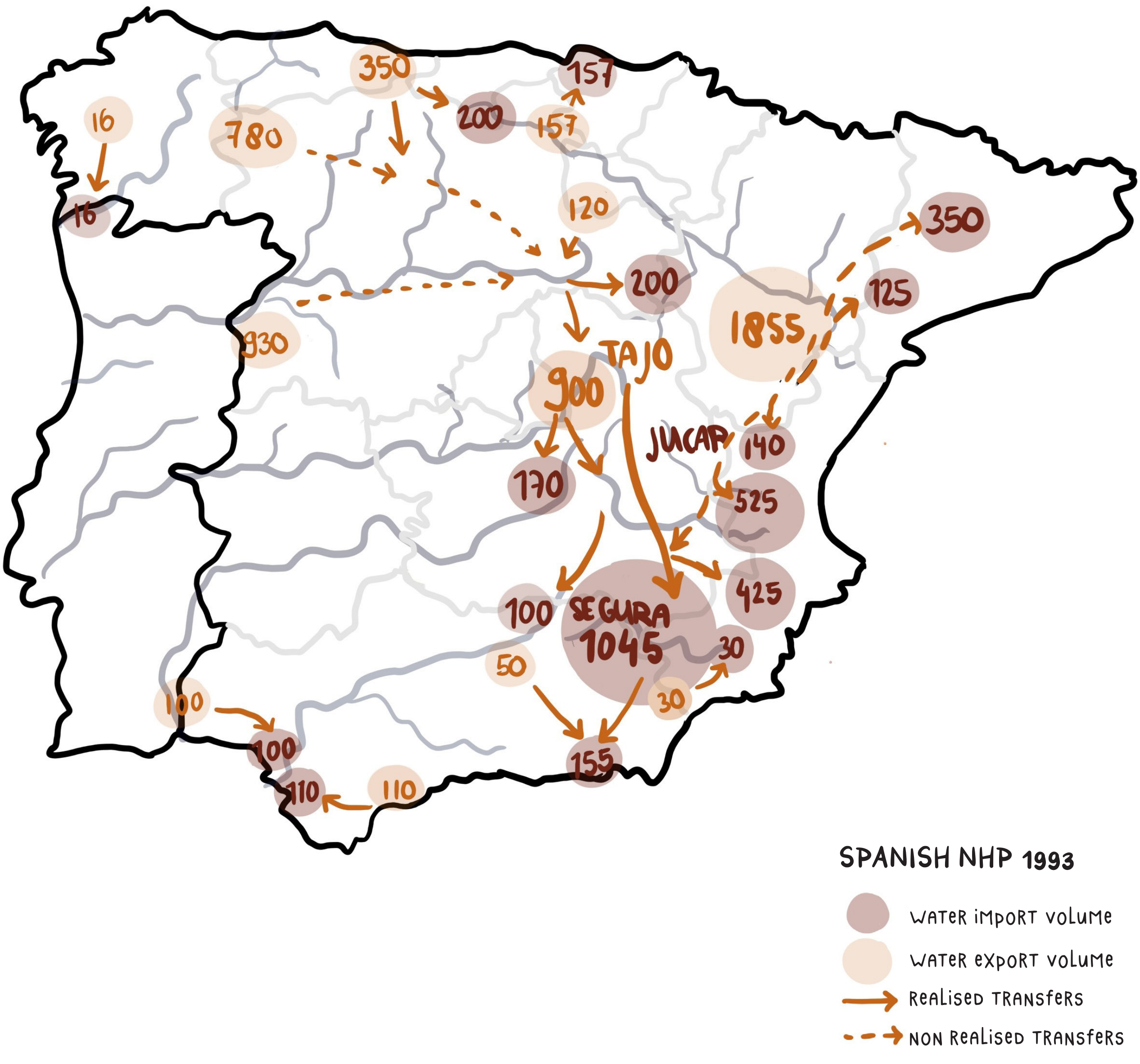


Figure 30. Planned volumes of water through transfers from the Spanish NHP 1993. Source: Made by author.

INFRASTRUCTURES
TAJO-SEGURA WATER TRANSFER

TAJO-SEGURA TRANSFER COURSE

The most prominent infrastructure in the basin is the Tajo-Segura water transfer (TST) and its canal system that covers 315 km. The infrastructure was initially designed in 1902's Plan Gasset. However, it was eventually built in 1967, and became operative in 1979. The transfer now provides 2.5 million inhabitants (and 3,5 million people in the summer season) with drinking water in the provinces of Murcia (57%), Alicante (42%), and Almeria (1%), and irrigation water for 55 municipalities.

The transfer starts at the Pantano de Entrepeñas and Pantano de Buendía, where the Tajo-Segura canal and the Riansares and Ciguola aqueducts transport the waters from the Tajo and Guadalajara rivers to the Bujeda reservoir, where it is pumped up to a height of 245 meters, through a length of 1070 meters. Afterwards, the water reaches the Alarcon reservoir. From there, the Fuensanta and the El Picazo canals transport a part of the water to Valencia, following the Jucár river. The rest of the water moves through the Tajo-Segura aqueduct and a 32 km long tunnel to the Talava reservoir, meeting the river Mundo. From here, the water reaches the Camarillas reservoir, which meets the Segura River. This point of the transfer

Figure 31. Course of the TST in Spain. Source: by author.

characterises the start of the irrigation water supply for the Segura River Basin. The river brings the water to the Ojo station, one of Europe's biggest water pumping stations, as it pumps 24 m3 of water per second to a height of 150 meters. Furthermore, it divides the canal into two directions. The left-hand side of the canal provides irrigation water for the irrigation communities of Riegos de Levante, in the province of Alicante, and Campo de Cartagena in Murcia. The right-hand canal flows through tunnels and aqueducts to reach the Embalse del Mayes, where the Guadalentin valley gets its irrigation water. Afterwards, the canal reaches the irrigation district of Almanzora in Almeria (SCRATSregantes, 2013).

TAJO-SEGURA TRANSFERRED VOLUMES

As a result of poor water management, political issues, and a lack of control over irrigation expansion, a structural water imbalance has been created in the SRB, starting with the promise of the Tajo-Segura transfer. When planned, a transferred volume of 1000 hm3/year was promised. However, political pressures against the transfer increased with the upcoming of democracy in 1978, leading to a political decision to reduce the amount of water transferred. Additionally, poor management of the Tajo reservoirs, where the two main basins (Entrepeñas and Buendia) were entirely emptied between 1979 and 1983, led to a physical reduction of the water to be transferred, as well as extra cuts (Ibor et al., 2011).

When the transfer became operative in 1979, the promised 600 hm3/year (at the time) was not met. The structural imbalance was identified already in 1988 with the hydrological 'Plan de Cuenca' (CHS, 1988). From 1992 to 1995, after a period of drought, the CHS confirmed that the transferred water could no longer be used to irrigate new agricultural areas by prohibiting informal water abstractions (Martinez-Fernandez & Esteve-Selma, 2004 & 2005). However, it was too late, as the irrigated area had expanded and farmers had invested in new irrigation systems.

In 1979, the Tajo-Segura transfer became operative. However, the government announced that the Tajo watershed administration would only transfer water that was considered a 'surplus', igniting debates and increasing conflict between users and political powers of the Tajo and the Segura basins about the amount of water to be allocated. According to the 1917 Law of Common Use, the 600 Mm3 that was to be transferred included 385 Mm3 to the agricultural sector, 83 Mm3 to the urban sector, and 132 Mm3 was seen as losses. The 1980 Law (52/1980, October 16) of the Economic Regime regulates the economic regime for the exploitation of the TST and the rights of irrigation use. It modified the volume to be transferred to 400 Mm3 for the agricultural sector, 110 for the urban sector, and just 90 Mm3 for losses. However, only an average of 348 Mm3 has been transferred historically, about a third of the total infrastructural capacity (Ibor et al., 2011).

DRIP IRRIGATION

Due to the disappointment of less water transferred than promised, farmers in the SRB area turned to other water sources, such as groundwater extractions. The agriculture sector invested in water-saving technologies, such as drip irrigation, which reached 53% of the irrigated area in the region by 1999 (INE, 1999; Ibor et al., 2011). From 1983 , new irrigation areas were supplied with transferred water or groundwater and provided with technical, water-saving irrigation systems such as drip irrigation. Drip irrigation is a water-saving technology that aims to improve the water supply guarantee, reduce groundwater abstractions, and reduce pumping costs. It has been developed to provide crops with just the right amount of water all year round.

The generalisation of drip irrigation systems was developed with financial support from the Ministry of the Environment and Rural and Marine Affairs and the state-owned company ACUAMED, and operationalised by the public company SEAIASA to improve and consolidate irrigation systems (Ibor et al., 2011). According to the financial framework, farmers contribute 30% to the investment, 24% gets funded by the EU, and 46% is funded by Spanish public funds or SEAIASA, together with regional governments. Regional governments often award subsidies to irrigation communities' initiatives and sometimes finance a project entirely (Ibor et al., 2011).

However, despite investing in water-saving technologies, farmers' hopes for water were on the planned Ebro-Segura water transfer of 2001. When the construction of this transfer was cancelled in 2004, further investments in drip systems and the connection to desalinated water sources (through the AGUA plan) had to compensate for this imbalance. However, when this did not happen fast enough, and as most surface waters were already entirely in use, groundwater extraction became a new economic and, therefore, political focus (Thiel, 2015).

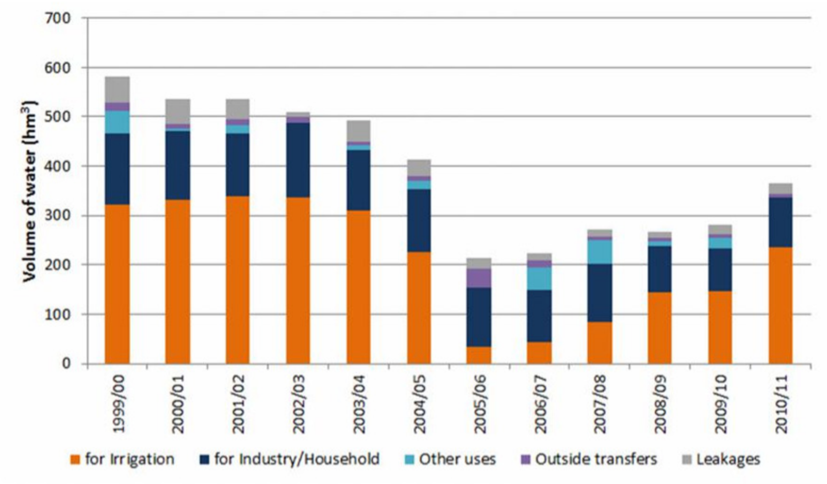


Figure 32. Volume of water received from TST in the SRB per sector from 1999 to 2010, retrieved from (Contreras & Hunink, 2015).

Figure 33. Drip irrigation in the agricultural fields of Campo de Cartagena. Source: image made by author.

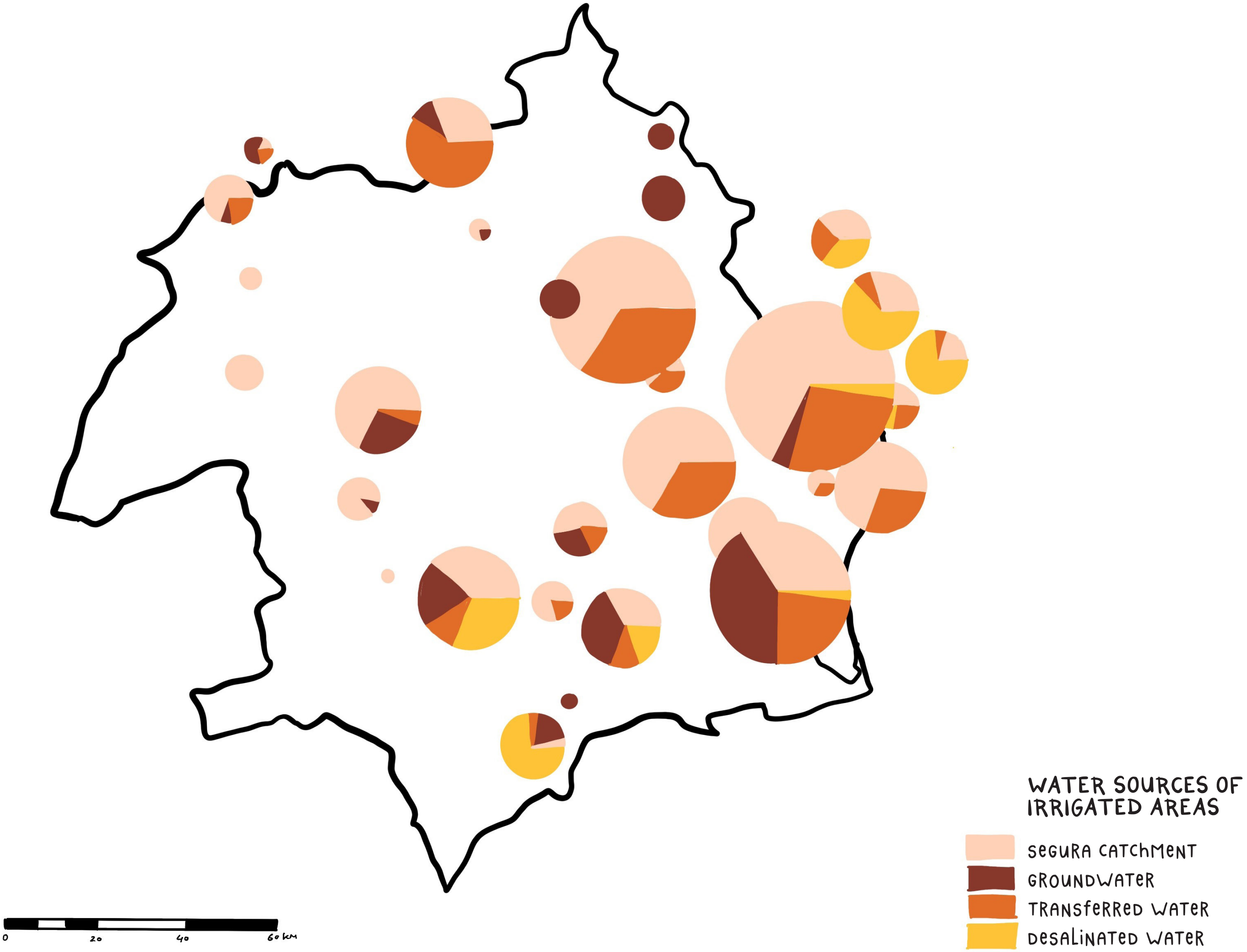


Figure 34. Map with diagrams of water sources for the main irrigated areas. Source: by author, based on: Simons et al. (2020).

OCCUPATION
LAND USE CHANGES

INTRODUCTION

Nowadays, climate change is increasing drought periods, and the new rules by the Water Framework Directive on achieving 'good ecological status' of the rivers and aquifers are pushing authorities towards further cuts in transferred water. In contrast, the demand for water in the region keeps increasing. The total demand was estimated to be 1,881 Mm3 for 2009, with 1,662 for agricultural uses, 189 for urban and industrial uses, and 30 for environmental uses, according to data from the CHS (Ibor et al., 2011). Because the water supply consisted of 575 Mm3 surface water (measured from 1980 to 2005), 700 Mm3 groundwater, and 348 Mm3 transferred water (on average of the period from 1982 to 2008), a structural water shortage of 258 Mm3 remained per year.

Land use changes through history are examined to understand and explain the demand side of the region's water system. The focus here lies on agricultural land use, as this is the biggest water-consuming sector in the region, accounting for more than 80% of the water demand. The amount of irrigated agricultural land in the basin grew significantly over the years, and thus the sectors' demand for water. Figure 34 shows a diagram of the different water sources per irrigation community, based on Simons et al. (2020). Secondly, urban expansions and tourism effects on water demand are discussed.

IRRIGATION EXPANSION

The traditional irrigated area covered 65,000 ha on the Segura River flood plain and in the Guadalentín and Mula valleys at the beginning of the 20th century. The total irrigated land cover reached 89,656 ha in 1933 after the opening of the Fuensanta reservoir with a water storage capacity of 223 Mm3. The state extended irrigation during the dictatorship (Franco's regime) and under the colonisation laws of 1939 and 1949. Irrigated agricultural land in the Low Segura District expanded uncontrollably afterwards, before being legalised by the Decree in 1953. If there was any 'surplus' water, those illegally created irrigated areas were to be supplied with water by law. After the law, the irrigated land had doubled in the Low Segura district. On the left bank of the river, the Levant region was expanded by the company 'Real Compañía de Riegos de Levante en la Margen Izquierda del Segura', and boosted beyond the legal limits of 9,900 ha to reach 39,300 ha. However, water demand could not be satisfied, and the real irrigated lands reached 25,000 ha (Ibor et al., 2011). Traditional irrigated areas are shown in Figure 35.

Total irrigated area in the SRB grew in 1954 to 104,420 ha and 117,230 ha in 1967, when the government promised the TST. However, the total irrigated area increased further than planned, reaching 196,874 ha in 1983, after the TST became operative, and around 230,000 ha until 2009 (see Figure 36) (Ibor et al., 2011).

INFRASTRUCTURAL LOCK-IN

The promise of the TST led to an infrastructural lock-in, where farmers were forced to switch from indigenous practices and dry agriculture to irrigated agriculture. In order to keep up with the other farmers, they were forced to invest in new irrigation systems that would make use of the promised water and would result in more profit. According to research by Martinez-Alvarez and others (2014), improving technological systems to make them more efficient in reducing water use can have unforeseen adverse effects and even result in a technological loophole. A technological loophole means that in some cases, when

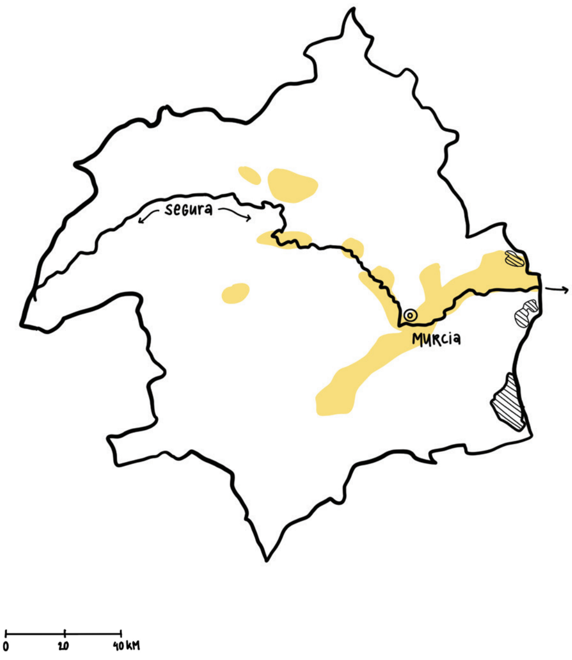


Figure 35. Traditional Irrigation in the SRB. Source: Made by author, based on (Martínez-Alvarez et al, 2017)

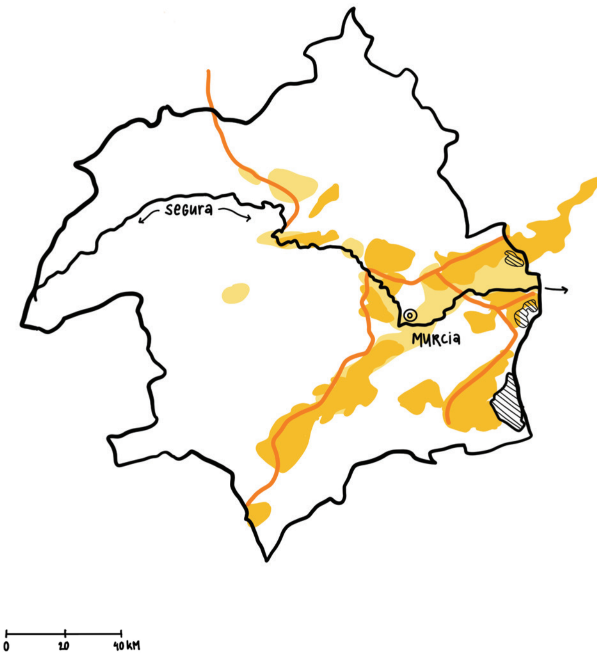


Figure 36. Irrigation agriculture after the promise of the TST. Source: Made by author, based on (Martínez-Alvarez et al, 2017)

efficiency is created, human behaviour adapts in ways that undermine the original incentives, for instance, because of economic incentives. The research points out that in the case of the modernisation of irrigation in the Segura River Basin, with the transition of traditional agriculture to drip irrigation systems, the Jevons Paradox happened. Instead of using less water because the systems were more efficient, water use for irrigation increased in the studied region (Martinez-Alvarez et al., 2014). Because investments in the system were made anyway, land that was unfarmable due to a lack of water became available for irrigation agriculture. This led to an expansion of irrigated area and a power shift from individual farmers to the governing board, creating a more centralised management structure and less community involvement. Because the new systems required a significant investment, individual farmers who could not afford the transition were forced to sell their land.

Due to the construction of 8 dams that increased storage capacity by 800 Mm3, a 50,000 ha increase in irrigated agricultural land occurred (see Figure 37). The generalisation of groundwater pumping techniques led to 80,000 ha more, thus increasing the water demand further. In addition, the promised 1000 Mm3 of annual transferred volume ended up being only 348 Mm3, leading to a structural water shortage (Ibor et al., 2011). The total irrigated agricultural area is shown in Figure 38.

URBANISATION AND TOURISM

The agriculture sector was not the only factor driving up the water demand in the area. Urbanisation, tourism, and irrational water use in the form of water parks also increased the demand throughout the previous century. With the focus on expanding irrigated regions during the build of the TST, urban villages emerged and urban cores expanded. After Franco's regime, industrialisation and modernisation policies that encouraged migration from rural to urban areas were implemented in Spain. The Segura Basin cities expanded as rural populations moved seeking better

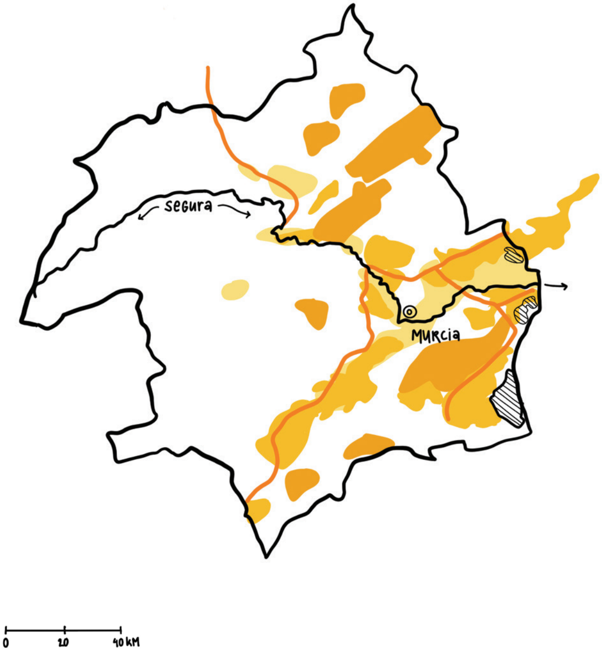


Figure 37. Irrigation agriculture after the development of groundwater extraction techniques. Source: Made by author, based on (Martínez-Alvarez et al, 2017)

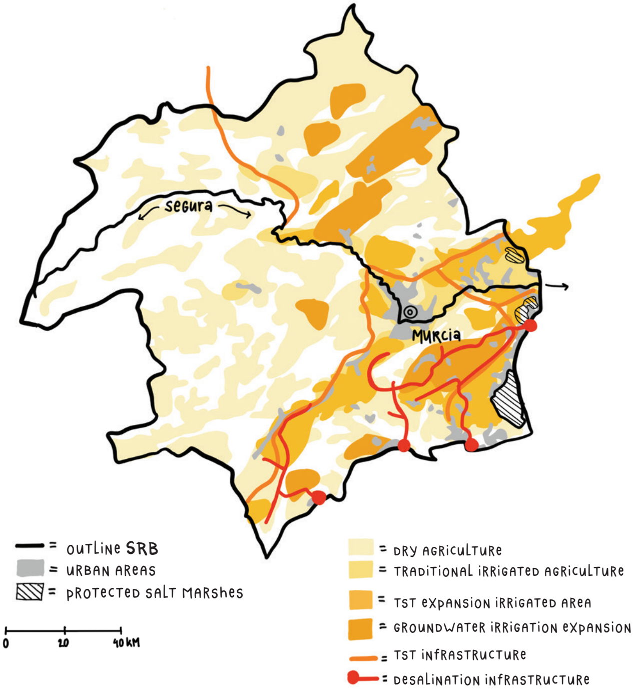


Figure 38. Total agricultural area. Source: Made by author, based on (Martínez-Alvarez et al, 2017)

employment opportunities. The largest urban centers within the basin are Murcia, Cartagena, and towns in the irrigation districts like Orihuela and Cieza.

Since the 1960s, the Mediterranean coast within the Segura Basin saw rapid development of tourism infrastructures. Coastal cities like Torrevieja and Orihuela experienced significant urban expansion due to tourist demand, second homes, and service sector growth. Especially many golf courses have been constructed along the Mediterranean coast since the beginning of the 21st century. From 2000 to 2010, the fastest growth of golf courses was seen in Valencia (38) and Murcia (19) (Lopez-Ruiz & Gonzalez-Gomez, 2023).

Figure 39. Segura River in Murcia. Source: made by author.

Figure 40. Image of an abandoned farm and water tank in the protected wetland area near Mar Menor. Source: Made by author.

SUBSTRATE
OVEREXPLOITATION

GROUNDWATER EXTRACTION

The cuts from the TST and miscommunication about the transferred volumes led to further groundwater extraction and intense aquifer overexploitation (Fornes et al., 2021). The number of wells for pumping groundwater in the basin increased from 7,829 (before the TST) to 20,350 in 1995 (just after the TST) (Ibor et al., 2011). Most of these wells were not controlled or registered by the river basin authority (Calvo, 2006). After the cancellation of the Ebro-Segura water transfer in 2004, due to the drought, and despite water-saving efforts from installing drip-irrigation systems, farmers were forced to continue with groundwater extractions to deal with the shortage. According to research by Zuluaga-Guerra et al. (2015), groundwater overexploitation reached 500 Hm3 from 1960 to 2021.

SEGURA RIVER POLLUTION

The increase in agricultural land use affected not only the groundwater aquifers. In the 1990s, the Segura River became one of the most polluted rivers in Europe, partially because of the food packaging industry in the region. In 2001, around 40,000 people demonstrated for a cleaner river. As a response, the Murcia Regional Government, the Segura River Basin authority (CHS), and local municipalities together launched the Segura River Project, which focused on wastewater collection and treatment upgrades (International River Foundation, 2025). Since 2003, water quality has improved, and since 2010, heavy pollution has been removed. Since then, otters and migratory birds have returned to the river, indicating biodiversity restoration.

CONCLUSION

The promise of the TST, in combination with poor water management at the time, led to uncontrolled irrigation agriculture expansion. Together with the development of the tourism industry, this economic profit-focused orientation led to a significant increase in the water demand in the area during this period, characterising the high water use of today and the start of groundwater overexploitation in the area. To tackle this, efforts have been made to install technical systems to improve agricultural water supply by optimising the water use. However, the example of the transition to drip-irrigation that led to a paradox and technological loophole highlights that implementing technological advancements that improve water efficiency needs to be combined with collaborative policies in order to prevent unforeseen negative consequences (Martinez-Alvarez et al., 2014). In addition, a mindset shift from individual approaches to acknowledging the interconnectedness of socio-economic and ecological systems is needed. This addresses the way we think about water, as well as how we manage it.

Figure 41. Image of desalination pipelines in the salt marshes of Torrevieja, a protected nature area. Source: Made by author.

CURRENT WATER SYSTEM
INTRODUCTION

After examining the history of water management decisions and land use changes in the basin, the current situation is explored in this chapter. First, structure of water management is explained. Second, socio-political tensions due to the Tajo-Segura Transfer are explained, setting out the water governance challenges authorities are facing.

Afterwards, the three layers of the network approach are again used to guide the analysis of the current water system in the basin. The system analysis is characterised in three sub-chapters: 1) water supply infrastructures, 2) water demand and use, and 3) the effects on the natural environment.

Figure 42. Points of concern for the Segura River Basin hydrological planning, from the latest CHS RMBP. Source: (CHS, n.d.).

WATER MANAGEMENT PLANS

GOVERNANCE FRAMEWORKS

CURRENT PLANS FOR THE WATER SYSTEM

The Spanish hydrological planning model consists of two planning instruments on different legal, geographic, and jurisdictional scopes:

1) The National Hydrological Plan, according to the Spanish law (10/2001 of July 5, 2001).

2) The Demarcacion Hydrological Plans (RMBPs, river basin management plans), according to the WFD (2000/60/CE of October 23, 2000), are aimed at establishing a framework for community action in the field of water planning.

The HP is created by MITECO (the Ministry for Ecological Transition and Demographic Challenge), which happens in cycles of 6 years. The plan currently in action is from the third cycle, from 2022 to 2027. The main instruments from the framework to develop water policies are River Basin Management Planning (RBMP), Flood Risk Management Plans (FRMP), Drought Management Plans (DMP), River Restoration Strategy (ENRR), and Groundwater Action Plan (PAAS) (MITECO, 2023). The EU Flood Directive provides the Flood Risk Management Plans. The river basin authorities develop the drought management plans (DMPs) through the drought observatory, a global data system of hydrological indicators developed by the Ministry. The objective of the River Restoration National Strategy (ENNR) is to enhance the longitudinal continuity of the rivers by removing obstacles (dams), replacing them with nature-based solutions, recovering vegetation along the river banks, and re-naturalising the river in urban areas. The Groundwater Action Plan (PAAS) aims to improve knowledge about the characterisations of (depleted) groundwater aquifers, monitor water networks, and study the relationships between water use and water body status (MITECO, 2023). Each HP needs a parallel Strategic Environmental Assessment, according to the Spanish law (21/2013 of December 9, 2013). Additional laws that the HP needs to comply with are:

1) Royal Decree 47/2022, January 18, about protecting water against diffuse pollution caused by nitrates from agriculture.

2) Royal Decree 1051/2022, December 27, about establishing standards for sustainable nutrition in agricultural soils.

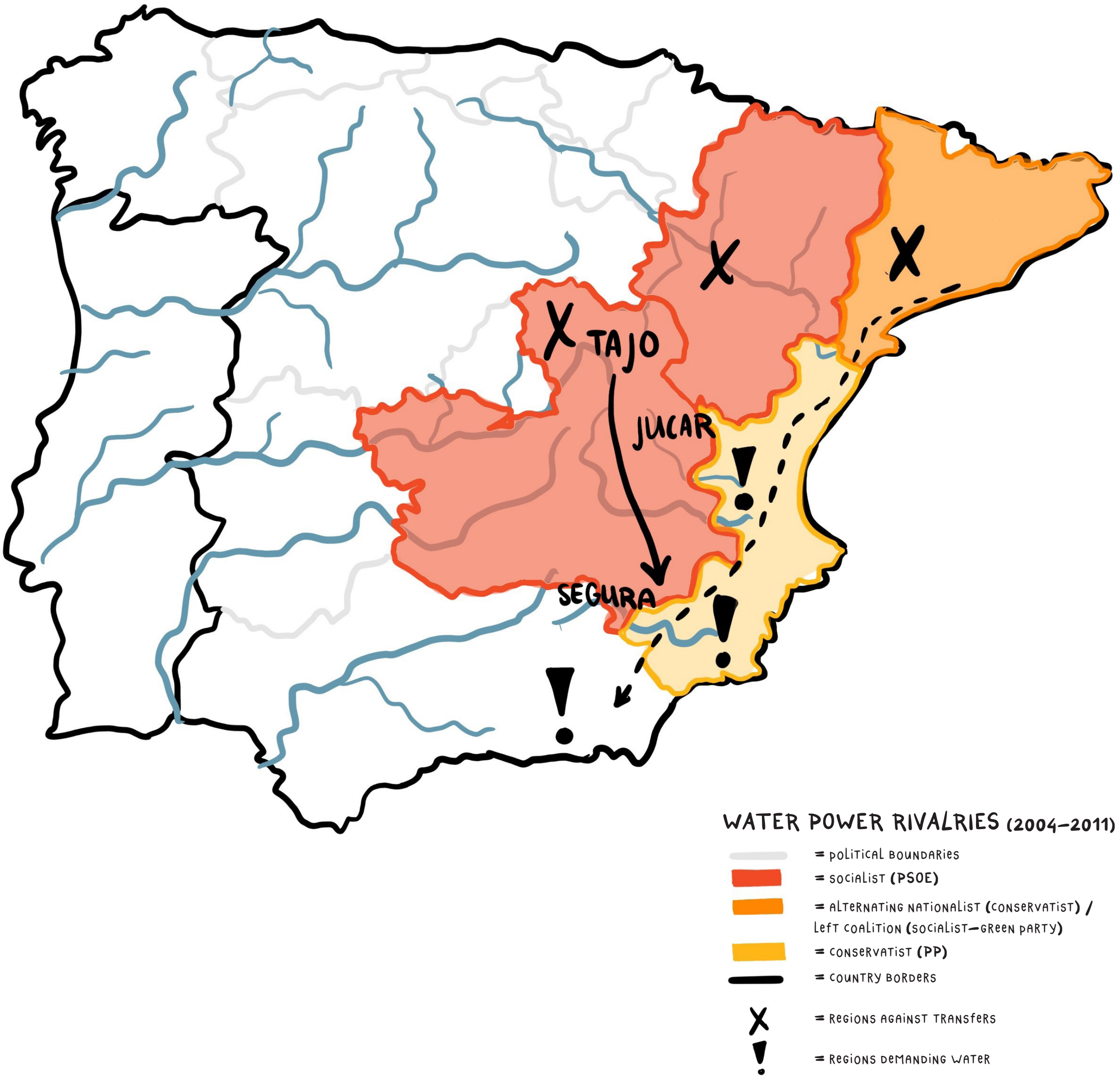


Figure 43. Socio-political conflict in Spain regarding the TST. Source: Made by author.

SOCIO-POLITICAL CONFLICT
TAJO-SEGURA TRANSFER

Due to ongoing water shortages, a political 'war over water' has emerged between the regions donating and receiving water. In Spain, water is a deeply political and economic issue with major socio-ecological consequences. The investment costs of hydrological infrastructures are high, and they require cooperation across different sectors and political regions. With ongoing droughts and increased attention for ecological well-being, the volumes of water to be transferred are a continuous political debate between the regions demanding water and the regions transferring water, which often try to protect their ecological state and own resources, since they are running out of water.

The Tajo-Segura Transfer in particular, is a key point of political tension. Its governance crosses regional boundaries, involving conflicting needs and interests. For instance, between 1986 and 2007, over 300 million euros were paid by the Levante area (one of the major water receiving irrigation communities) to the donor basin. By 2018, 191 million euros had been paid for the Campo de Cartagena alone (Hamed et al., 2019). The law of 1980 (52/1980, October 16) regulates the economic regime for the exploitation of the TST and the rights of irrigation use. The maximum volumes to be transferred were 450 hm3/year in total, where 110 hm3 was reserved for domestic use, 400 hm3 for irrigation, and 30 hm3 for losses of the agricultural user. However, only an average of 295 hm3/year has been transferred since its operation (Miteco, 2022).

From June 2017 to March 2018, transfers through the Tajo-Segura system were halted due to severe drought, putting pressure on both drinking water and irrigation. Hamed et al. (2019) and CHS (2007) reported that the 1994 drought caused an 11–19% drop in production, a 14% decrease in irrigated area, leading to a total production loss of 120 million euros.

This transfer is the reason for many protests and has long been on the political agenda. Since the 1990s, farmers and citizens have demanded more water and investment. Irrigators in Alicante, Murcia, and Almería resist water cuts, while farmers in Castilla-La Mancha also request more water for new crops and irrigation. With the EU Water Framework Directive requiring all surface waters to reach 'good ecological status' by 2027, the Tajo basin is now prioritising ecological health, leading to cuts in water sent to the Segura basin. On 19 January 2023, the Royal Decree updated the hydrological planning for 12 districts (for the period of 2022–2027), including the revision of ecological

Figure 44. "*In the Levante, without a transfer, desert and unemployment*", during a protest by the Sindicato de Irrigantes del Acueducto Tajo-Segura (SCRATS) in Madrid, against cutting transferred water volumes of the Tajo-Segura transfer in January 2023. Source: Image by Fernando Alvarado, retrieved from (Bachiller, 2023).

flows from the Tajo to the Segura. In response, the provinces of Valencia, Murcia, Castilla-La Mancha, and Andalusia submitted over 5,000 pages of objections, and protests for and against the cuts were held in Madrid.

According to Fernando López Miras (president of the Region of Murcia), the lower Segura basin already lacks sufficient water for irrigation. With the new cuts, "turning on the tap will become a luxury" for many families in the Spanish Levante, he says (Bachiller, 2023). Meanwhile, José Luis Vega (president of the Provincial Council of Guadalajara) described the situation of the Entrepeñas and Buendía reservoirs as "dreadful", calling for Levante farmers to rely on desalinated water instead, warning that continued extractions would lead to total drought (Bachiller, 2023). He emphasised that extractions of drinking water should be prioritised over irrigation used for Southern agricultural profit.

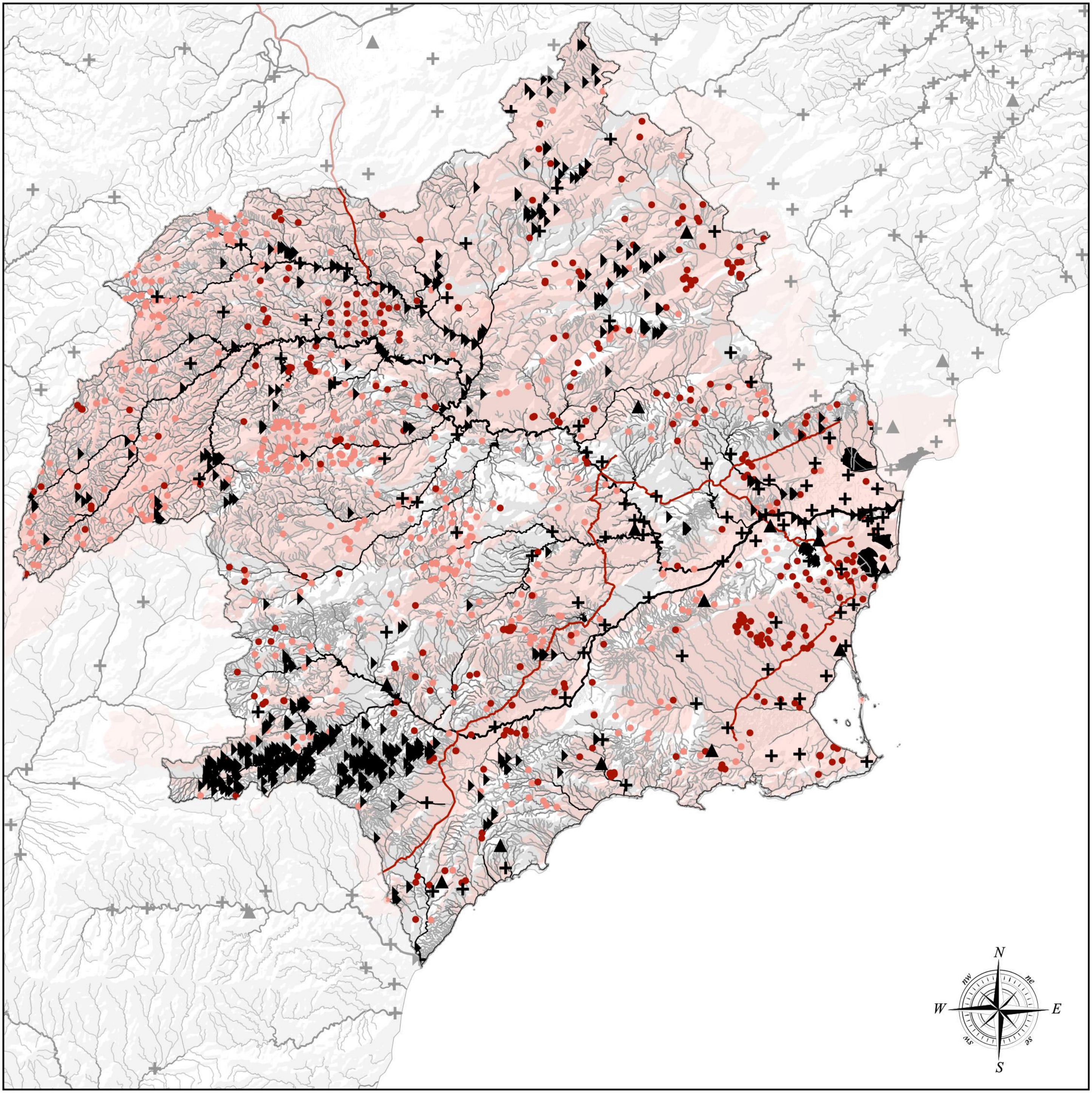
The third vice-president of the Government and Minister for the Ecological Transition and Demographic Challenge, Teresa Ribera, stated that the various demands are incompatible with one another and the general interest. She argued that it is the government's responsibility to find the best response to maximise benefits for all. At the same time, she noted that setting an ecological flow for the Tajo River is a legal obligation that cannot be delayed (Bachiller, 2023). According to Ribera, the planning now recognises the reality of climate change: "We have to be much more prepared for extreme drought and severe flooding, that is the reality" (Rejón, 2023).

Figure 45. Image taken during a protest by the Sindicato de Irrigantes del Acueducto Tajo-Segura (SCRATS) in Madrid, against cutting transferred water volumes of the Tajo-Segura transfer in January 2023. Source: Image by Fernando Alvarado, retrieved from (Bachiller, 2023).

CONCLUSION

Prolonged droughts due to climate change and a new political recognition for the importance of ecological flows due to rules set by the WFD have resulted in cuts from the Tajo-Segura water transfer in the latest National Hydrological Plan. Socio-political tensions between the sending and receiving basins are rising, and politicians are having a hard time balancing the needs of nature and humans. A socio-ecological balance needs to be found to provide a just transition of the water system.

Interventions could include prioritising drinking water over irrigation water as uses of transferred water, and focusing on more water self-sufficiency within the receiving basins to reduce reliance on transferred water. Eventually, the transfer could be phased out due to the implementation of renewable water sources and networks.



Author - February 2025

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WATER INFRASTRUCTURES

WATER SUPPLY MANAGEMENT

INTRODUCTION

The water resources available in the basin consist of: conventional resources (surface and groundwater), external resources (the TST and to a lesser extent the Negratín-Almanzora and the Júcar-Vinalopó water transfers), and non-conventional resources (seawater desalination, water reuse, and irrigation return flows). Despite the availability of resources, a structural water shortage dominates the basin. In total, 1870 hm3/year of blue water is used in the region, while there is only an average availability of 1319 hm3/year (Aldaya et al., 2019), coming to a shortage of 551 hm3/year.

With the recent cuts from the TST and the prospect of a further decrease in water availability due to climate change, efforts to reduce this shortage are necessary. This paragraph provides a short overview of the current water supply and distribution system and recent efforts to increase the water availability in the region.

WATER MANAGEMENT

Water is managed by multiple institutions and organisations in the basin. At the higher levels, the leading public institutions are Mancomunidad de Canales del Taibilla (MCT) and Confideración Hidrográfica del Guadalquivir (CHS). The river basin Water Authority CHS accounts for most of the management, policies, and control over the water system in the basin. It is in charge of most infrastructures (canals and dams) and manages the distribution of the incoming water flows from the Tajo-Segura and Negratín inter-basin transfers (Contreras & Hunink, 2015).

The MCT distributes the water to most of the municipalities of the basin. The main network for water distribution to the urban sector is the Taibilla Supply System. It supplies 2,5 million people by distributing drinking water among urban

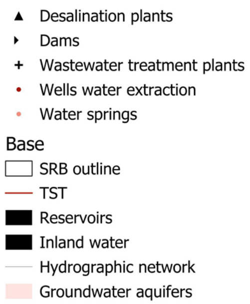


Figure 46. Water supply infrastructures in the SRB. Source: Made by Author, based on datasources from CHS (2025).

and industrial users in the provinces of Murcia and Alicante (Ibor et al., 2011). From 2000 to 2010, 56% (on average) of the water managed by the MCT came from the Tajo-Segura transfer. This was followed by 22% surface water and 12% groundwater resources. Since 2005, desalinated water emerged as a new water resource, reaching 24% of the total in 2008. Irrigation return flows in the basin reach 125 hm3/year, of which 60 hm3/year is collected in the irrigation canals of the traditional irrigation network called 'Azarbes', located in the 'Vegas del Segura' plains (CHS, 2015).

DEFICIT

One of the issues related to water management in the basin is the structural water deficit. Several studies point out the significance of the deficit as a result of leakages from outdated infrastructures in the basin. However, no official statement on the yearly volume of deficit is made. Deficits through leakages are not only a characteristic of this area, as Spain has been known to be dealing with this problem due to the infrastructure projects of the last century. Spain's water network is said to be dominated by network losses, accounting for 25% of the national consumption in 2015 (PwC, 2018). This number is relatively high compared to other European countries. Real network losses, meaning outdated infrastructures and leaking pipelines, cover 15% of the total loss. The remaining 10% are apparent network losses, indicating measurement errors, unauthorised consumption, and fraud (Fornés et al., 2021). A possible cause of these apparent losses could be the problem of unauthorised groundwater pumping, which was mentioned before.

NON-CONVENTIONAL WATER RESOURCES

The United Nations (UN) has pointed out that the worldwide adoption of non-conventional water use is essential to achieve water availability, sustainable resource management, and sanitation for all, which is in collaboration with Sustainable Development Goal (SDG) 6 (López-Ruiz & González-Gómez, 2023). This has also been discussed by the European Commission (EC) in the New Circular Economy Action Plan (European Commission, 2020).

Because of the drought periods, groundwater depletion, cuts of the TST, and the socio-economic consequences of the overall water shortage, the General State Administration has developed a network of seawater desalination facilities.

DESALINATION PLANTS

Since the mid-2000s, desalination has been pushed to diminish the area's water shortages. In 2004, when the socialist government cancelled the build of the Ebro-Segura transfer and the AGUA program of desalination and reuse started, 34 desalination plants were planned to be built to make up for the water imbalance that was created by the reductions in the amount of water that was transferred from the TST. However, due to a lack of investments because of a wet period at the time, the plan got cancelled, and these goals were never met. In 2015, seawater desalination in the region consisted of 139 hm3 (CHS, 2015). Currently, 13 IDAMs are operative in the SRB, 3 of which are of general interest to the State, and are owned by the state-owned company AQUAMED.

The Torrevieja desalination plant (located in Torrevieja, Alicante) has a production capacity of 240.000 m3/day. It is the largest desalination plant in Europe and the second-largest desalination plant in the world that uses reverse osmosis technology. It covers 60 hm3/year of irrigation

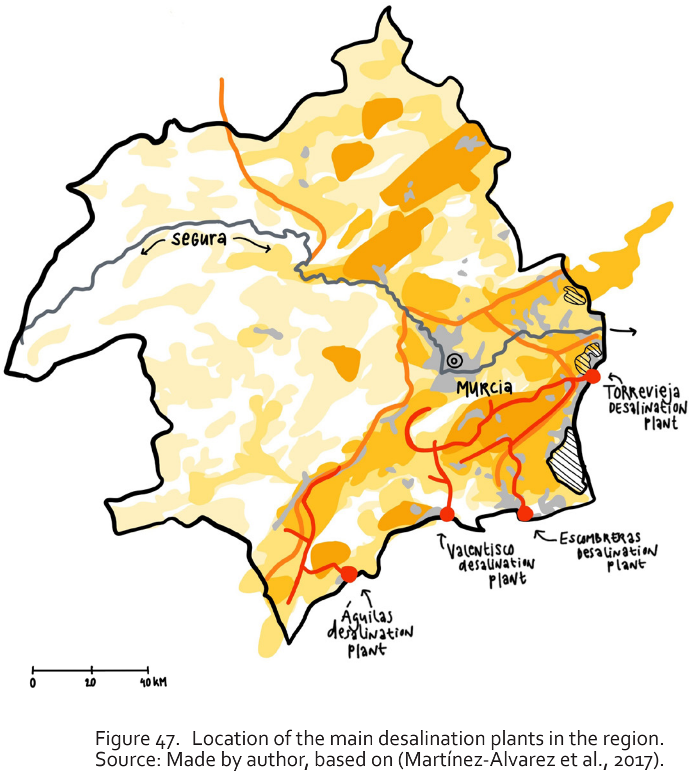


Figure 47. Location of the main desalination plants in the region. Source: Made by author, based on (Martínez-Alvarez et al., 2017).

shortage in the irrigable area of the TST and an additional supply of 20 hm3/year to the Vega Baja West area. The plant has been designed to produce 80 hm3/year, with a possibility to expand to 120 hm3/year. Plans to expand the plant to this full capacity have been confirmed in 2024, with a signed contract of €89.5 million. After the expansion, the plant will provide water to the population of the Mancomunidad de Canales del Taibilla and for the irrigation of the Campo de Cartagena area (Sacyr, 2024).

The Valdelentisco desalination plant (located in Cartagena, Murcia) has been operational since 2008 and has a production capacity of 42.35 hm3/year. Initially, it was built with a theoretical maximum capacity of 70 hm3/year, anticipating further expansions. Currently, AQUAMED is planning to expand to this full capacity (CHS, 2025).

The third-largest desalination plant in the region, called the Águilas-Guadalentín desalination plant, is located in Águilas, Murcia. The plant has been operative since 2011 and produces 60 hm3/year, providing 16.000 ha of irrigated land with water in Alicante, Murcia, and Almeria. The plant was built to reduce the overexploitation of aquifers in Murcia for crop irrigation. Also, this plant has plans to expand. With a €51.5 million project, the plant will grow to be the second largest in Spain, increasing the current capacity by 30.000 m3/day, reaching 70 hm3/year by 2027. Of this amount, 20% of the water will be supplied to the population (130.000 inhabitants) and 80% will be used for irrigation purposes (Grupo TYPSA, 2025).

Water desalination is a non-conventional technique used to increase available water resources by separating salts from a brackish solution (brackish water or sea water) and converting it into water suitable for supply to populations, industrial or agricultural use (irrigation). While there are multiple possible processes, the treatment process used in the SRB is reverse osmosis.

The process consists out of four phases: double filtration (by gravity and pressure), double pass reverse osmosis to eliminate boron, recovery of energy using isobaric chambers, and remineralisation (Sacyr, 2021). These processes are carried out in desalination plants called IDAMs (Sea Water Desalination Facility).

Figure 49. The Torrevieja desalination plant from above. Source: (Cristina, 2023).

Figure 48. Expansion plans of the Valdelentisco desalination plant. Source: (CHS, 2025).

ENVIRONMENTAL CONSEQUENCES

While it seems like a sustainable solution for the water shortages, expanding these desalination plants does not come without a cost, both in terms of investments and environmental disturbance and pollution.

For instance, the Valentisco desalination plant currently emits 949.365 kg CO_2/year, reaching a total of 16.139.218 kg since its operation in 2008. The expansion of the desalination plant would mean a 43% increase in annual electricity consumption, as well as CO_2 emissions, compared to the current situation. This would require additional measures to mitigate the negative consequences of increase in energy demand (and use of fossil fuels) and increased emissions. According to AQUAMED, these difficulties are addressed by using the transformation to install more efficient equipment, which will reduce energy consumption and emissions per m^3 of water produced. Additionally, part of the electricity consumption is to be retrieved from a photovoltaic installation, reducing the increase in annual emissions from +43% to +8-13% (CHS, 2025).

Next to this, the plant is located in a Natura 2000 Network of Special Conservation Area (ZEC) and Special Protection Area for Birds (ZEPA), as well as in the Regional Park "Sierra de la Muela, Cabo Tiñoso and Roldán". These protected nature areas should not be disturbed, requiring special caution and additional measures to ensure a sustainable implementation. For instance, water inlet and brine disposals should be located and measured carefully, and should cause no pollution or disturbance. However, except for a ditch for the pipes, the project report does not mention any cautions regarding the ZEC/ZEPA (CHS, 2025). With regard to habitats of community interest around the seawater inlet, however, the new intake tower and the outfall bypass will be installed on the seabed, in a sandbank.

SOCIO-ECONOMIC CONSEQUENCES

Next to environmental consequences, the expansion of desalination plants also has consequences for the consumer, as the desalination process is very costly compared to other water sources. According to the cost recovery principle by the WFD, EU states are mandated to recover the financial, environmental, and resource costs of using water, to ensure fair water distribution and justice for nature (WFD 2000/60/EC, Article 9). This would mean that water tariffs should reflect the real cost of water services, including environmental and resource costs. The pumping and deficit costs of desalination had not been included in the water prices so far. This has already resulted in additional irrigation fees since January 2023 for desalinated water from all desalination plants. If subsidies for irrigated water use are phased out according to the cost recovery principle, farmers might face even larger water tariff increases.

Desalinated water is already more expensive (0,6 – 1,0 €/m3) than other water sources (0.05 – 0.3 €/m3), due to the high costs of the operation process. Next to this, energy costs will rise further, leading to even higher prices that are not affordable for irrigators. If all associated costs were included in the pricing, desalinated water would cost around 0,9 – 1,3 €/m3 (Aldaya et al., 2019). Even though the planned construction of solar photovoltaic plants linked to irrigation desalination plants and the Júcar-Vinalopó pipeline is aimed at reducing these costs, the prices are still higher than those of groundwater and transferred water, potentially leading to more tensions and illegal groundwater extractions.

Furthermore, social acceptance of desalinated water for irrigation is lacking, as farmers perceive the quality of the desalinated water to be less than surface or groundwater (Gómez-Ramos et al., 2024). This is due to the high boron content, making it unsuitable for certain crops without mixing it with conventional water.

The government faces a complex trade-off between economic feasibility, compliance with the established environmental regulations, and social acceptability. To deal with this complex trade-off, the CHS states in the new Hydrological Plan for the basin that corrections must be established for situations of overexploitation of aquifers due to existing irrigation in areas lacking a water supply guarantee. This will be done based on the contribution of new water sources, thereby proposing full repayment of the additional costs of these water sources, not to risk the economic productive capacity of the area (CHS, 2025b).

The average price of agricultural surface water is 0.05 €/m3 (200 €/ha) and 0.2 – 0.3 €/m3 (800 €/ha) for groundwater (Aldaya et al., 2019). If environmental costs were added for the buyer, according to the cost recovery principle, prices would increase between 0.3 and 0.5 €/m3 on top of the current prices (Garrido & Calatrava, 2009). For the TST water supply, the price is 0.3 €/m3, and the Taibilla supply costs 1.2 €/m3. Reclaimed water costs 0.15 €/m3, while desalinated water costs around 0.7 €/m3, but can exceed 1.0 €/m3, depending if the plant operates at nominal capacity or not (Aldaya et al., 2019).

REUSED WATER

The Royal Decree of 2007 (RD) builds the legal framework for water reuse, defines what should be understood by reuse, and makes a distinction between treated water and regenerated water (López-Ruiz & González-Gómez, 2023). In this definition, regenerated water receives extra treatment, making it suitable for uses other than treated water. According to the law, the reuse of regenerated water is only allowed for agricultural, urban, recreational, and environmental use. According to the European Commission, water reuse can be considered a reliable water supply because it is mainly independent of seasonal drought and weather variability and, therefore, able to cover peaks of water demand (European Commission, n.d.). Next to this advantage, wastewater reuse benefits the environment and ecosystems, as polluted water gets treated before it is discharged into nature. If water is reused more, the pressure on aquifers and groundwater bodies will drop, diminishing overexploitation (Gil-Meseguer et al., 2019). Because of current technology treatments that allow for qualitative water production, the reused water can be used for many purposes and by several sectors, including the domestic sector as drinking water (Jodar-Abellan et al., 2019).

Spain is a leading country in Europe in the total amount of water that is reused, as well as regulating the reuse of water. Since 2007, the country has had a legal framework for water reuse, and over the last two decades, the percentage of reused water has grown significantly.

However, in recent years, plans have been cancelled and the growth has stagnated, leading to the prediction that the goals set by the EU Commission will not be met (López-Ruiz & González-Gómez, 2023). The fine imposed on the Spanish government in 2018 by the European Commission for non-compliance with the 1991 directive on wastewater treatment proves that Spain must improve the capacity for regenerated water (López-Ruiz & González-Gómez, 2023).

In the region of Murcia, almost all treated water is reused (95.6%), the highest percentage in all of Spain and a leading district on water reuse in the world (López-Ruiz & González-Gómez, 2023). According to the INE (2020a), 80% of the treated water is used for irrigation purposes, of which 65.8% goes to irrigation agriculture, and 26.1% to the irrigation of golf courses and public parks. According to a different source, AEAS-AGA (2020), the destination of reused water per sector in Murcia would be 49% to the agriculture sector, 12% industry, 9% gardens, sport and leisure, 0.5% to sewer and street cleaning, and 28% to other uses.

Because the quality of the treated water is higher than that of desalinated water, and because the costs are lower, farmers prefer this non-conventional water source over desalinated water (Gómez-Ramos et al., 2024). Additionally, regenerated water use in agricultural practices decreases fertiliser consumption as the nutrients in the water are beneficial for the soil, thus improving crop production (Salgot & Folch, 2018).

However, acceptance of reused water for irrigation purposes has not yet been met by farmers and consumers of local products. As a study by Molinos-Senante et al. (2013) points out, economic viability is the main obstacle to implementing reuse projects. Due to the high costs per cubic meter, regenerated water is found to be one of the least favoured water sources among farmers (Government of Spain, 2020). Consumers are reluctant to buy products irrigated with reused water, due to a lack of awareness and a general feeling of disgust (Lahlou et al., 2021). Furthermore, perceived health risks and environmental awareness explain the consumers' reluctance in residential uses (López-Ruiz et al., 2021).

Not only does regenerated water have to have buyers, acceptance of producers and consumers is necessary for circular economic projects to be successful (Urbinati et al., 2017; Kuah & Wang, 2020). Thus, with the implementation of additional reuse facilities and infrastructures, the government should focus on awareness of sustainable water use and social acceptance of wastewater reuse.

CONCLUSION

The recent focus within water governance and management has been on improving the water supply through non-conventional water sources such as desalinated and reused water, to diminish the socio-political conflicts, enhance water security, maintain economic productivity, and improve environmental health. However, due to financial and political issues and poor water management, focusing mainly on short-term economic profits, developing non-conventional water supply sources has stagnated in recent years, and most plans were cancelled.

Nonetheless, Murcia is currently a leading municipality regarding the amount of water that is reused, and the three biggest state-owned desalination plants in the basin are planning to expand to their full capacity, improving the desalinated water supply by 2027.

However, these non-conventional water sources do not nearly compensate for the full decrease in water availability due to the droughts and the cuts in volumes transferred through the TST, and a structural water shortage remains. From the lack of information about the water deficit, it can be concluded that the water management companies and authorities currently overlook the structural deficit in the area, and more research on the possible causes, as well as action to reduce or prevent it, is necessary.

Additionally, both solutions implemented come with challenges such as public awareness, social acceptance, and socio-economic justice, which are currently underexplored. Because costs are higher and the water is perceived as less clean, farmers prefer surface or groundwater, resulting in illegal groundwater extractions and forced closing of small farms. These challenges must be addressed simultaneously when implementing solutions to tackle water scarcity, and good communication is of the essence.

A possible starting point could be the stimulation of a water user mindset change, focused on water scarcity awareness and social acceptance of desalinated and reused water as primary water sources. Further suggestions would be to research and prepare for the (socio-economic) effects of implementing the cost-recovery principle and adequate policy and subsidy revisions to diminish economic losses and social tensions.

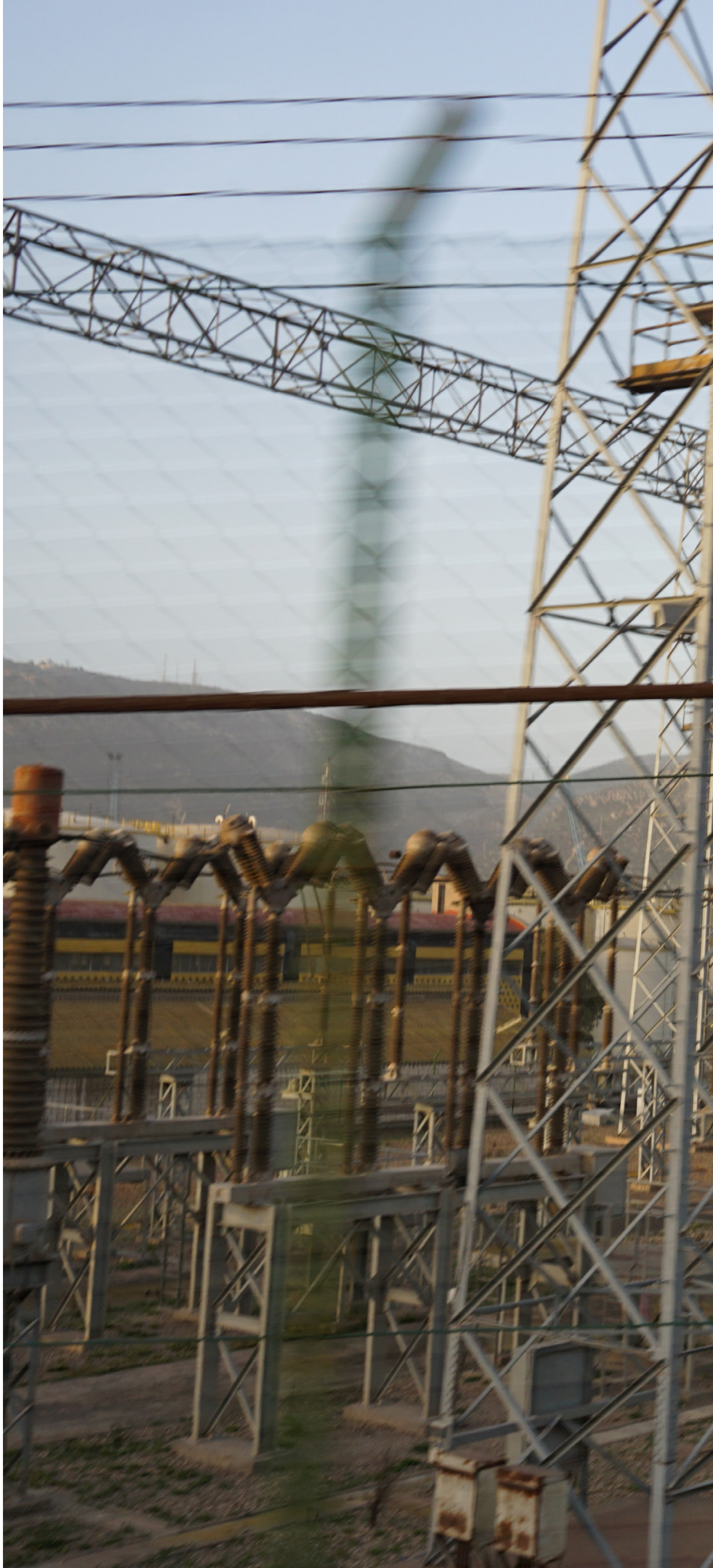


Figure 50. Image of the energy landscapes in the industrial area of the Cartagena food export harbour. Source: Made by author.

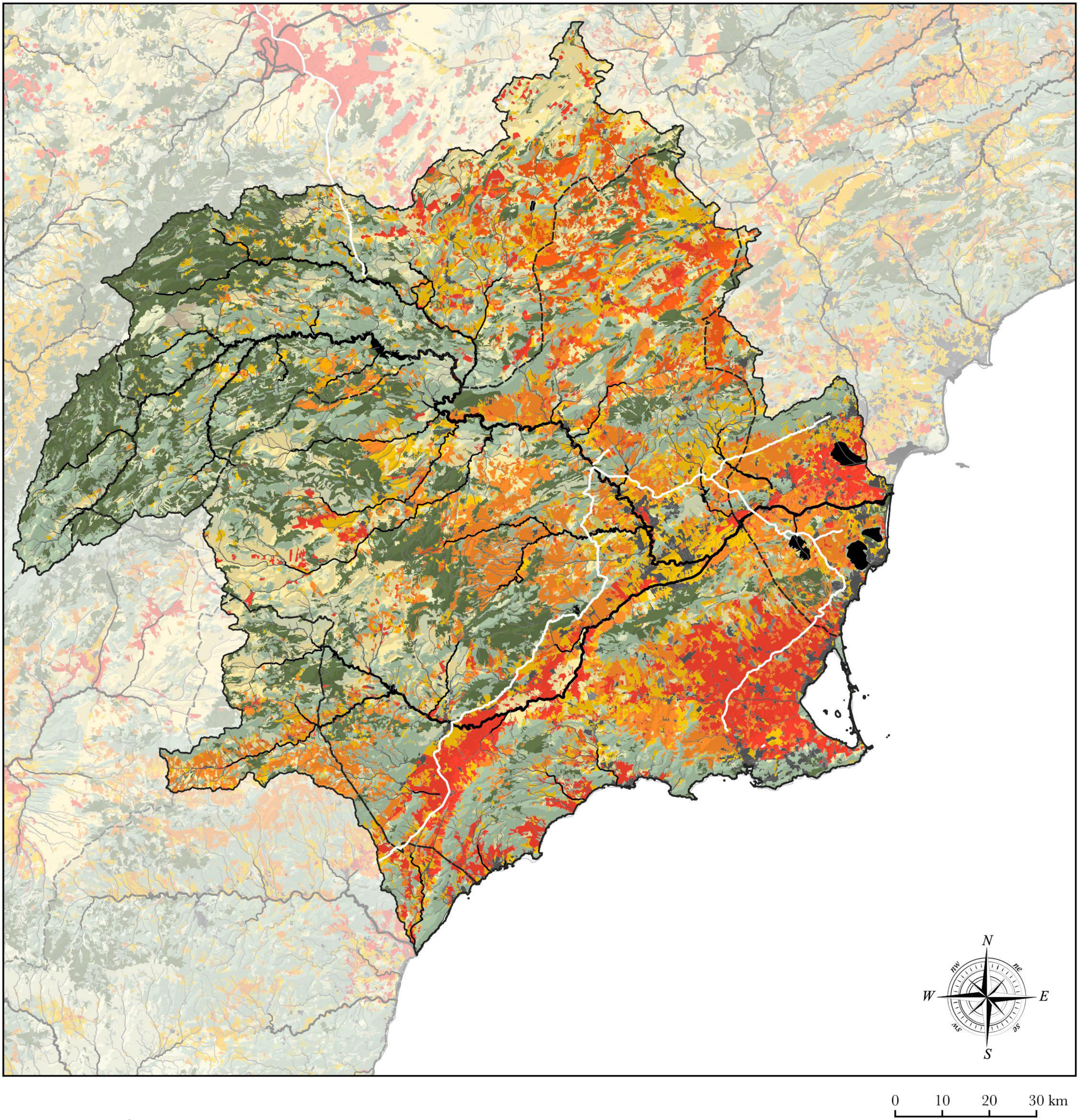
Figure 51. Image of the plastic foil landscapes of the quilted agriculture of Campo de Cartagena, near Cartagena city. Source: Made by author.

WATER DEMAND CHANGES
INTENSIVE AGRICULTURE

INTRODUCTION

This paragraph aims to set out the current water demand changes of the main water-using sectors within the basin, to form the analysis of the occupation layer according to the network approach. Agriculture is the main water-using sector of the basin, and will therefore be the primary focus of this paragraph. Tourism, as an upcoming water-demanding sector, will be discussed briefly as well.

This paragraph builds upon the historical analysis of the occupation layer, which showed the expansions of irrigated agricultural area over time in the basin. The transition from dry agriculture towards irrigated agriculture is still happening in the basin, despite the increasing water shortages. In 2015, the main land uses were woodlands (50,6%), agriculture (40,6%), urban (4,7%), surface waters (1,8%), and unproductive land (2,3%) (CHS, 2015). Of the agricultural area in the basin (7720 km2), approximately 50% was rain-fed and 50% was irrigated agricultural land in 2015 (CHS, 2015). According to a more recent document published by the CHS (2020), irrigated land has reached 60%, leaving 40% of dry agriculture. Figure 52 shows the land cover of the basin in the year 2018 (Corine Land Cover, 2018).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WATER USE INTENSITY

Despite the advancements in water-saving technologies, this agricultural land use transition has come with an increase in water demand. Agriculture accounted for 80% of the blue water (fresh surface and groundwater) use in the region in 2016, using 1366 hm3/year (Aldaya et al., 2016). Nowadays, the total agricultural water demand has reached 1487 hm3/year (CHS, 2020).

This is because different crops can be produced with these irrigation methods, which are characterised by a higher water use intensity. The difference between dry agriculture and more water-demanding agriculture practices is shown in the map from lighter to darker yellow, respectively (see Figure 53). On the same page, examples of locations with agricultural practices of different water use intensity are shown according to the same legend, together with the satellite images of these locations.

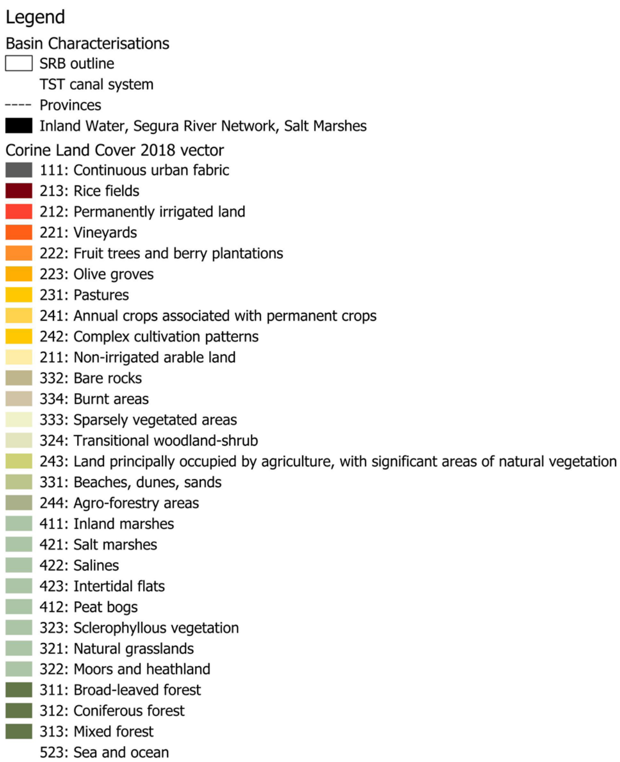
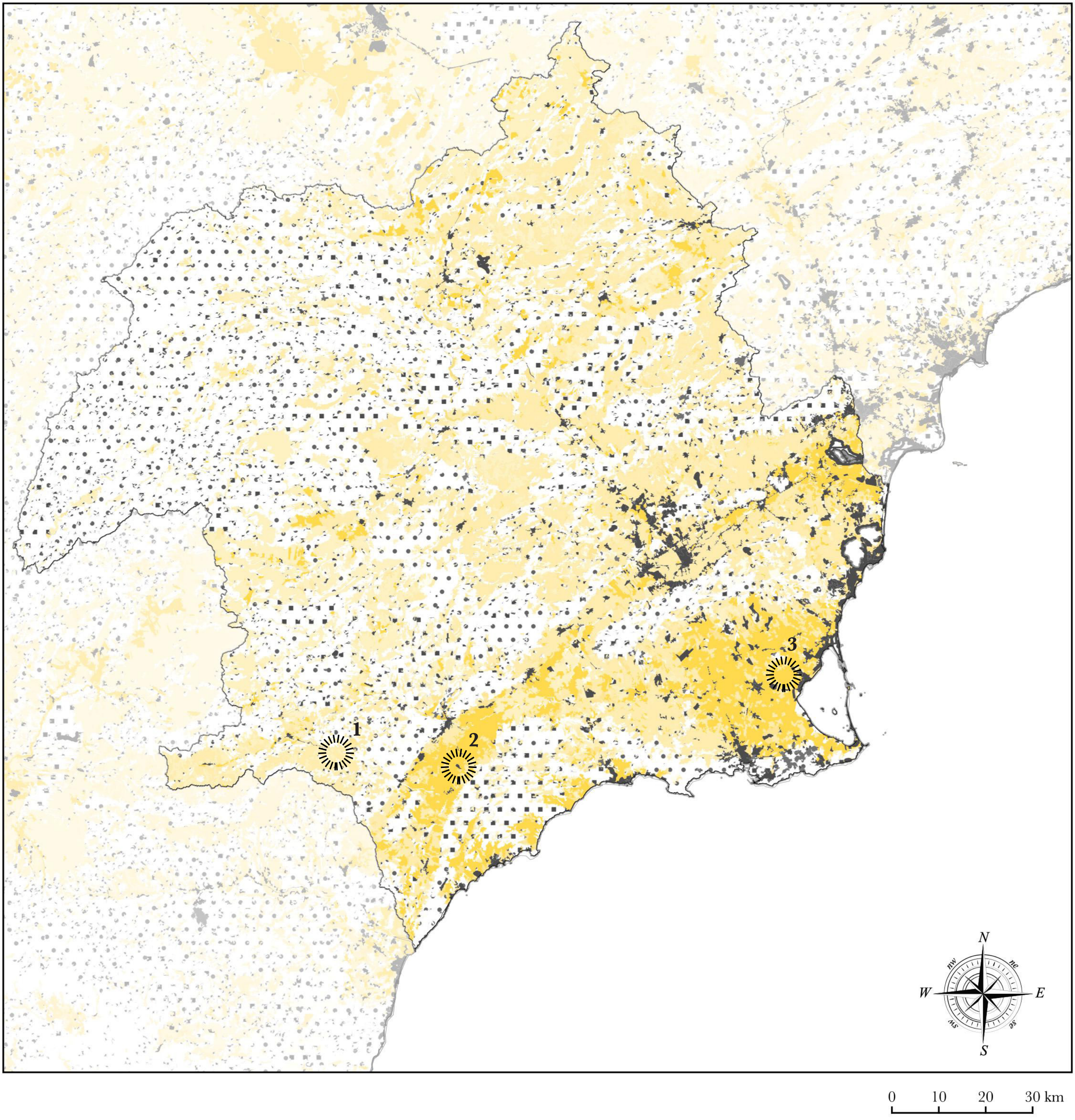


Figure 52. River Basin Land Cover. Source: made by author, based on (Corine Land Cover, 2018)

Figure 54 shows the evolution of agricultural land use related to water use intensity over time for the Campo de Cartagena sub-basin. This graph indicates the transition to different, more water-intensive forms of agriculture. Instead of only applying drip irrigation systems to the existing woody crops of the traditional dry agriculture (irrigated tree crops), the shares of irrigated horticulture and greenhouse agriculture grew significantly (FutureWater, n.d.). The increase in water-intensive irrigation agriculture for the province of Murcia is documented by the Regional Ministry of Water, Livestock and Fisheries (CREM, n.d.-a), showing a particular increase in agricultural fields covered by plastic foils (quilted agriculture) on a larger scale. Localised irrigation areas in Murcia grew from 122.939 ha in 2009 to 138.019 ha in 2022, and quilted agriculture grew from 12.475 ha to 18.363 ha.

The main reason for this trend is the economic value of irrigated agriculture (2700M/year) over rain-fed agriculture (400M/year) (Aldaya et al., 2019). Next to this advantage, irrigated agriculture has a lower risk and vulnerability to climate variability, resulting in steadier yields. The more the environment in which the crops are produced is controlled, the more these advantages occur. This leads, however, again to a paradox. Drought pushes the need for irrigation methods and plastic covers to prevent evaporation, detaching the field from the natural surroundings, and hindering local biodiversity. This increases the need for fertiliser to provide nutrition for the crops, polluting the surface run-off and groundwater. Additionally, the transition to irrigated horticulture means a loss of woody crops and thus, permanent roots that hold the soil. This contributes to the problems of soil erosion, reduced water retention capacity, and desertification. In more extreme cases, the soil has become unfit for agricultural practices, calling for a transition to greenhouse agriculture or even abandonment of land, both accelerating the desertification process of the area further.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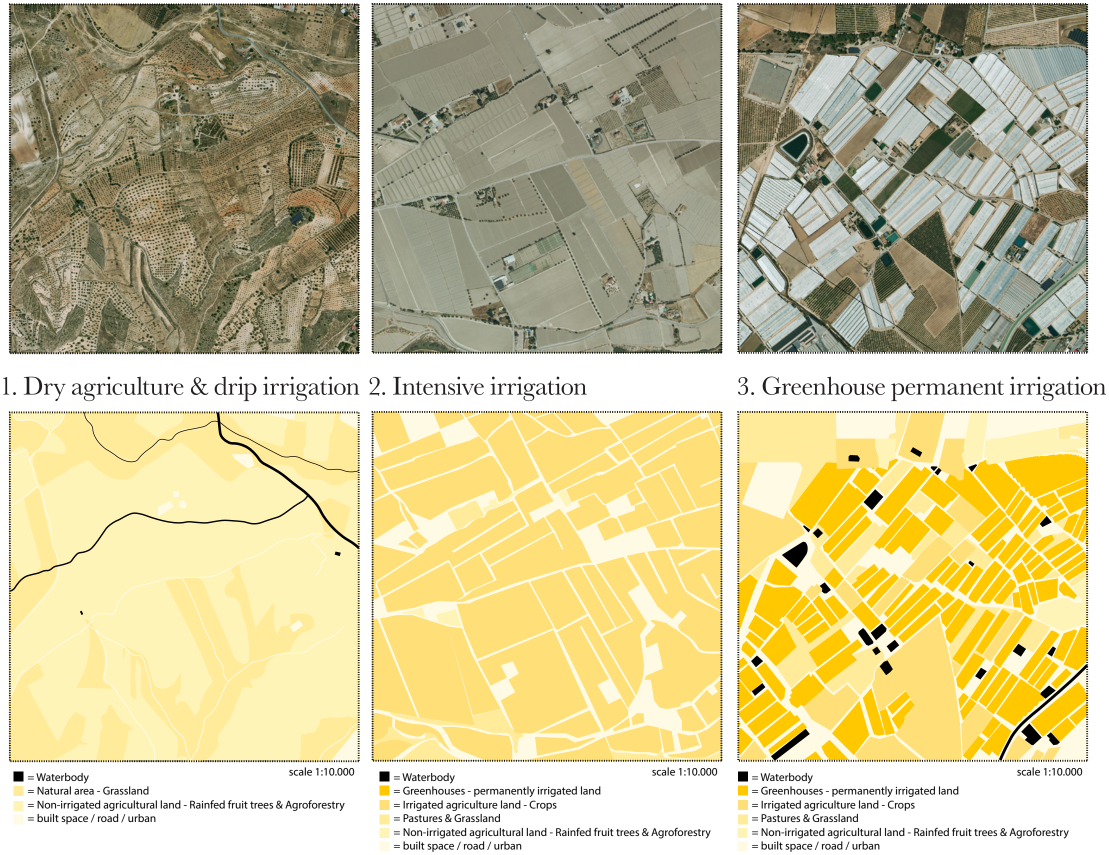
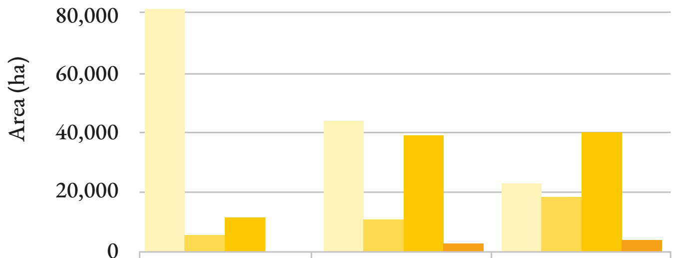


Corine Land Cover 2018 vector
- Urban area
- 212: Permanently irrigated land
- 241: Annual crops associated with permanent crops
- 231: Pastures
- 213: Rice fields
- 221: Vineyards
- 222: Fruit trees and berry plantations
- 242: Complex cultivation patterns
- 223: Olive groves
- 211: Non-irrigated arable land
- 244: Agro-forestry areas
- 243: Land principally occupied by agriculture
- 311: Broad-leaved forest
- 312: Coniferous forest
- 313: Mixed forest
- 321: Natural grasslands
- 322: Moors and heathland
- 323: Sclerophyllous vegetation
- 324: Transitional woodland-shrub

Evolution of land use related to the intensity of water use in Campo de Cartagena (Southeast of the Segura River Basin)



	1977	2000	2020
Rainfed tree crops	80,820	43,612	22,432
Irrigated tree crops	5,880	10,912	18,156
Irrigated horticulture	11,520	39,588	39,715
Greenhouses	64	2,260	3,924

Figure 53. Different forms of agriculture in the SRB, according to estimated level of sustainability. Source: made by author, based on (FutureWater, z.d.).

Figure 54. Graph of agriculture transition towards more intensive water use systems. Source: made by author, based on (FutureWater, z.d.).

ECONOMIC VALUE

The transition towards more water-intensive irrigation goes hand in hand with the water productivity of the crops produced with these new methods. As Aldaya and others (2019) point out, water productivity analyses by sub-sectors are helpful in understanding the economic incentives of the basin activities.

Water productivity within the agriculture sector is defined as crop yield per cubic metre of water consumption. This includes green water (precipitation) for rain-fed areas and green and blue water for irrigated areas (Cai & Rosegrant, 2003). The water consumption includes beneficial water consumption, where the water consumption directly contributes to crop growth, and non-beneficial water consumption, including distribution and conveyance losses due to evaporation and sinks (which are not reusable). Beneficial water consumption is measured by water use efficiency (at the river basin scale) (Keller et al., 1996).

A more recent definition of water productivity, however, also includes the social value for the region, defining water productivity as the amount of value (in terms of benefits and services) created per volume of water consumed to produce this value (Waterproductivity, 2022). It depends on the amount of output, the nutritional value, and the socio-economic value that is derived. Therefore, it not only acknowledges the amount of crops produced per unit of water and the amount of economic profit made, but also social values such as jobs.

To determine the water productivity of agriculture in the basin, the (clusters of) most produced crops are analysed, in accordance with the economic profit they make. Additionally, the water use efficiency of the new systems and the effects on social benefits in the form of jobs are discussed.

CROP MAJORITY

Within the SRB, citrus trees cover 29% of the cultivated irrigated area, and outdoor vegetable crops 28%, followed by 16% of fleshy fruit trees (Aldaya et al., 2019).

A simplified zoning map of the different crops produced in the basin, based on the combination of different land use data sources (EC JRC, 2022 & CORINE Land Cover 2022), is presented in Figure 56.

WATER FOOTPRINT

Cereals have a high global average water footprint compared to other primary crops (1600 m3/ton for cereals, compared to 200 m3/ton for sugar crops) (Mekonnen et al., 2011). Wheat and rice are the crops with the highest average blue water footprint. However, when more is produced at once, the water footprint lowers. The relationship between average yield and water footprint per ton of cereal has been visualised by Mekonnen and Hoekstra in Mekonnen et. al (2011), shown in Figure 55. This graph illustrates how increasing cereal yields reduces the water footprint per crop produced. The transition to monocultural production methods could therefore be explained from an economic point of view, where water costs would be less with higher production. Combined with a higher yield, this method results in higher profit. However, the amount of profit depends on the economic productivity of the crop produced.

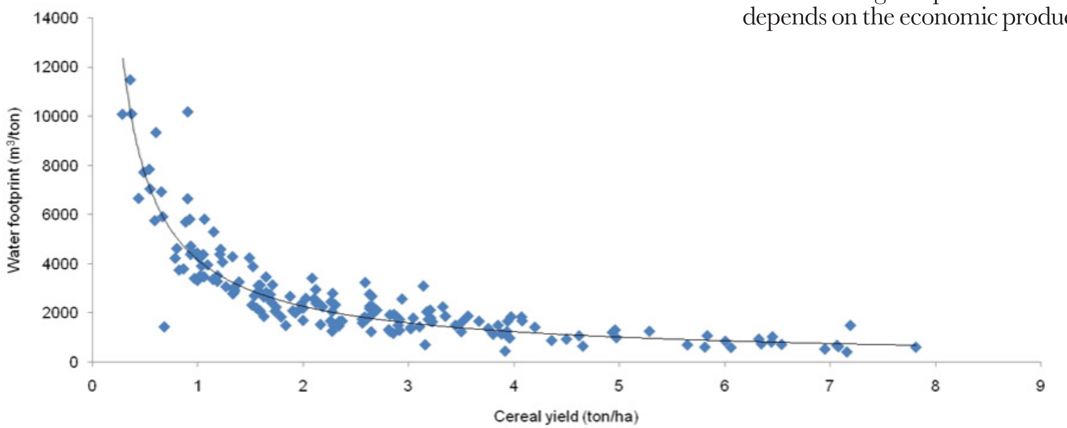


Figure 55. The relationship between average cereal yield and water footprint per ton of cereal (from 1996 – 2005, average country data). Source: Mekonnen et al. (2011).

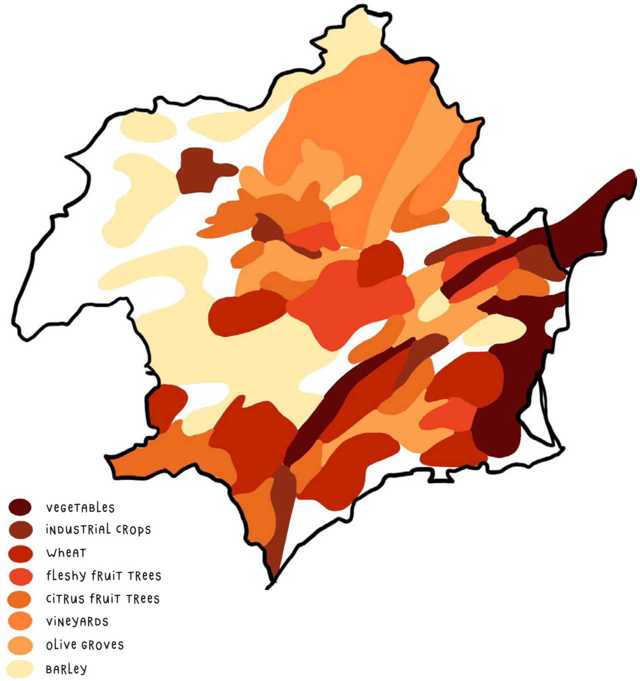


Figure 56. Simplification of the different crops produced in the SRB. Source: made by author, based on (EC JRC, 2022 & CORINE Land Cover 2022).

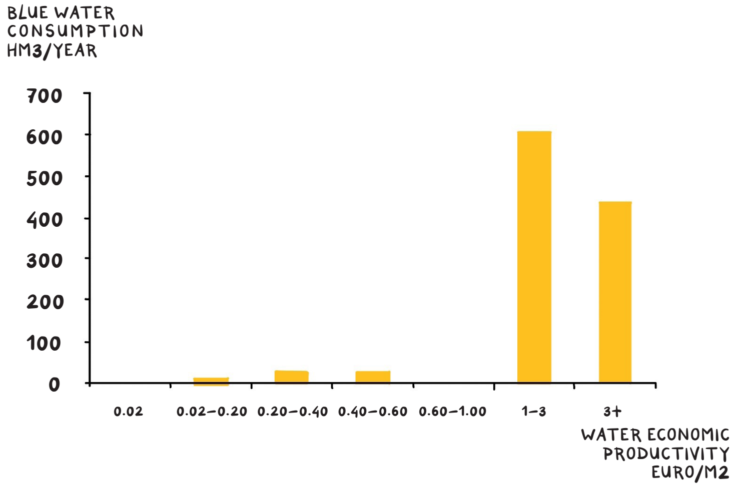


Figure 57. Blue water consumption by productivity range in irrigated agriculture in the SRB. Source: Aldaya et al. (2019), based on based on CHS (2015) and data from the Government of Spain and the green water footprint (Aldaya et al., 2017).

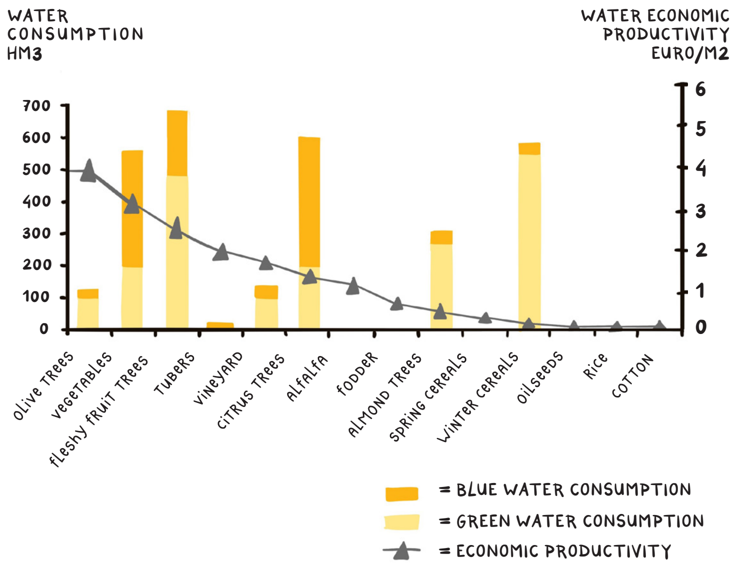


Figure 58. Blue and green water consumption and blue water economic productivity in the SRB. Source: made by author, based on: (Aldaya et al, 2019), (CHS,2015), data from the Government of Spain (2015), and the green water footprint (Aldaya et al., 2017).

ECONOMIC WATER PRODUCTIVITY IN THE SRB

Aldaya and others (2017) have researched the relationship between water consumption and water economic productivity in the SRB. As can be concluded from Figure 57, a correlation between the two can be found. The production of more water-intensive crops that have a high blue water consumption through irrigation often generates more economic profit for the farmer. However, this depends on the type of crop produced and the agricultural watering method used. Figure 58. shows the relationship between blue and green water consumption and blue water economic productivity for the different crops produced in the SRB. Traditional crops (cereals: wheat, barley, oats, rice, maize, sunflower) and industrial crops (cotton) have a water economic productivity between 0,1 and 0,3 €/m3 (Aldaya et al., 2017). This number is higher for almond trees (0,5 €/m3) and citrus trees (1,4 €/m3). Fleshy fruit trees, potatoes, and vineyards reach 2 €/m3, and olive trees 4 €/m3. Vegetable crops under protected plastic covers (such as tomatoes, melons, lettuce, and peppers) reach 7 €/m3 (Aldaya et al., 2017).

Protected vegetable production has the highest water economic productivity, as it is characterised by a relatively low (blue) water consumption. The greenhouse vegetables (covering 3% of the total irrigated area in the basin, 7800ha) consume 5% of the blue water in the region, and together have an economic value of 14% of the total irrigated agriculture (380M€/year) (Aldaya et al., 2019). This would explain the crop change to covered vegetables in the form of greenhouse agriculture and plastic covers.

However, if the social value for the region was to be taken into account, this type of agriculture would score much lower, as these vegetables are not consumed in the area. Next to this, the transition to quilted and greenhouse agriculture led to semi-mechanised monocultures of agricultural production, reducing the number of jobs in the region. This is supported by data derived from the INE, obtained from a survey (Economically Active Population Survey) in 2024 that was published on the CREM website of the Autonomous Community of Murcia. With the growth of irrigated and greenhouse agriculture in Murcia, the number of people employed in the agriculture sector in the region has been declining since 2017 (from 80.5 thousand to 73.3 thousand in 2023) (CREM, n.d.).

VIRTUAL WATER EXPORT

In total, 40% of the economic value in the SRB is produced with 60% of the available water (Aldaya et al., 2019). The trade of the agri-food sector exports is key to this economic production, mostly with other European countries. The region of Murcia accounts for 20% of the Spanish exports of fruits and vegetables. Since 2005, the area has been a net exporter of lettuce (42% of the vegetables produced) and citrus fruits (49% of all fruits, with 63% being lemons) (Aldaya et al., 2019). Therefore, the virtual water export of the region is high.

Virtual water refers to the volume of water consumed in producing a certain good or service along its process chain (Allan, 2011). Virtual water trade (also called virtual water flow) refers to the volume of virtual water transferred from one area to another, as a result of the trade of products (Aldaya et al., 2019).

The SRB is a virtual water-exporting region, due to the many water-intensive crops produced (mainly fruits and vegetables) that are exported outside of the area. In total, 1253 hm3/year of water is virtually imported (related to feed for pig farms) and 1598 hm3/year is virtually exported (Aldaya et al., 2019). Related to fruit and vegetables alone, the region of Murcia virtually exported 494 hm3/year from 2005 to 2015 (Aldaya et al., 2019).

ORGANIC AGRICULTURE

Apart from highly industrialised agriculture focused on maximising economic production, occupational agriculture in the form of local small farms exists too in the basin. In 2012, organic agriculture in Murcia alone reached 59,000 ha, which was 3,7% of Spain's total organic farming area at the time (Government of Spain, 2018). This form of agriculture is less harmful to the environment through its services for the landscape and provides social support and value. Therefore, it should be promoted through water management.

TOURISM

The tourism industry is growing rapidly, especially along the Mediterranean coast. The coastal areas of the Segura Basin experienced substantial urban-residential growth starting in the mid-1960s, because of the rise in tourism that came with the region's economic expansion during Franco's regime. Over the last decades, a trend in the region can be noticed where apartment buildings, golf courses, and luxurious resorts are being built, especially for seasonal tourists. In the summer season, the population in the basin almost doubles due to the number of tourists. This has an enormous effect on the water demand in the region. The urban areas surrounding the coastal lagoon Mar Menor experience an increase in population of 10 times during the summer season (Marín et al., 2015), resulting in an escalation of peak water demand during the dry months.

The irrigation of golf courses is the most significant factor in this increase in water demand. Despite the known water stress, golf courses and resorts are abundant in Spain (with a total amount of 446), especially near the Mediterranean coast, with Andalucia scoring the highest with 106 courses (Statista, 2021). The fastest growth of golf courses was seen in Valencia (38) and Murcia (19) in the first decade of the twenty-first century, because of economic incentives. An average golf course of 18 holes consumes between 1500 and 2000 m3 of water per day during the summer, up to 300,000 m3 per year (Lopez-Ruiz & Gonzalez-Gomez, 2023). Per hectare, an average golf course could generate from €12,000 to €48,000 per year, compared to €6,500 to €10,000 per hectare for productive agricultural land in Murcia (Maestu & Gomez, 2009).

Figure 59. Image of the export industry in the harbour of Campo de Cartagena, in Cartagena city. Source: Made by author.

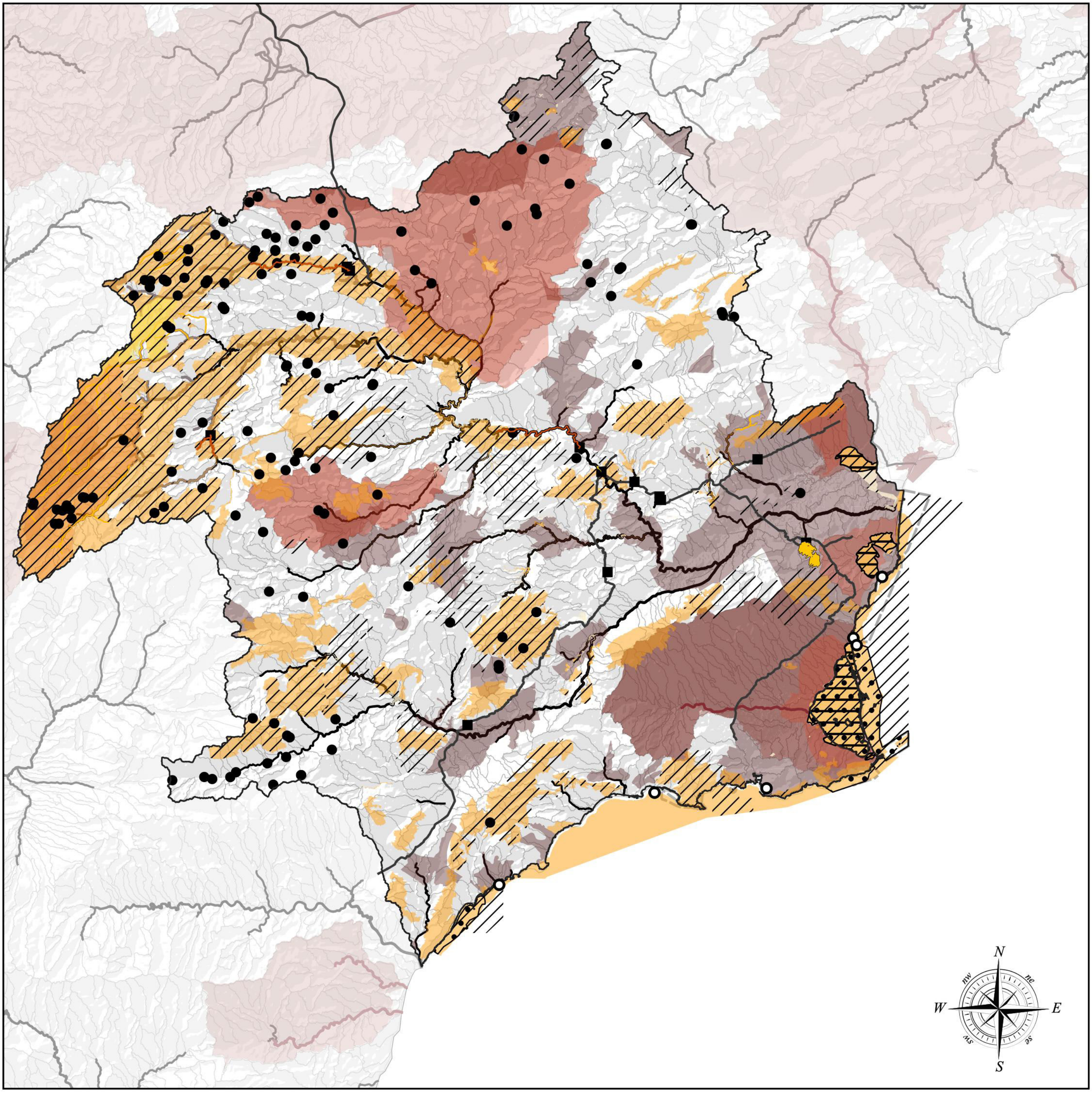
CONCLUSION

Land use in the basin is characterised by high water use, anthropogenic activities that are focused on maximum economic profit in the form of intensive agriculture and tourism. These unsustainable activities are the main drivers of the increased water demand (and thus water scarcity) in the SRB.

A recent transition from rainfed agriculture to intensive irrigation and greenhouse agriculture was noticed in the basin, enabling big cooperations to semi-mechanise the export production of crops that earn the most economic profit. Even though most irrigated lands are equipped with a drip-irrigation system that measures and adjusts the water supply to the needs of the crops, the transition towards more water-intensive systems is an important contributor to the water scarcity in the area. These crops often use more water, which is then virtually exported, contributing to the water shortage. Additionally, socio-economic benefits for the citizens and individual farmers in the region are decreasing. Automation of the production process leads to job losses, and the increase in profit only benefits some of the bigger companies. This is an unsustainable form of agriculture, which is responsible for the water scarcity in the region.

Suggestions for a transition to a more sustainable agri-food system would include focusing on more local food production and distribution, organic agriculture practices, and de-transitioning to rain-fed agriculture with permanent woody crops or less water-demanding crops. Sustainable agriculture and water use need to be promoted by means of good water management, knowledge exchange, good collaborations, and a change in perception of food production towards degrowth. This transition must happen in coordination with nature restoration efforts, using nature-based solutions and technological innovations.

Figure 60. Image of an empty container ship entering the export harbour of Campo de Cartagena, in Cartagena city. Source: Made by author.



Author - February 2025

NATURE CONDITIONS

WATER DEPLETION AND POLLUTION

Water Supply
- Protected reservoirs for water supply
- Protected rivers for water suppy
- Surface water abstraction points
- Groundwater abstraction points
- Coastal water abstraction points

Protected Habitats
- RAMSAR - internationally protected wetlands
- Special protected areas
- ZEPA - special protection areas for birds
- Wetlands protected by Spain
- Groundwater protection
- SCI - LIZEC - special conservation zones related to water
- Fluvial natural reserves - riverine protected areas

Ecologically vulnerable areas
- Vulnerable zones
- Sensitive zones
- Sensitive areas - water catchment areas
- Sensitive areas - drainage basins
- Sensitive areas - rivers

Protected areas of economic interest
- Shellfish production
- Fishing interest
- Trout waters Castilla La Mancha

Base map
- Inland water
- Drainage network
- SRB outline
- TST

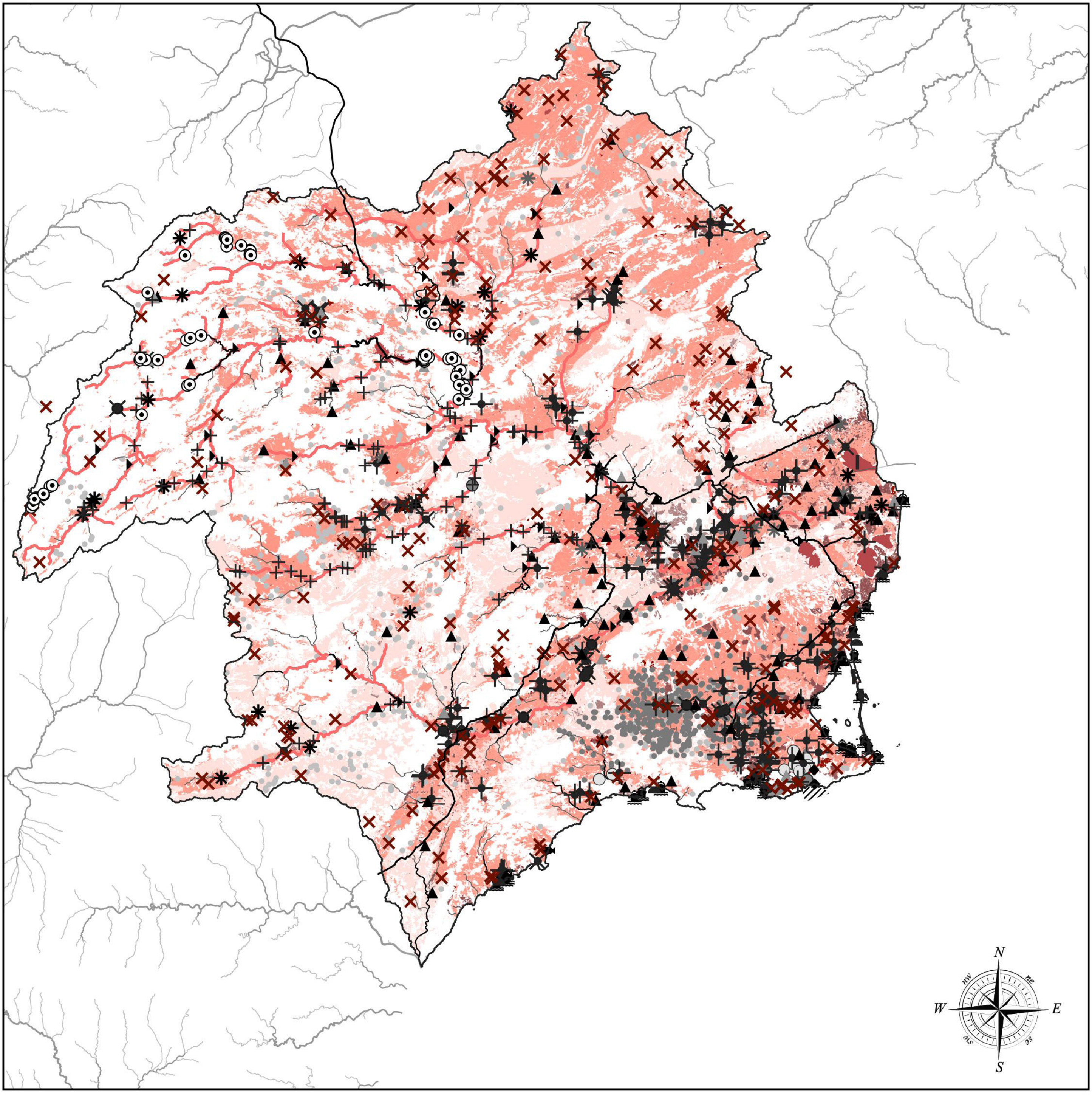
Figure 61. Protected and vulnerable areas and water abstractions. Source: Made by author, based on data from CHS (2025) .

The commodification of nature, through a history of overexploitation of water resources in the region, has had noticeable effects on the natural conditions of the basin. Exploring these effects and their causes is relevant to achieving a good ecological status, as required by the Water Framework Directive (WFD) for the management of European rivers.

In this paragraph, the state of the natural environment and the waterbodies in the basin as they are now, as a result of these agricultural and urban activities, are examined.

SURFACE WATER CONDITION

The river's regime has been modified drastically over the years, where the natural flow has vanished in the Low Segura area and the river bed only receives small quantities of return flows from agriculture, polluted wastewater, and sewage water (Ibor et al., 2011). Some areas stay dry for most of the year, apart from the desembalses. Desembalses are periods of around 25 days, in which the river flows through the traditional irrigation areas of La Vega because the dams release the water. Desembalses occur only up to four times a year. When this happens, accumulated



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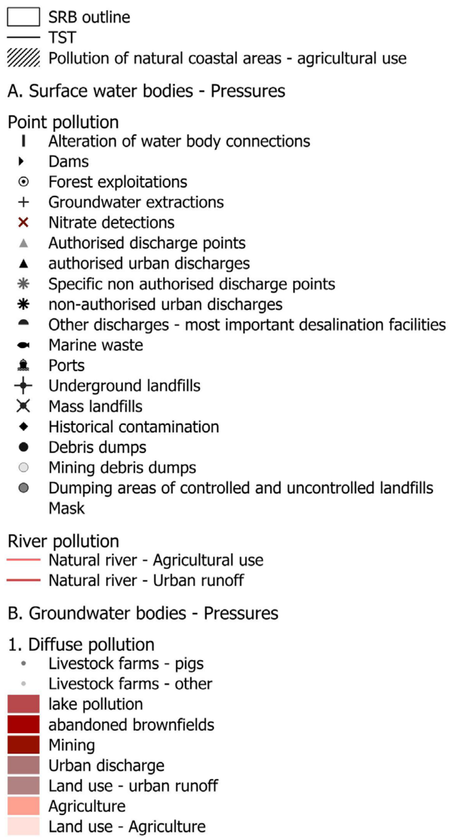


Figure 62. Diffuse and point pollution in the SRB. Source: Made by author, based on data from CHS (2025) .

pollution on the river bed gets swept away, polluting the agricultural lands that receive the water first. The different uses of the soil and the environmental conditions of the basin together determine the distribution of pollutants in the river. The geomorphology of the basin and the water flow of the catchment area (from high to low altitudes) characterise the basin and define the transport of materials that are suspended or dissolved in the water. Therefore, the anthropogenic activities causing pollution have to be taken into account when designing for mitigation and managing the environmental status of a river basin.

Since the 21st century, pollution of the Segura River has reached alarming levels. Concentrations of mercury, nickel, tin, ammonia, and phenols led to the implementation of oxygen injectors near Orihuela and Rojales to reduce the smell of the pollution (Ibor et al., 2011). While significant improvements have been noticed in the Rivers 'health, in 2019, 15 waterbodies were identified as vulnerable by the regional government of Murcia, due to a concentration of nitrates that exceeded the norm set by the EU (Zuluaga-Guerra et al., 2023).

Because pollutants are distributed across the entire floodplain through irrigation canals, soil and water salinity is increasing rapidly.

According to research by Javier et al. in 2015, the highest concentration of pollutants and toxicities is observed in the lowlands, where urbanisation and industries are causing the biggest input of contaminants into the water and soil. Within this area, most pollutants were accumulated in the downstream points near Orihuela. These pollutants included chromium, lead, zinc, nickel, and copper and endocrine-disrupting compounds (Javier et al., 2015).

Restoring the ecological flow of the rivers and other surface water bodies in the basin has been on the agenda of the CHS for years. While efforts have been made to clean the rivers in the basin and restore the ecological flow, many remain severely altered to completely manmade. According to the hydrological report published by MITECO (2023), 21 (17%) out of a total of 114 surface water bodies in the region did not yet achieve good chemical status (see Figure 63). Additionally, 62 water bodies still have to achieve good ecological status by 2027 (see Figure 64).

Next to this, 46 water bodies with fixed flow that require permanent control, still lack these control measures. It is important to work on these problems and restore the ecological flow of the rivers, to comply with the rules set by the WFD on 'good ecological status' of water bodies in 2027. Through Spanish legislation, an ecological flow is defined as a flow that contributes to achieving good ecological status or potential in rivers as a minimum value, to support the fish life that would or could naturally inhabit the river, as well as its riparian vegetation (MITECO, 2023).

DIFFUSE NITRATE POLLUTION

Excessive concentration of nitrates and traces of pesticides as a result of irrigation return are the main polluting elements in the basin, affecting numerous waterbodies and hindering the WFD objectives, such as the law (91/676/CEE) about regulating the protection of waters against pollution caused by nitrates from agricultural sources (CHS, 2020). Pollutants from agricultural run-off not only influence the river's health, as they also reach groundwater bodies through the soil. According to a report by the CHS, almost 90% of the surface masses and 86% of the underground masses of the demarcation are under pressure from agricultural uses (CHS, 2020). The main areas mentioned to be affected are the areas of (1) Campo de Cartagena, (2) the Guadalentín Valley, and (3) Vega Alta, (4) Vega Media, and (5) Vega Baja (see Figure 65).

In 2020, the CHS reported that 23 groundwater bodies in the basin were polluted with nitrates (García Mariana, 2020). According to a report from MITECO published in 2023, this number has reached 26. Currently, 30% of the surface water bodies (34 out of a total of 114) and 41% of the groundwater bodies (26 out of a total of 63) are suffering from significant pressures due to diffuse pollution of agricultural origin, mainly because of fertilisers and pesticide use (see Figure 68 and 71) (MITECO, 2023). In addition, livestock farms are one of the main sources of ammonia infiltrated in the soil (Marín et al., 2015). Furthermore, golf resorts contribute to groundwater contamination as well, as they are fertilised too.

Good chemical status in surface water bodies

	Category	River s		Lakes			Transition	Coastal		Total
	Nature	N	MM	N	MM	A	N	N	MM	
Chemical Fitness Targets (No. masses)	Reached already in 2021 (PH 3er cycle)	57	7	1	12	3	1	12	-	93
	Horizon 2027	10	3	-	3	-	-	2	3	21
	Total	**67**	**10**	**1**	**15**	**3**	**1**	**14**	**3**	**114**

N: Natural **MM**: Heavily Modified **A**: Artificial

Figure 63. Good chemical status of surface water bodies. Source: MITECO (2023).

Good ecological status/potential in surface water bodies

	Category	River s		Lakes			Transition	Coastal		Total
	Nature	N	MM	N	MM	A	N	N	MM	
Good ecological status/potential targets (No. masses)	Already achieved in 2021 (PH 3er cycle)	28	-	-	10	3	-	10	1	52
	Horizon 2027	39	10	1	5	-	1	4	2	62
	Total	**67**	**10**	**1**	**15**	**3**	**1**	**14**	**3**	**114**

N: Natural **MM**: Heavily Modified **A**: Artificially Man-made

Figure 64. Good ecological status of surface water bodies. Source: MITECO (2023).

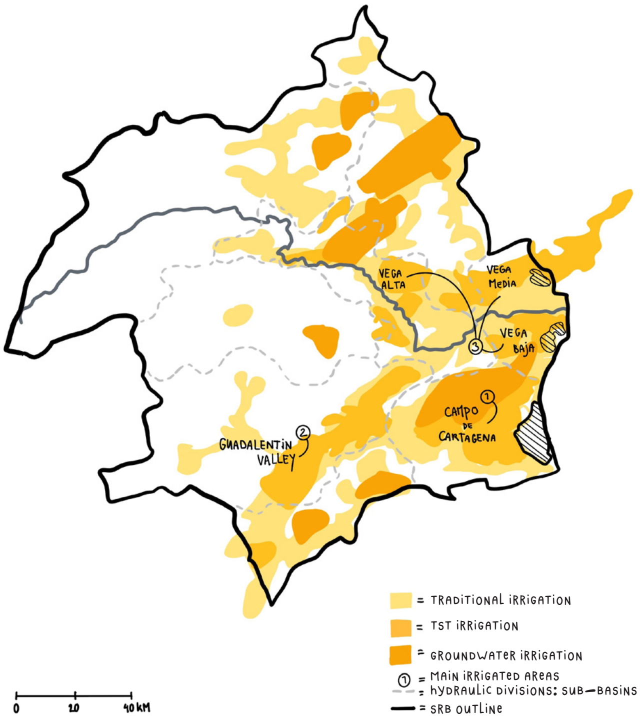


Figure 65. Main irrigated areas in the SRB, affected by nitrate pollution. Source: made by author, based on (CHS, 2020).

According to Foster and Custodio (2019), nitrate infiltration from irrigation water into permeable soil happens at a slower rate than table-water depletion in the area. This means that diffuse groundwater pollution through the accumulation of nitrates is a threat to the groundwater (and thus drinking water) quality in the basin. The diffuse groundwater pollution is also of economic concern, as it makes the groundwater unsuitable for irrigation, unless it is denitrified. In addition, nitrification contributes to the eutrophication of nearby wetlands, which is a threat to the biodiversity and ecological status and well-being of the basin (Steffen et al., 2015).

In all three main irrigated areas, nitrate values well over the "good condition" limit of 50 mg/L have been recorded in the groundwater bodies (CHS, 2020). In the Vegas Media and Baja area, drainage and sewage networks allow for circulation flows for better channelling of irrigation returns before discharge into the sea.

CAMPO DE CARTAGENA AREA – 43,000 HA

In the Campo de Cartagena area, nitrogen and other nutrients and salts reach the Quaternary and Pliocene aquifers and end up via gullies (which act as drains) in the Mar Menor coastal lagoon. An underground contribution of 1575 tons of nitrates has been estimated to have reached Mar Menor in 2018/2019 as a result of 8.5 hm3 agricultural discharge with a nitrate concentration of 204 mg/L (CHS, 2020).

GUADALENTÍN VALLEY – 40,000 HA

For the Guadalentín Valley, the nitrogen load for the irrigated land has been estimated at 262 kg N/ha/year. Of this number, 170 kg N/ha/year comes from fertilisation. The rest comes from irrigation water, the substrate, and atmospheric deposition. Two thousand sixty tonnes of nitrates are estimated to end up in groundwater bodies in the area (CHS, 2020).

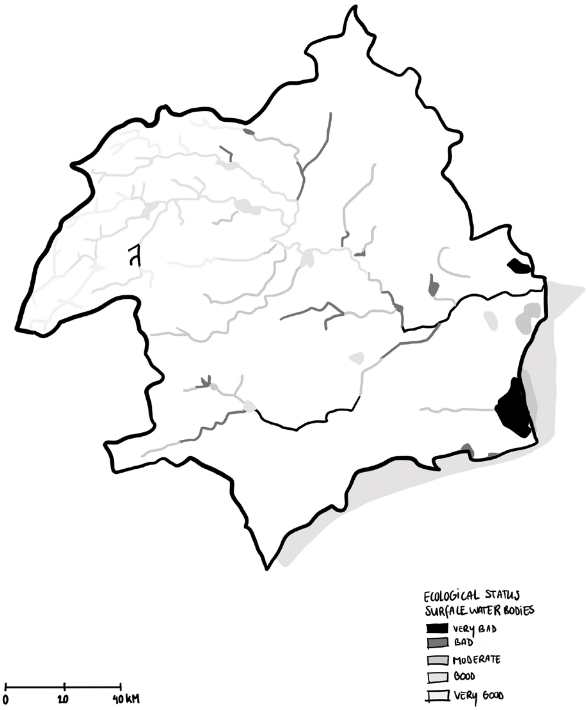


Figure 66. Ecological status of the surface water bodies in the SRB. Source: Made by author, based on (MITECO, 2023).

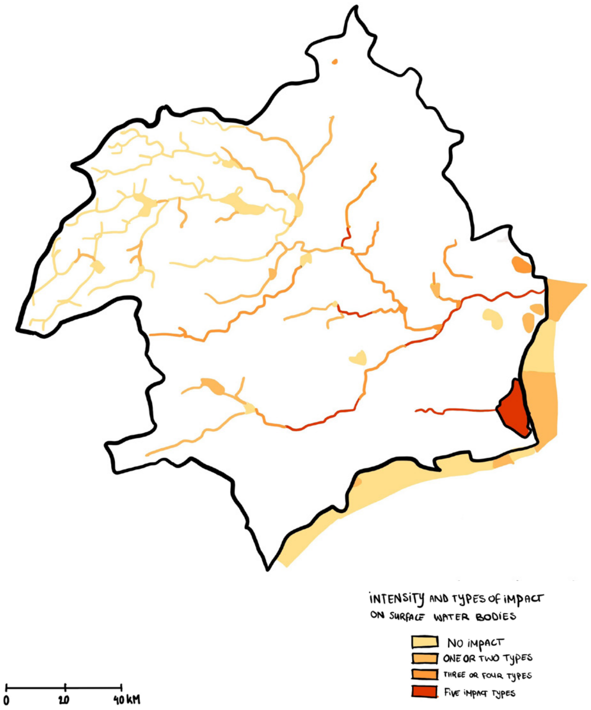


Figure 67. Surface water bodies impacted by diffuse nitrate pollution. Source: Made by author, based on (MITECO, 2023).

VEGAS MEDIA AND BAJA – 58,000 HA

For the Vegas Media and Baja, the nitrogen load has been estimated at 270 kg N/ha/year in Vega Media and 274 kg N/ha/year in Vega Baja, together representing a total contribution of 9,700 tonnes of N/year. In this region, salinisation of the water resources circulating in the Segura river because of the irrigation return system are another major problem to the water quality.

To protect the waters against nitrate contamination from agricultural sources, the Autonomous Communities within the SRB declared several 'vulnerable zones', with a total area of 2,533 km2 (12.5% of the total area) (CHS, 2020). The vulnerable zones defined correspond to the three main irrigation areas (Figures 62 & 65). The number of declared vulnerable zones is growing with each new hydrological plan.

In total, 39 groundwater bodies (62%) are at high risk of not achieving good ecological status in 2027, and 21 groundwater bodies (33%) are at high risk of not achieving good chemical status (MITECO, 2023). In fact, the situation is so severe that 36% of the groundwater bodies (9 in total) will most likely not reach good chemical status by 2027, and exemptions on the deadline for those water bodies are considered (see Figure 69).

GROUNDWATER LEVELS

Next to the threat of pollution, groundwater overexploitation is also still a present issue in the basin, despite the desalination efforts. As water from wells is still cheaper than using desalinated water for irrigation, and it does not cause boron-related problems, groundwater depletion continues in the basin at a rate of 231 hm3/year (Aldaya et al., 2019).

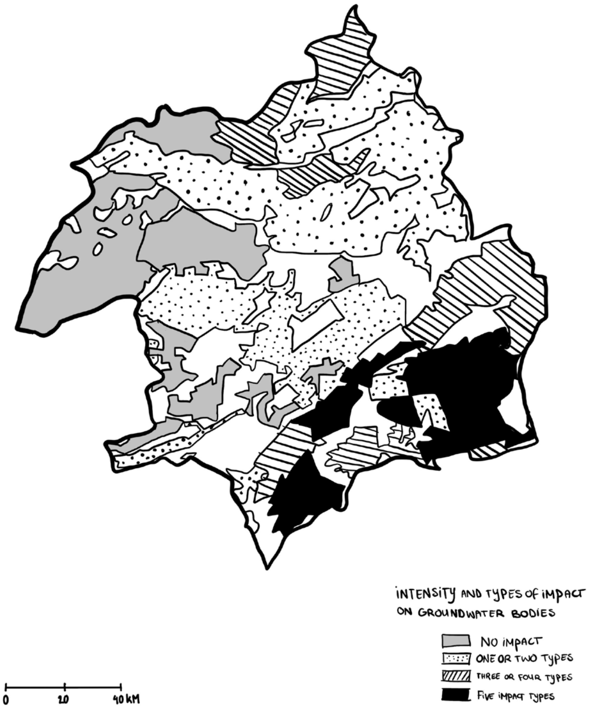


Figure 68. Groundwater bodies impacted by diffuse nitrate pollution. Source: Made by author, based on (MITECO, 2023).

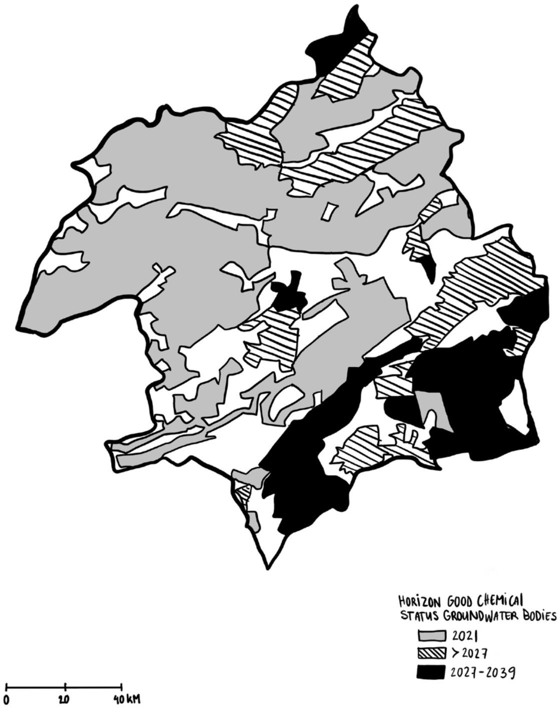


Figure 69. Exemptions for achieving good chemical status of the groundwater bodies in the SRB. Source: Made by author, based on (MITECO, 2023).

Currently, 27% of the surface water bodies and 65% of the groundwater bodies in the basin are subject to significant abstraction pressures and 37 out of 41 groundwater bodies present is impacted by groundwater overexploitation (see Figure 70) (MITECO, 2023). This is partly due to the fact that there are many unauthorised wells and springs operative in the region.

When transferred water volumes from the TST are low, overexploitation of groundwater sources in the Low Segura basin causes marine water intrusion into the aquifers, resulting in an increase in water salinity and a decrease in water quality. Especially in the Northeast of the basin, the groundwater bodies have reached alarming levels in terms of quantity. This is due to the fact that the irrigated areas in this region are not connected to any other possible water source. Therefore, connecting these areas to renewable water supply infrastructure, as well as managing wells in these areas and subsidising rainwater collection and forms of dry agriculture, are crucial actions in these areas to restore the water supply in the groundwater aquifers and prevent further exploitation.

However, even after exploitation ceases, the natural recovery time of intensely overexploited aquifers can range from decades to more than a century. (Custodio et al., 2016, MASE, 2015). The possibility of recovery is especially concerning in heavily polluted aquifers, such as the Campo de Cartagena area. Focusing on depollution methods is another crucial action in these areas.

PROTECTED WETLANDS

There are 120 wetlands in the SRB, occupying a total surface area of 230 km2 and accounting for 1.6% of the total surface area. 70 of these wetlands are protected areas based on the European Habitats directive (92/43/EEC) and Birds Directive (79/409/EEC) (CHS, 2015). In total, 6,735 km2 (33,2% of the territory) is a protected ecological area (MITECO, 2023).

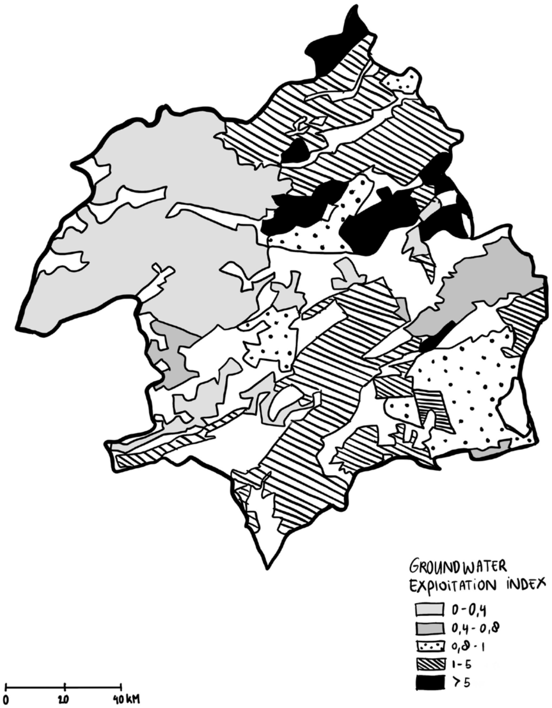


Figure 70. Exploitation index of the groundwater bodies in the SRB.
Source: Made by author, based on (CHS, 2020).

Good quantitative and chemical status of groundwater bodies

Good condition targets	Already achieved in 2021 (PH 3rd cycle)	Horizon 2027	Horizons> 2027	Total
Quantitative	25	38	0	63
Chemist	40	14	9	

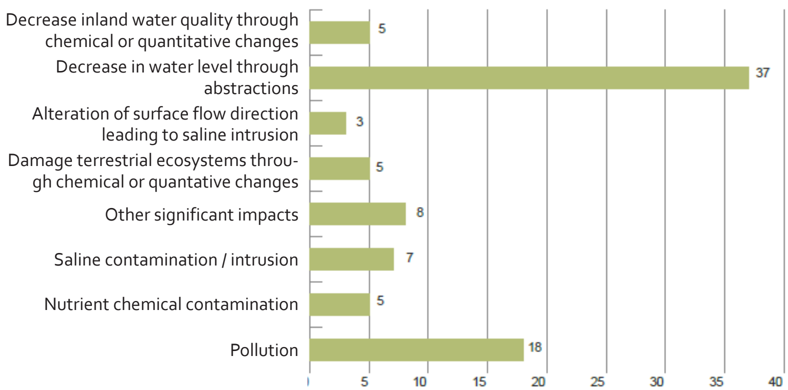


Figure 71. Verified impacts on groundwater bodies in the SRB.
Source: MITECO (2023).

Protected natural habitats are threatened by the impact of human activities such as agriculture, mining, urban development, and tourism. For instance, the implementation of the TST caused an altered plant and animal population in wetland areas of the basin, because it created different water conditions and increased nutrients (Marín et al., 2015). This has led to ecosystem degradation and biodiversity loss across the basin. According to research conducted by Zuluaga-Guerra et al. (2015), around 333,100 ha of drylands and agro-natural landscapes were lost due to agricultural development.

MAR MENOR COASTAL LAGOON

Ecological degradation caused by anthropogenic activities within the Segura River Basin is most noticeable in the Mar Menor coastal lagoon.

The Mar Menor Lagoon is a hypersaline lagoon with salt marshes and is one of the biggest coastal lagoons in the Mediterranean, covering an area of 135 km2. Its importance for biodiversity is categorised by the numerous international protection schemes, such as the listing as

Figure 73. Watercourses, saltmarshes and urban areas along Mar Menor. Source: (Marín et al., 2015).

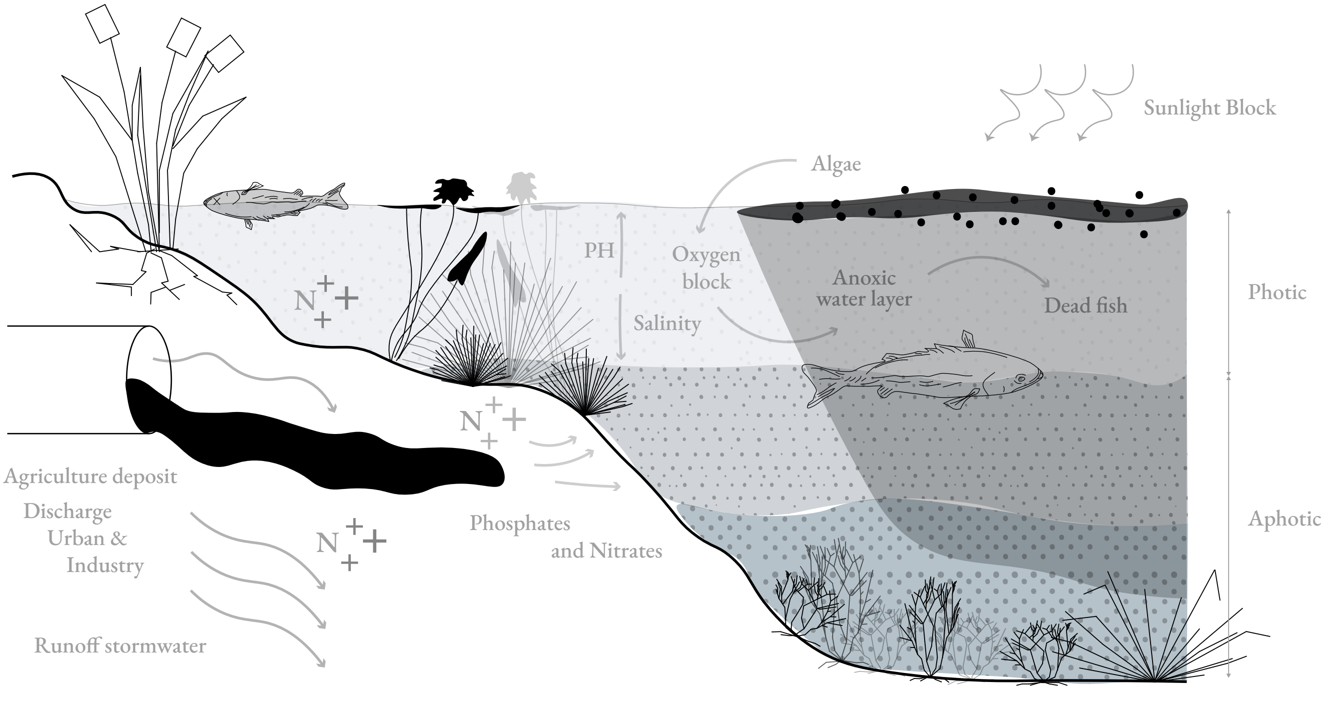


Figure 72. Section of the pollution in Mar Menor. Source: Made by author.

a Ramsar International site in 1994, Special Protected Area of Mediterranean Interest (SPAMI) according to the Barcelona Convention of 2001, and as a Site of Community Importance (SCI) within the Natura 2000 Network of the EU Habitats Directive. Additionally, the site is listed as a Specially Protected Area (SPA) for aquatic birds (the nesting, migration, and wintering), and is protected by European legislation (Marín et al., 2015; Lloret et al., 2015). A total of 179 aquatic bird and 46 fish species have been identified in the area and 23 habitats of Community Importance, of which 9 are considered a priority (Marín et al., 2015). The nacre species, critically endangered and native to the Mediterranean region, are especially protected (MITECO, 2023).

However, the rapid increase of irrigation agriculture and urbanisation to accommodate seasonal tourism has altered the natural landscape and increased waste management issues, as well as discharges of untreated urban wastewater. Therefore, more nutrients and pollutants reach the lagoon. Because of this, environmental changes in the lagoon have been occurring for years. With rising temperatures due to climate change, these effects are intensified. Additionally, the increase in flood risk associated with climate change has increased the chances of urban and agricultural pollution reaching the lagoon.

Freshwater input into the lagoon happens through six ramblas, which are wadis connected to the lagoon through wide but shallow gullies. During floods, they carry many sediments and great quantities of water. One third of the agricultural area of Campo de Cartagena (441 km2) is drained into the Albujón wadi, which is the principal watercourse of the lagoon and the origin responsible for the inputs of nutrients (Velasco et al., 2006; García-Pintado et al. 2007). The three wadis connected to the lagoon that are located South of Mar Menor carry (during rain events) metal waste and mineral deposits from the mining areas (Marín et al., 2015).

The expansion of irrigated agricultural land because of the TST led to a stressed water balance and increased pollutants in the water. Fertilizers and pesticides, coming from the Campo de Cartagena agricultural lands, contribute to nutrient loading, which causes eutrophication and habitat degradation. The rising nutrient levels cause a plankton population increase (Gilabert, 2001; Pérez-Ruzafa et al. 2005). Because of its shallow depth and restricted exchange with the sea, Mar Menor is particularly vulnerable to eutrophication. The accumulation of phytoplankton causes algae blooms, which reduce the amount of available oxygen and sunlight. In light-deprived shallow areas, anoxic conditions are created. Here, organic matter accumulates, which causes a progressive deterioration of the sediment and the production of toxic sulphites. This process has degraded the water quality of the lagoon and caused the local fish population to decrease, which had adverse effects for the commercial fishing industry (Pérez-Ruzafa et al., 2002). This process is perceived as the eutrophic crisis of the Mar Menor lagoon (see Figure 72) (Alvarez-Rogel et al., 2020; Martinez-Fernandez et al., 2014). Additionally, the increase in the nutrient levels in the water created favourable conditions for the jellyfish population, which grew immensely. This has negatively impacted the tourism industry.

Urban areas currently occupy most of the land surrounding the lagoon, and experience a population increase of ten times during the summer due to tourism. These newly built urban tourist developments have generated a degradation of the landscape, loss of biodiversity and fertile soils, and problems related to waste(water) management, which require new water treatment facilities and infrastructure (Marín et al., 2015). Heavy metal concentrations associated with historical mining activities in the area have been found in the lagoon's sediments (Marin-Guirao et al., 2005a, 2005b, 2007, 2008). As increasing floods and storms transport more heavy metals from the mountains to the lagoon, monitoring these levels becomes essential for environmental and human health.

Since 2020, the lagoon is legally protected by the Spanish law (3/2020 of July 27, 2020) on the recovery and protection of Mar Menor. Since 2022, the Mar Menor lagoon became the first European ecosystem with a legal personhood with three responsible governance structures to represent the lagoon in its right to protection, conservation, maintenance and restoration (Eco Jurisprudence Monitor, 2023). The organisations representing the lagoon are a committee of representatives, a monitoring commission, and a scientific committee. Furthermore, the Integrated Management Plan for Protected Areas of the Mar Menor and Mediterranean Coastal Strip and the Integrated Green Program of Actions are forming a framework of action, working on the recovery of the Quaternary aquifer of the Campo de Cartagena area, the Albujón wadi, and Mar Menor. In May 2026, the lagoon will appear in trial as a private prosecutor to hold polluters accountable and seek reparations for ecological harm, operationalising the Rights of Nature.

RISK AND URGENCY

Within the Campo de Cartagena area, large traditional agricultural areas have been reclassified to urban use, which are built on or around wadis. Because the Campo de Cartagena is the drainage area of the basin, these urban areas are highly prone to flooding. Additionally, the dune systems and beaches surrounding Mar Menor in the Southeast coast have been damaged by urban development and tourism and have disappeared by more than 60% over the last 40 years (Marín et al., 2015).

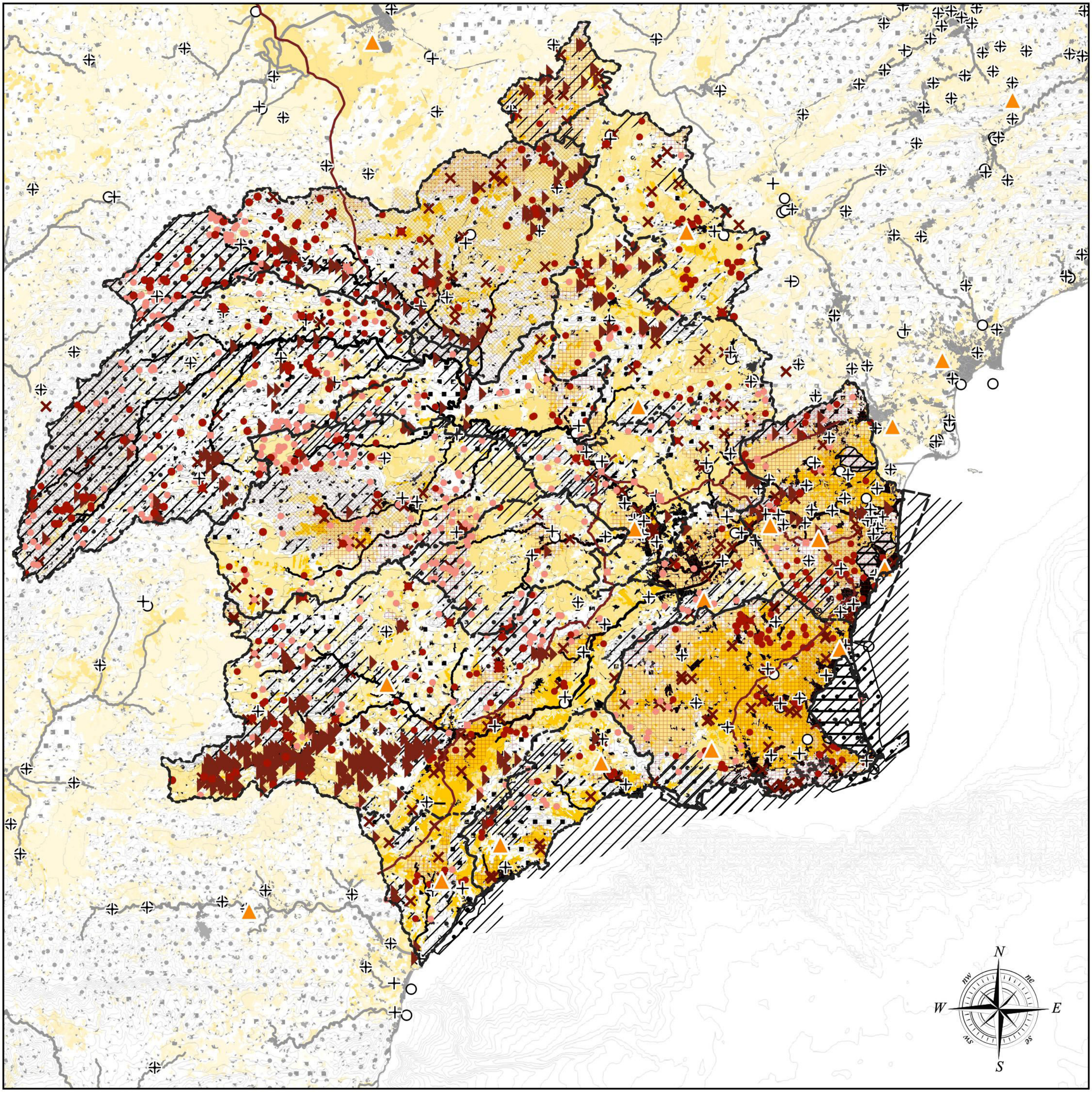
It is important for the water quality, protection of (special) birds and their habitats, overall biodiversity of the basin and for human safety in the form of flood control, that these wetlands near the Mar Menor lagoon are protected and maintained, so that natural water retention spaces stay functional.

CONCLUSION

Anthropogenic activities such as irrigation agriculture, tourism and urbanisation have caused severe environmental problems to the Segura River Basin. Intensively irrigated agriculture is the main source of pollution and groundwater contamination. The problems created include negative effects on the flood protection, biodiversity, surface and groundwater availability and quality, as well as human and ecological health.

Environmental degradation is most visible at the protected Mar Menor coastal lagoon. Increases in plankton and jellyfish populations due to nutrients and heavy metals from agricultural runoff and mining activities have led to eutrophication and loss of biodiversity. Tourism along the coast further intensifies the pollution of the lagoon, the Segura river, and the groundwater aquifers of the main irrigated districts.

Figure 74. Birds swimming in the polluted water of Mar Menor, adjacent to the wetland area carrying agricultural run-off water, with urban constructions in the background. Source: made by author.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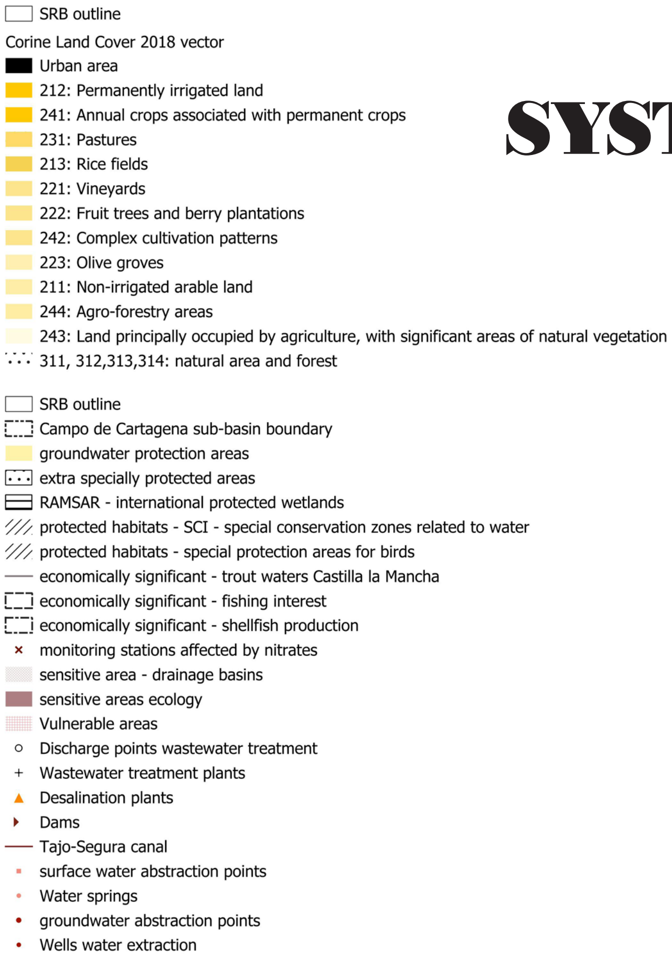


SYSTEM SYNTHESIS

AND SYSTEMIC TRANSITIONS

INTRODUCTION

As a conclusion of the analysis of the current situation of the water system in the Segura River Basin, a synthesis of the three layers examined is made in this chapter. Figure 75 shows a synthesis map of the problems and systemic elements identified in the region.

CHANGES IN THE SYSTEM

For the Segura River Basin, the transitions of the adaptive cycle of the water system can be explained as follows. The river basin developed its water systems early on by exploiting resources through agricultural growth and transitions, and urban development. This can be marked as the exploitation phase (r). Over time, these systems became more rigid due to heavy reliance on infrastructures such as the Tajo-Segura Transfer, centralisation of management, and inefficient water use practices. This phase is highlighted as the conservation phase (K).

Currently, the system is in the release phase (Ω), where stressors such as prolonged droughts due to climate change and ecological degradation signal the collapse of the existing management structures and overexploitation

Figure 75. Cumulative map of the water supply elements in the region, overlayed on the land use intensity. Source: made by author.

patterns. A transition towards the reorganisation phase (α) provides a window for innovative and sustainable solutions like integrated water resources management, circular water systems, and stakeholder collaboration. The shift of focus in water management from transferred water through infrastructures towards non-conventional and renewable water sources (such as desalination) already signals this system's reconfiguration of the reorganisation phase.

However, the analysis of the current system has shown that insufficient progress has been made so far, and the government is faced with a paradoxical interest. This research dives further into the question of how to design for, stimulate, and implement this transition. The different problems and solutions to those problems require different measures and approaches, while ensuring equality, justice and feasibility. This complex task requires inter-scalar and intersectoral collaborations, fostered by a socio-political and socio-environmental paradigm change.

ANALYSIS CONCLUSIONS

From the analysis, it can be concluded that the water system in the SRB is disrupted due to many ongoing and interrelated factors that are deeply rooted in the historic and socio-political context.

Agricultural activities are the main cause of water scarcity and aquifer depletion in the region and the primary source of pollution. Therefore, a framework for the transition of the water system in the region should primarily focus on transforming the agricultural land use and food production and distribution system.

Desalination efforts and wastewater treatment and reuse systems are present in the region, but unsustainable inter-basin water transfers and groundwater extractions still supply most of the water, and water subsidies are distributed in an unfair manner. A second focus of the framework for the transition of the water system should therefore be on

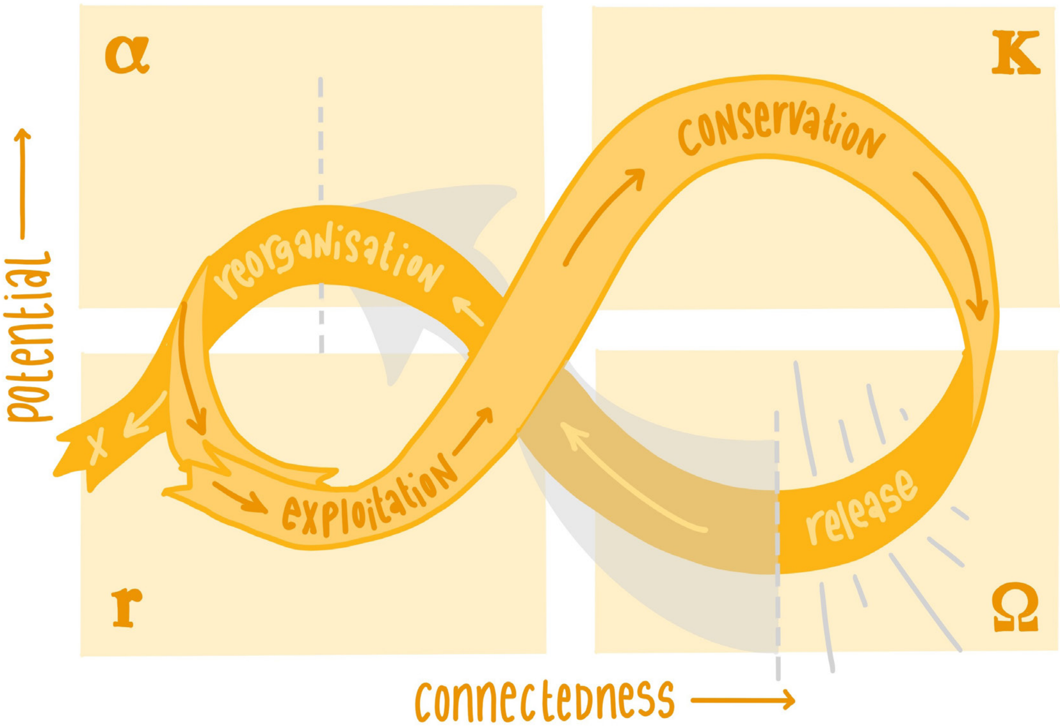
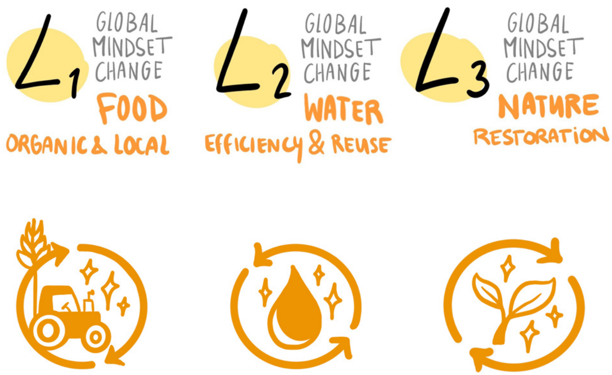


Figure 76. The Adaptice Cycle of the Panarchy Theory, showing the current position of the water system in the SRB. Source: made by author, based on (Gunderson & Holling, 2002).

implementing integrated water resources management principles, together with the spatial design challenge of renewable water production systems and the socio-political challenge of stimulating efficient water use.

Thirdly, the analysis of the substrate layer has shown an increase in attention to nature's well-being over recent years. Aquifer restoration, desertification prevention, and protection of special bird habitats are becoming increasingly important due to climate change and prolonged droughts. First steps into the restoration of natural landscapes and processes have been made in the basin, but more concrete actions need to be undertaken, and a feeling of responsibility needs to be instilled.



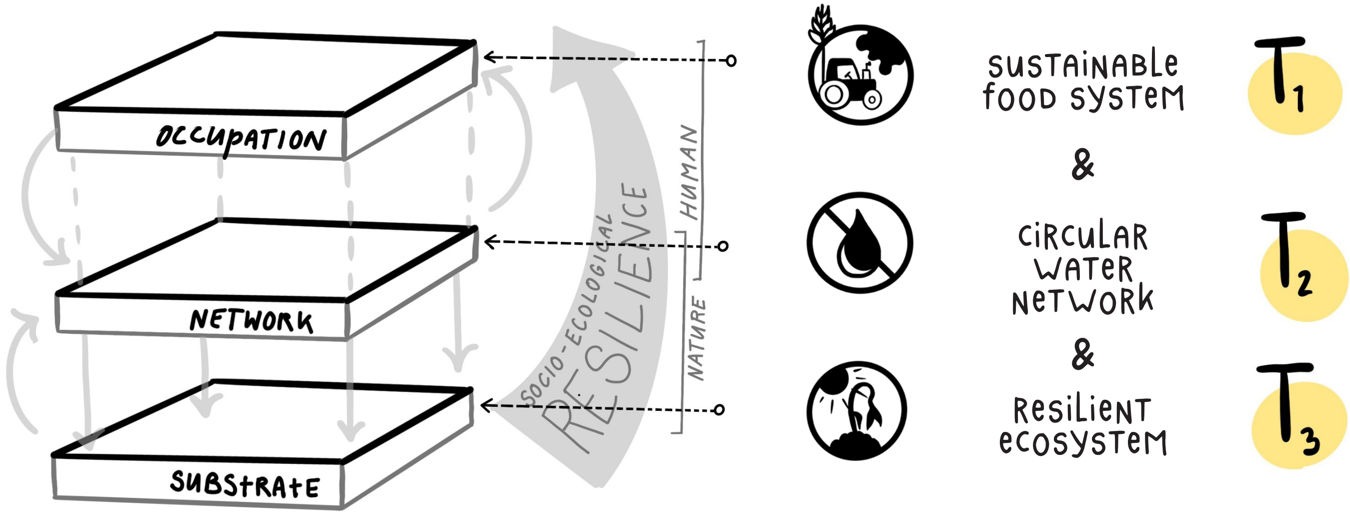


Figure 77. Conclusion of the integrated analysis of the water system in the SRB according to the Network Approach. Source: made by author.

SYSTEMIC TRANSITIONS AND LEVERAGE POINTS

The three approaches to include in the symbiotic framework for systemic change can be translated into three system transitions: T1) Sustainable Agriculture, T2) Renewable Water, and T3) Nature Restoration (shown in Figure 77). Each of these transitions comes with a global driver to support it. These global drivers are seen as leverage points for societal change and are imagined as preconditions for the further development of the methodology and design.

The three global mindset changes are:

L1) a changed perspective on food production and consumption towards local food self-sufficiency and organic food consumption,

L2) a changed perspective on water use towards responsible consumption and on water supply towards renewable water production, fair distribution, and pricing, and

L3) a changed perspective on natural processes and the landscape towards a zero pollution tolerance, prioritizing nature-based solutions, expanding and protecting biodiversity and ecology, and responsible recreation.

Together, these transitions, backed up by the leverage points, form the framework for systemic symbiosis of the water system transition (shown in Figure 78).

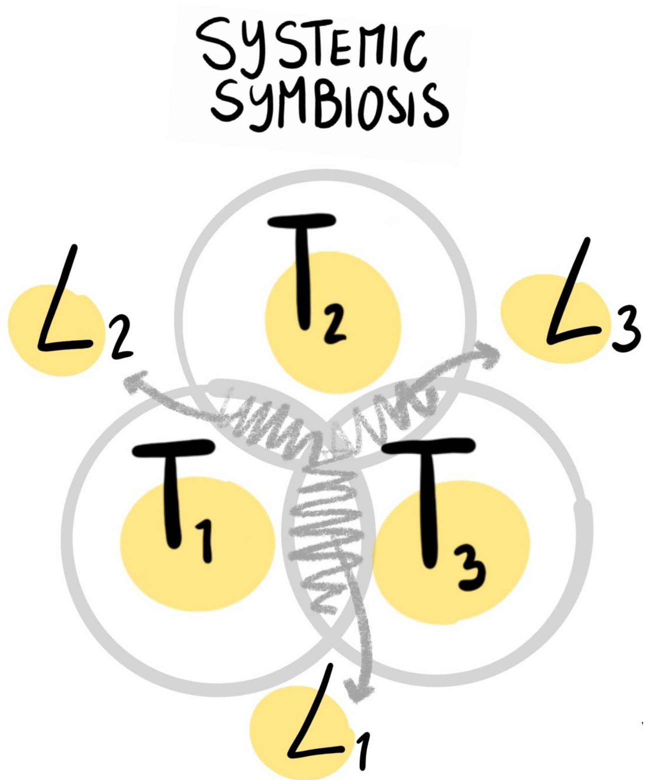


Figure 78. Systemic Symbiosis framework, derived from the integrated analysis. Source: made by author.

Figure 79. Image of the industry in the harbour of Cartagena. Source: made by author.

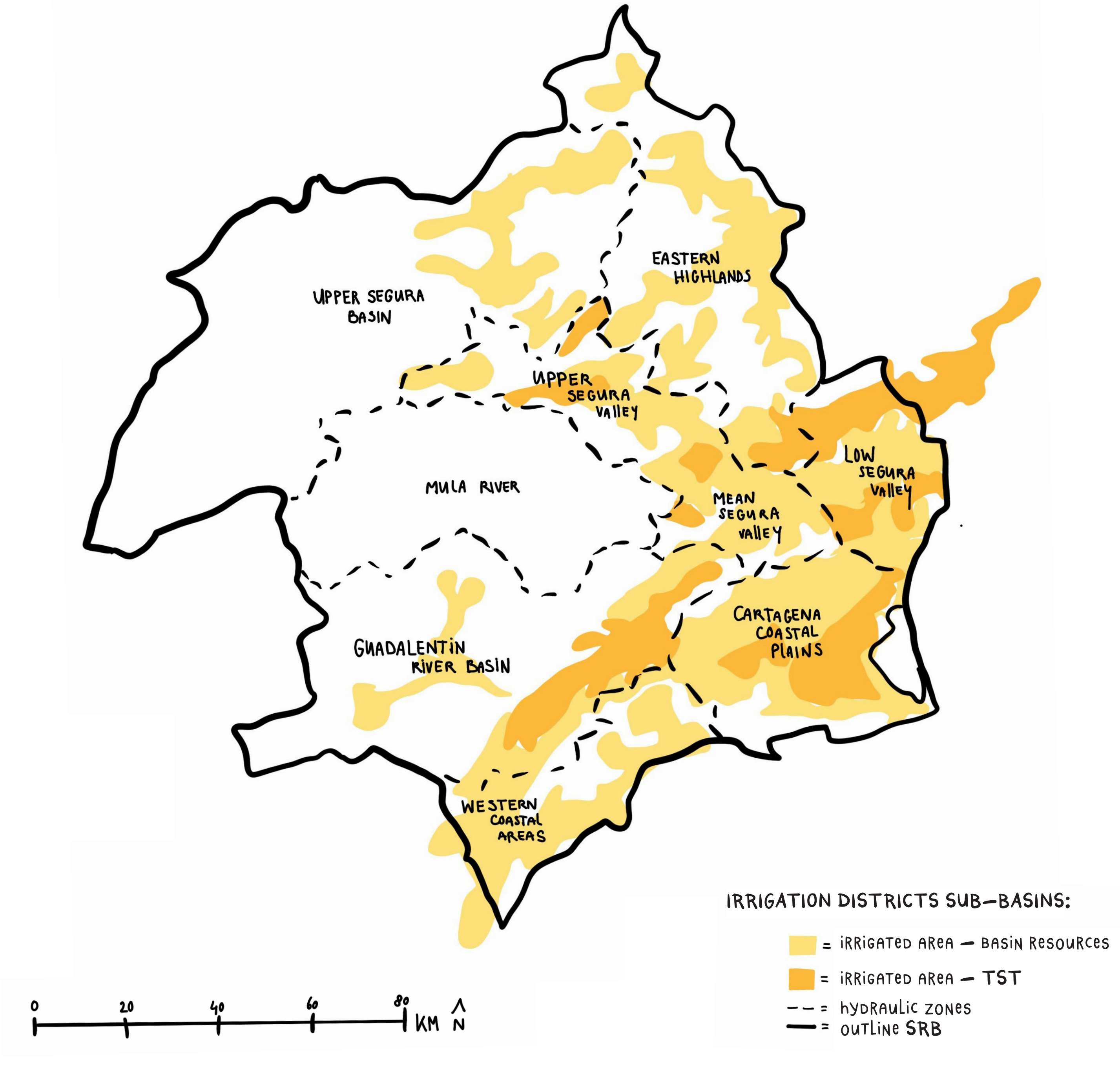
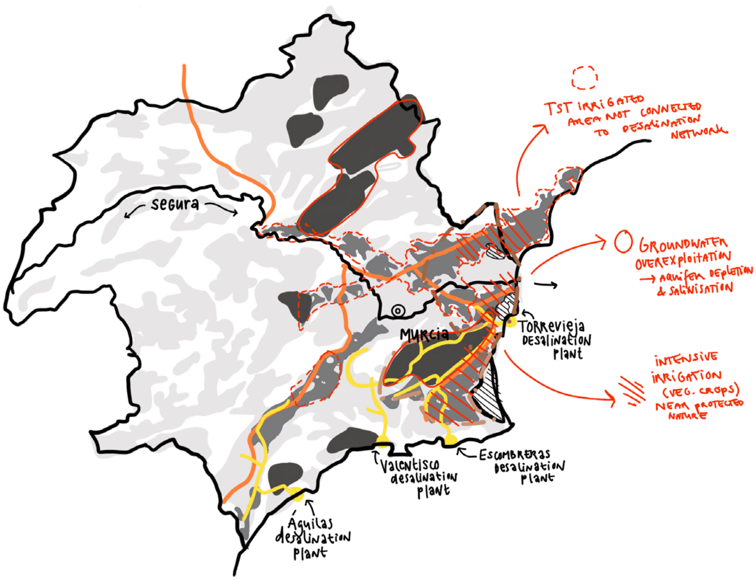


Figure 80. The irrigated areas in the sub-basins of the SRB. Source: made by author.

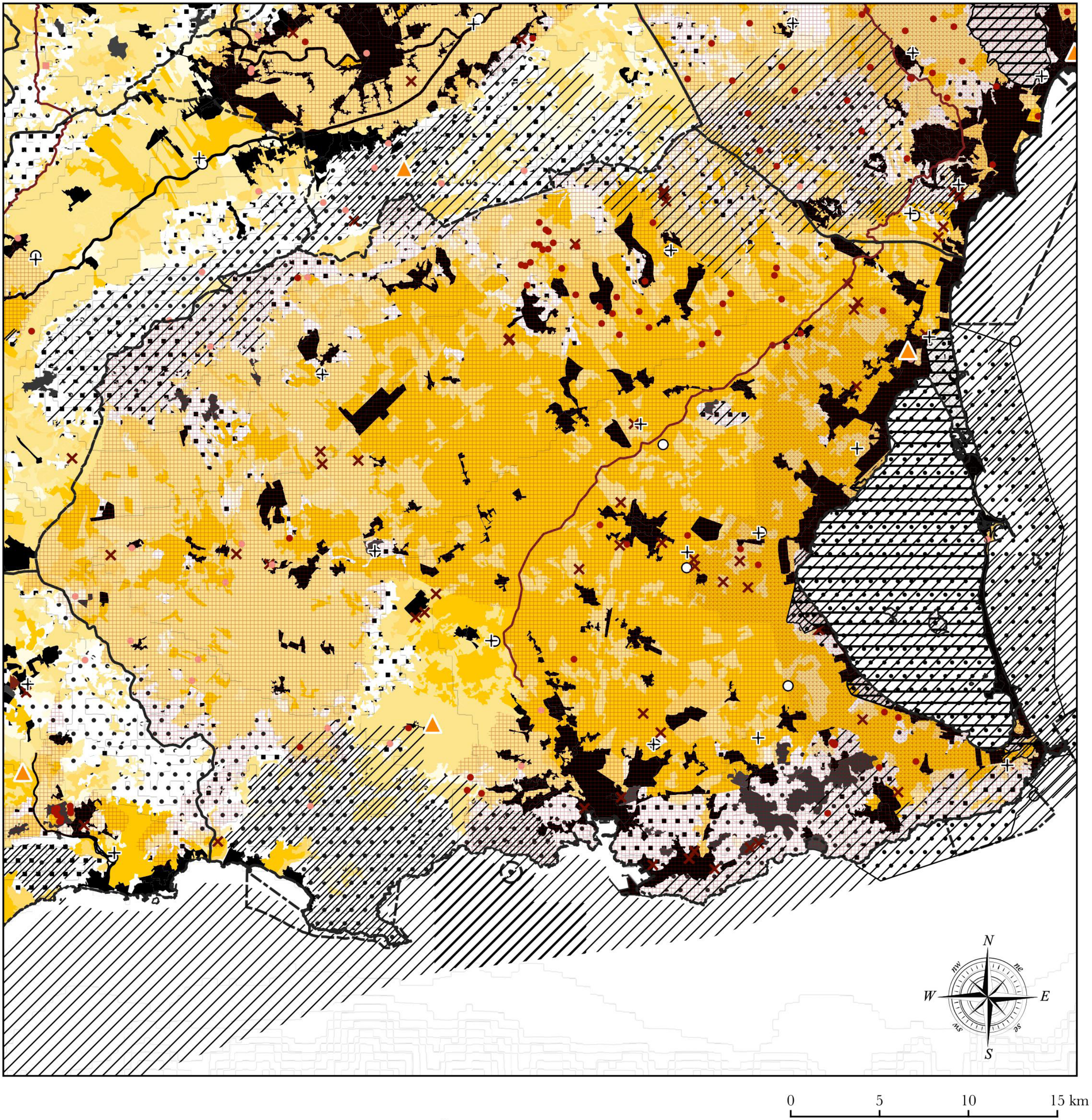
DESIGN LOCATION
INTRODUCTION



For the transition from the analysis of the basin's problems to the design for a symbiotic future, a smaller scale is examined, where different solutions are applied in test scenarios. The hydraulic zone (sub-basin) of the Cartagena coastal plains (Campo de Cartagena) is chosen as the location to test the design methodology (see Figure 80). This location was chosen based on the analysis's conclusions, highlighting the sub-basin as a crucial area for the transition of the water system, as many problems and potentials overlap in this area (see Figure 81).

The overlap of the problem conclusions and characteristics on the sub-basin scale is shown in Figure 82.

Figure 81. Sketch of problematic areas in the basin. Source: made by author.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CAMPO DE CARTAGENA

Intensive irrigation agriculture practices in the form of large greenhouse clusters and monocultural food production characterise the sub-basin. The biggest harbour of the region is located in the South of the sub-basin, in Cartagena. Through this harbour, most of the food produced in the region is exported to the rest of Europe. Because the sub-basin is located in the Southeast of the basin, it is the lowest point where irrigation and rainwater discharge into the sea. Because of these reasons, the soil and water in the area are highly polluted, groundwater aquifers are depleting, and the area is highly dependent on water transfers from the TST. Tourism is growing rapidly, and spatial claims for urban dwellings and golf courses are putting pressure on the wetlands, affecting protected bird species and natural flood control.

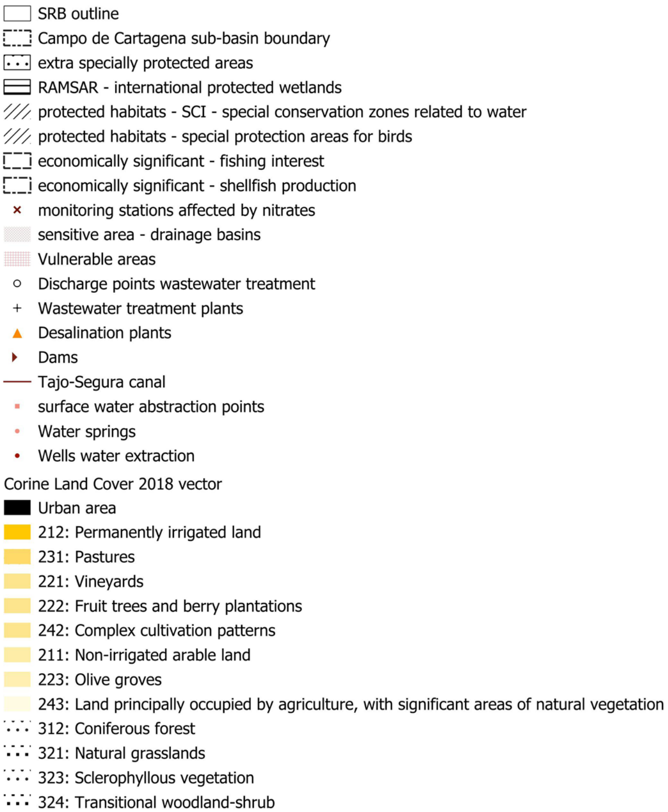


Figure 82. Synthesis of the problems and characteristics in the Campo de Cartagena sub-basin. Source: made by author, based on data from (CHS, 2025).

FIELDWORK OBSERVATIONS

To analyse the systems on the sub-basin scale further, a fieldwork study was conducted. Figure 83 shows a sketch of the route that was taken and the places that were visited. Figure 84 shows a collection of observations and conclusions derived from the fieldwork visit.

The obervations confirmed the need for water-saving methods, water storage, and depollution, as many natural areas in the lowlands seemed polluted, and the soil was in poor conditions. Most of the land in the region was covered with plastic foils and poorly constructed greenhouses, where large parcels filled with monocultural (vegetable) crops were fenced off. The water in the TST canal was at a very low level, despite the heavy rain period in which the fieldwork took place.

However, some farmers in the area already contributed to the sustainable agriculture transition, as organic farming methods were observed as well.

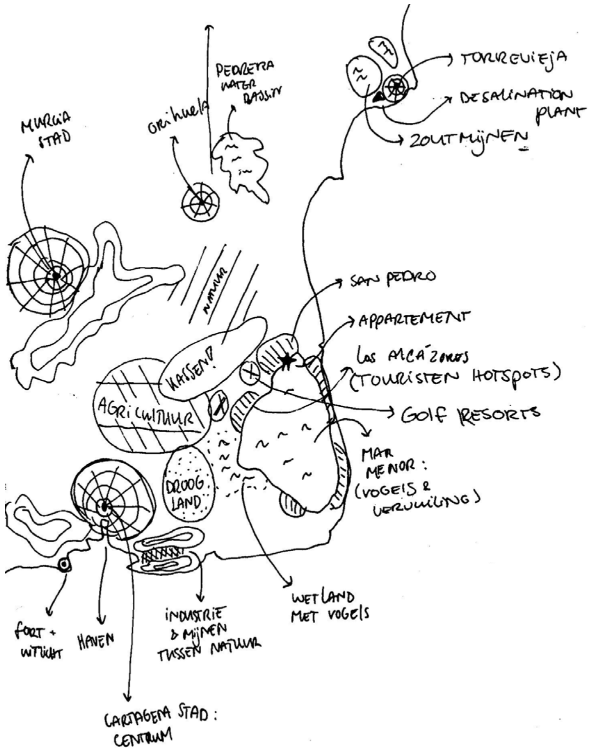


Figure 83. Sketch of the field visit elements and locations. Source: made by author.

OBSERVATION: DRip iRRiGATiON SYSTEMS AND pLASTiC COVERS ARE USED ALL OVER THE BASiN, FOR VEGETABLE CROP GROWTH. THEY LEAVE piLES OF pLASTiC ON THE FiELDS AFTER HARVESTiNG.

OBSERVATION: NETS AND pEST REpELLENT pLANTiNG USED iN FLOWER FARMS.

OBSERVATION: SMALL DiTCHES AND pONDS WERE CONSTRUCTED iN A NATURE RESERVE NEAR MURCiA FOR AMpHiBiOUS CREATURES AND WiLDLiFE.

OBSERVATION: STRip CROppiNG USED iN BETWEEN THE pERMANENT WOODY CROpS FOR WATER RETENTiON, pEST CONTROL AND BiODiVERSiTY pRESERVATiON.

OBSERVATION: THERE ARE MANY CONSTRUCTiON SiTES AND BARE LAND FiELDS ALONG THE COAST. RiGH RiSE AppARTMENT BUiLDiNGS AND LARGE ASpHALT pAViNGS ARE CONSTRUCTED iN FLOOD pRONE AREAS, WHiLE MOST OF THE TOWNS SHOW VACANCY SiGNS.

DESIGN IDEAS:

CAN AGROTOURiSM AND ECOTOURiSM BRiNG THE AREA TO LiFE iN THE LOW SEASONS, WHiLE REDUCiNG WATER DEMAND ?
CAN CLiMATE ADApTiViTY AND URBAN DEVELOpMENT GO HAND iN HAND ?

OBSERVATION: WATER FLOW REGULATION OF THE TST CANAL THROUGH THE IRRIGATION FIELDS. LOW WATER LEVELS IN MARCH..

OBSERVATION: WATER POLLUTION IN THE PROTECTED SALINE WETLAND OF TORREVIEJA, WHERE THE DRINKING WATER DESALINATION FACILITY INLET IS POSITIONED.

DESIGN IDEAS:

WHAT IF THE TRANSFER INFRASTRUCTURE WAS REPURPOSED ?
CAN THE WATER BE REGULATED BETWEEN FARMS, BY THE FARMERS ?

OBSERVATION: THE WETLAND WAS NOT SO WET – EVEN AFTER THE RAINY PERIOD THE PREVIOUS DAYS.

OBSERVATION: EROSION OF THE COASTLINE SHOWS HOW THE AREA IS UNPROTECTED.

OBSERVATION: IN THE LOWLANDS, THE RAIN CAUSED THE AREA TO BLOOM IN SPRING, WHERE FURTHER NORTH, THE LANDS SEEMED TOO DRY TO GROW CROPS.

Due to a few days of heavy reainfall in the area, the lowlands were in full bloom, showing almost no signs of struggles with drought and desertification.

In between the sea and the lag
of **600** m wide is fully built w
buildings of tourism appartmen
almost all vacant and for sal
cars divided the connection bet

Abandoned water mill and aquduct, connected to an abandoned farm. It shows the heritage of the region, but was left neglected within the protected wetland area.

Next to big industrialised monocultural farms, also small farms exist in the area. An old man was spotted on his bycile, cycling through his fields, with a dog on a leash and a basket of fresh broccoli on the back of the bike.

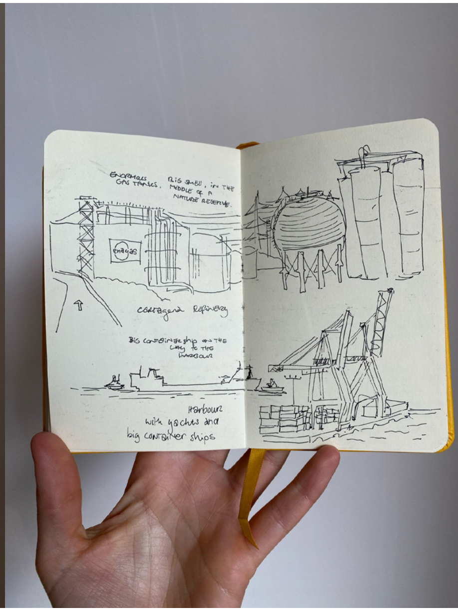
In the inland, t
landscapes and areas
that formed a sea o

Figure 84. Sketches of the field visit observations. Source: made by author.

OON, A SMALL STRIP
VITH APPARTMENT
NTS THAT WERE
E. A HIGHWAY OF
TWEEN THE WATERS.

FROM UP CLOSE, THE DRIP IRRIGATION SYSTEMS DID NOT SEEM SUSTAINABLE AT ALL, AS THEY ARE MADE OUT OF SMALL PLASTIC TUBES THAT CREATE PILES OF PLASTIC WASTE WHEN BIG PLOUGHS RUSH THROUGH THE LANDSCAPE.

THE HARBOUR OF CARTAGENA IS WHERE THE FOOD EXPORT INDUSTRY OF THE REGION IS MOST VISIBLE: BIG CONTAINERSHIPS LINE UP AND LANDSCAPES OF REFINERIES AND CRANES DEFINE THE COASTLINE.



HE CAR ROADS DIVIDED NATURAL
S OF AGRICULTURAL PRODUCTION
F PLASTIC OR BARE DESERTS OF
ABANDONED LAND.

IN A TOURIST VILLAGE NEAR THE LAGOON, AN ECO-TOURISM ROUTE WAS CREATED, PROVIDING INFORMATION ABOUT THE HISTORIC AND ECOLOGICAL RELEVANCE OF THE SALT MARSHES.

IN THE OUTMOST SOUTHEAST CORNER OF THE BASIN, LOCAL HERITAGE IS MAINTAINED IN A BEAUTIFUL SMALL VILLAGE WHERE LOCAL FISHERMEN GATHER.

SYMBIOTIC VISION

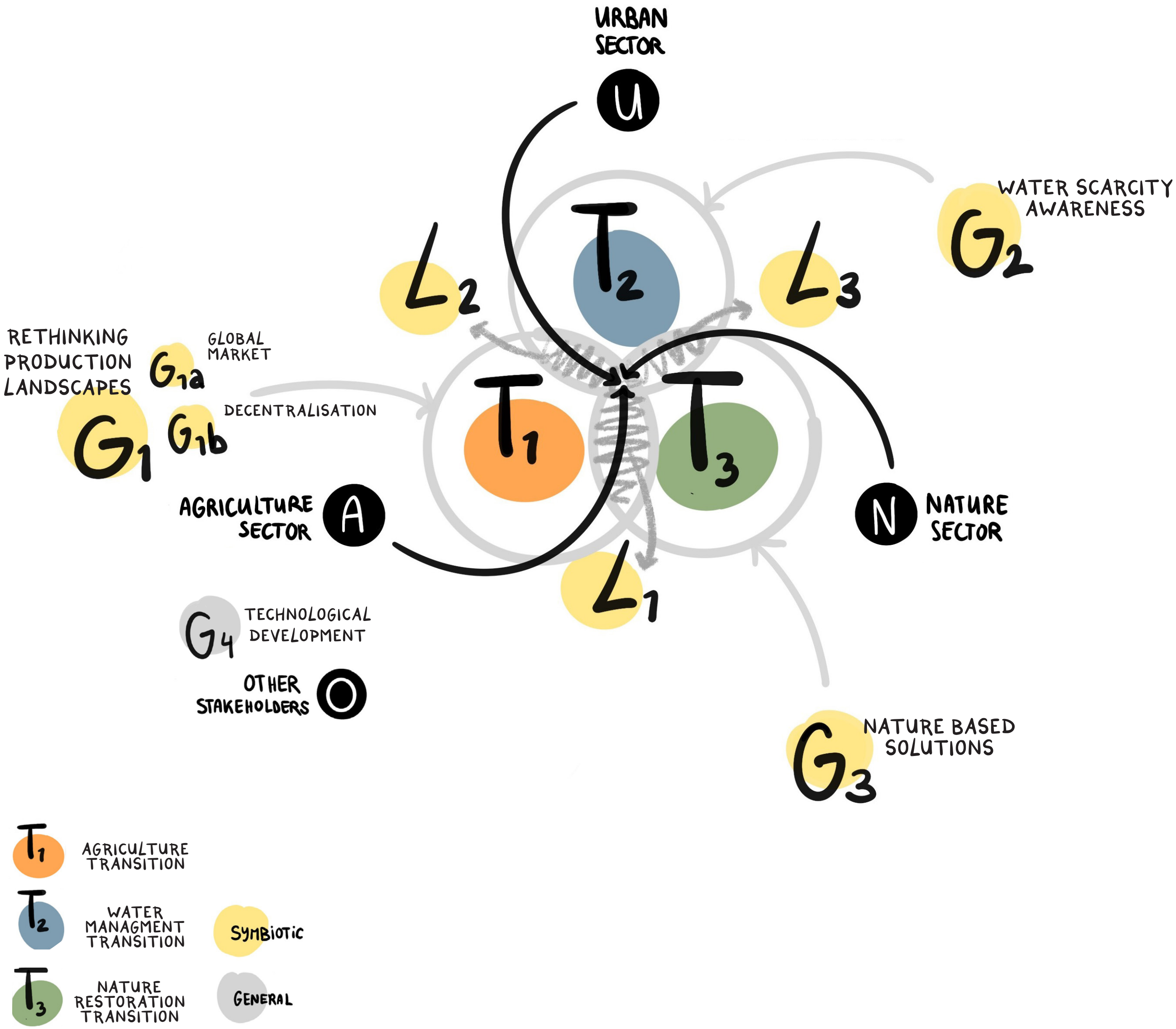


Figure 85. Vision framework: Systemic Symbiosis, global drivers and sectors involved. Source: made by author.

VISION FRAMEWORK

GLOBAL SOCIETAL CHANGES & STAKEHOLDERS INVOLVED

Building on the framework for systemic symbiosis from the analysis conclusion, a symbiotic vision framework for the region was created (see Figure 85). The vision framework connects the three identified transitions to broader global societal changes. These societal paradigm changes influence the formulation and operation of the transitions. Next to this, several different stakeholders that were derived from the analysis are impacted by, and have an impact on the transitions. Varying positions, opinions and visions are at play, and therefore, each stakeholder group should be included in the vision making and strategy making process.

A = AGRICULTURE SECTOR

- LOCAL FARMERS
- BIG PRODUCTION COMPANIES
- EXPORT INDUSTRY
- PACKAGING INDUSTRY
- TRANSPORT INDUSTRY
- IRRIGATION COMMUNITIES

N = NATURE SECTOR

- NGO
- ACTIVISTS
- LOCAL COMMUNITIES
- LEGAL COURT
- NATURE CONSERVATORIES

U = URBAN SECTOR

- MCT
- AQUAMED
- RIVER BASIN AUTHORITY – CHS
- MUNICIPALITIES
- SACYR
- GOLF COURSES
- TOURISTS
- RESIDENTS

O = OTHER STAKEHOLDERS

- RESEARCH INSTITUTES
- NATIONAL GOVERNMENT
- MITECO
- TAJO BASIN AUTHORITY
- EU – WFD

Figure 86. SGD's used as inspiration for the vision framework. Source: (UN, 2015).

Figure 87. EU Green Deal - Farm to Fork strategy. Source: CBI (2025)

POLICY FRAMEWORKS

THE NATIONAL, REGIONAL AND SUB-REGIONAL FRAMEWORKS

According to the European Green Pact, Spain within the EU is part of an ecological transition. Therefore, the main focus of the HP is to comply with the rules for sustainability and ecological restoration set by the EU and WFD. The three main strategies related to water planning are:

1. TOXIC-FREE ENVIRONMENT AND THE "ZERO-POLLUTION" STRATEGY.

This strategy aims to reduce air, water, and soil pollution by 2030.

The objectives set are:

- Reduce deaths by air pollution with 55%
- Reduce plastic litter in the sea by 50%
- Reduce released microplastics by 30%
- Reduce nutrient losses and chemical pesticides by 50%
- Reduce the number of EU ecosystems where pollution threatens biodiversity by 25%
- Reduce the number of people suffering from chronic transport nuisance with 30%
- Reduce waste generation and municipal waste by 50%

2. THE "FARM-TO-FORK" STRATEGY

This strategy is aimed at stimulating sustainable food consumption and promoting healthy food for all, as well as complying with the rules of the European Commission to reduce food waste by 2030.

The objectives are:

- Reduce the use of chemical pesticides by 50%
- Reduce the amount of nutrient losses without improving soil fertility by 50%
- Reduce fertiliser use by 20%
- Reduce the sales of antimicrobials (antibiotics and antifungals) by 50%
- Ensure that 23% of the total agricultural land is organic farming by 2030.

3. PRESERVATION AND RESTORATION OF ECOSYSTEMS AND BIODIVERSITY.

This strategy is aimed at restoring biodiversity by 2030. The objectives are:

- Increase the amount of Protected Areas (SPAs) to 30% of the EU territory and seas
- Restore degraded ecosystems
- Increase the amount of organic farming area
- Halt and reverse the decline of pollinating organisms
- Reduce pesticide use and risk by 50%
- Re-establish the condition of free-flowing rivers (25.000 km in the EU)
- Plant 3 billion trees in the EU

CONCERNS OF THE SRB

The specific concerns of the basin that the RBMP (CHS, 2025) focuses on are:

- Climate change adaptation
- Sustainable groundwater exploitation
- Diffuse nitrate pollution
- TST irrigation systems sustainability
- Improvement of the Mar Menor state
- Environmental flow regimes and the effective implementation
- Cost recovery of water services and a sustainable water management model
- Control of abstractions and irrigated areas
- Socio-economic importance of irrigation
- Overexploitation of aquifers (mainly in the southeast of Albacete and Altiplano in the Northwest region of Murcia)
- Hydro-morphological restoration of the river area
- Allocation and financial regime of desalination resources
- Pollution from point source discharges
- Social irrigation of general interest to tackle depopulation (in the North of the basin)
- Environmental regeneration of Portman Bay

The objectives of the third HP for the SRB are:

1. Achieve good status of the waterbodies and comply with the environmental objectives.
2. Promote sustainable use of water, meeting current and future demands.
3. Guarantee good water quality.
4. Prevent the extreme climate effects of droughts and floods, reduce the vulnerability to climate change, and increase resilience.
5. Achieve water security for people, the protection of biodiversity, and socio-economic activities.

CONCLUSION

For the SRB, the Farm-to-Fork strategy is essential to include in a water transition framework, as most of the land use and water-using activity is characterised by unsustainable agriculture practices. The Farm-to-Fork strategy has two main components: organic agricultural production and a local food production and distribution chain. These components form the main regional focus directions (R) within the sustainable agriculture transition (T1) (see Figure 88). Since a trend of technological agriculture development in the region has been discovered during the analysis, innovative food production technologies could be added as a third regional focus decision within the agricultural transition.

Additionally, the third EU Green Pact strategy needs to be incorporated. In Spain, the Natura 2000 network consists of 138.000 km2, which is 27,4% of the national territory. In the Segura river basin, 6,735 km2 (33,2% of the territory) is a protected ecological area. It is of great importance that these areas are protected and biodiversity is restored. Combined with the concerns of the SRB on environmental flow regimes, diffuse nitrate pollution, the Mar Menor state, and desertification, integrating the strategy to preserve and restore biodiversity into the water system transition framework is crucial.

Furthermore, from the Zero-Pollution strategy, the first point is the most crucial to implement in the SRB, as soil and water pollution through nitrates from agricultural practices disturbs the ecosystem in the protected natural areas. Together, the protection, expansion, and depollution of the natural area in the SRB form the main components of the ecological restoration transition (T3). Secondly, waste reduction, especially in the food industry, needs to be focused on. In the SRB, specifically along the coast, upcoming tourism also pollutes the natural area. To connect this industry to the resilient water system transition, sustainable recreation has to be included in the framework as well. Additionally, the analysis has brought forward that climate change adaptation, flood risk protection, and desertification prevention have to be included in a resilient water system framework for the region. Therefore, these components are also included in the ecological restoration transition.

To achieve water security in the region, the renewable water systems transition (T2) focuses mainly on fair water distribution, increasing renewable water supply, circular water flows, and reduced water consumption.

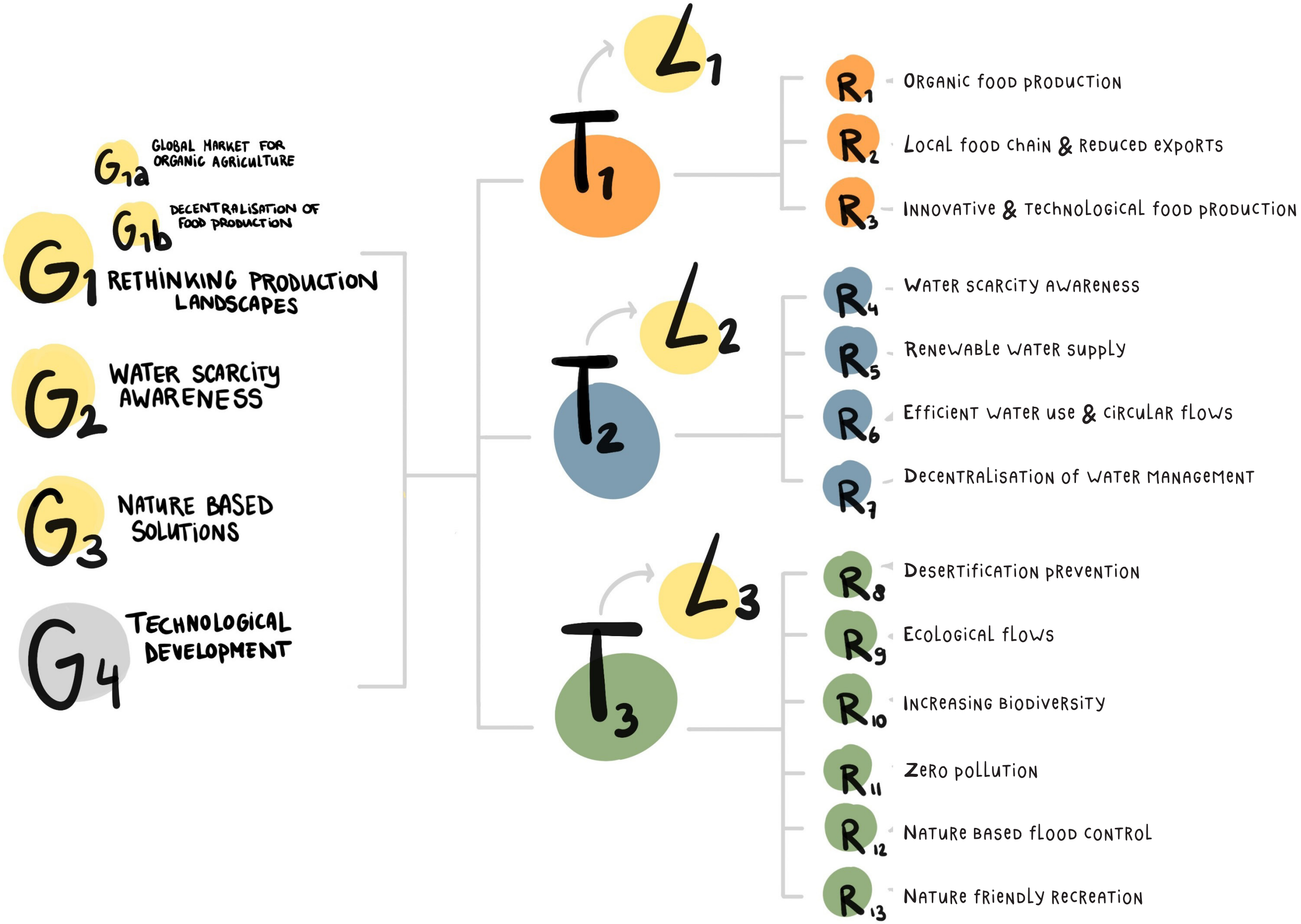


Figure 88. Start of a decision tree in symbiotic design of the water system. Source: made by author.

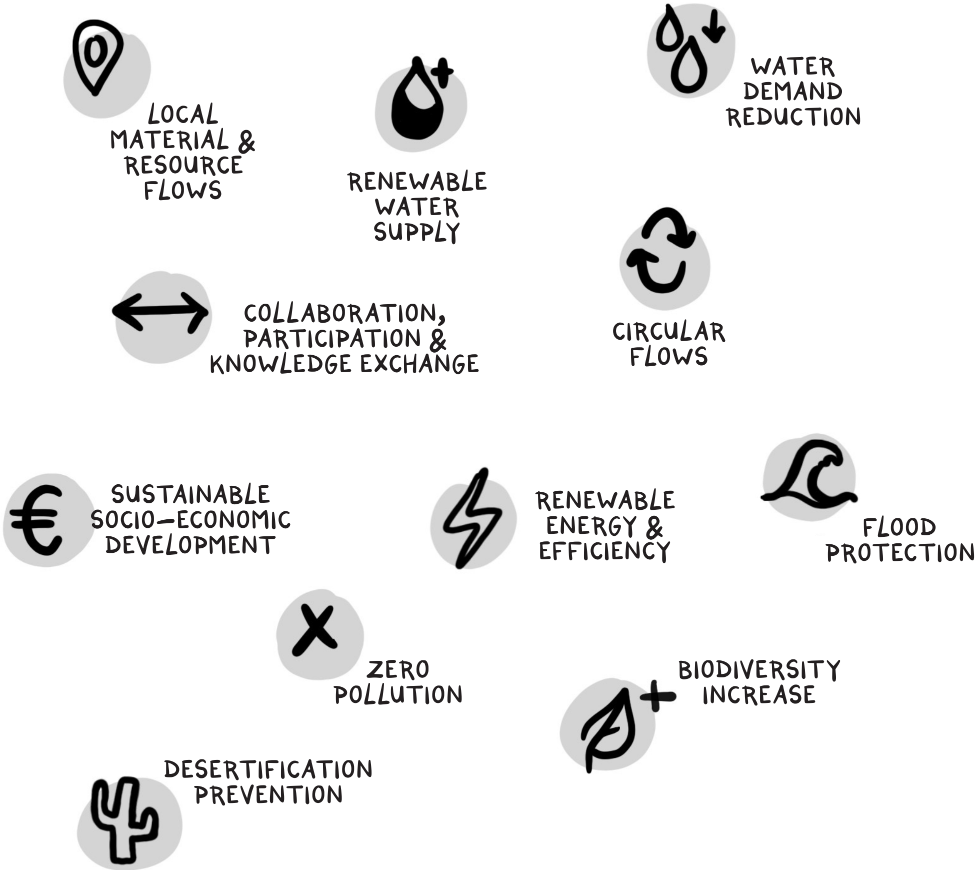


Figure 89. Design principles for the transition of the water system in the region. Source: made by author.

VISION OBJECTIVES
FOR A RESILIENT WATER SYSTEM IN THE REGION

Several spatial design objectives for the symbiotic vision are derived from the analysis conclusions and the policy document analysis (see Figure 89). They sum up a conclusion of integrated problems in the region, and form the basis for finding symbiotic solutions across the identified transitions of the water system. With these objectives in mind, symbiotic design interventions are sought after.

SYMBIOTIC INTERVENTION

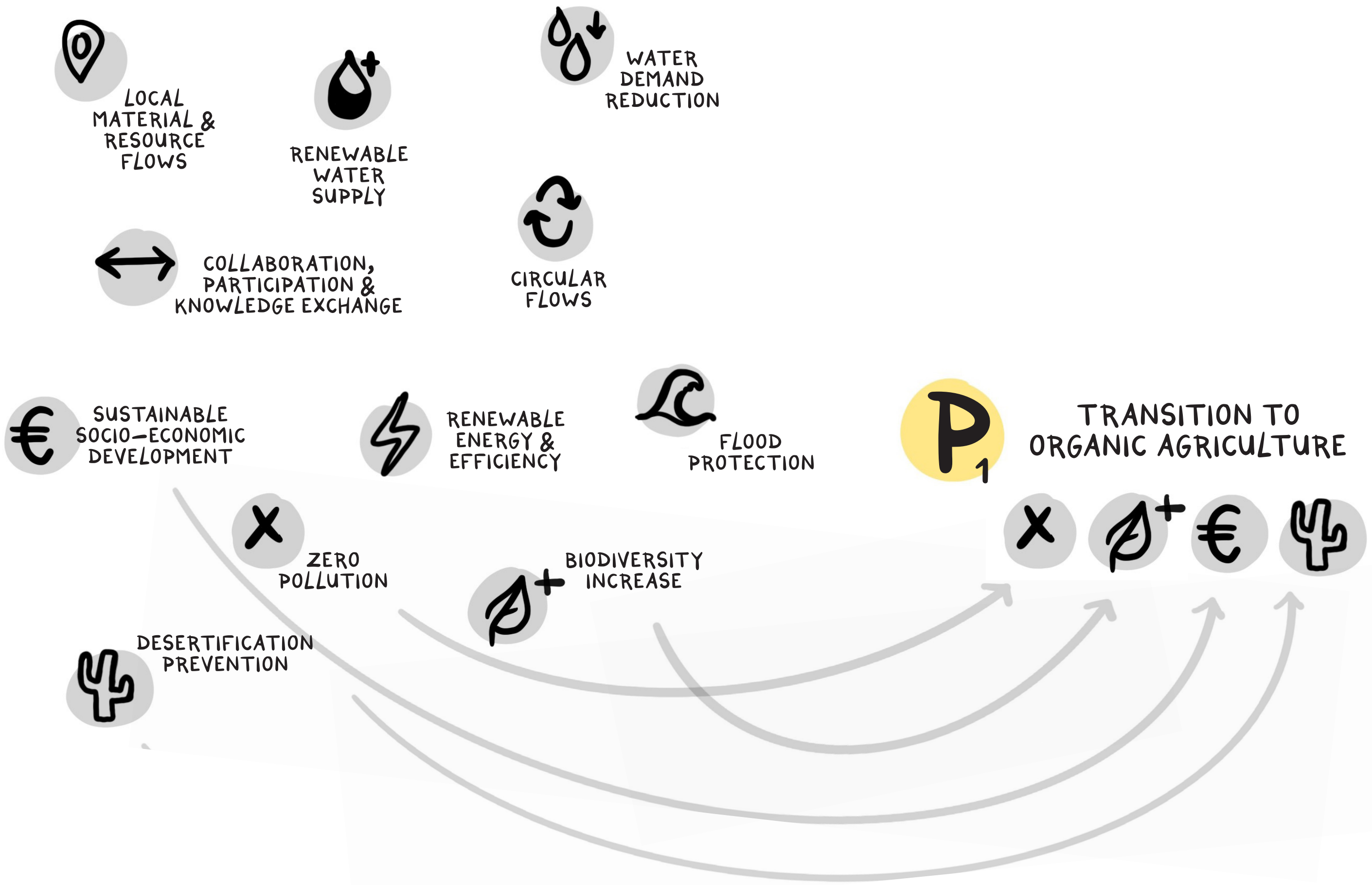


Figure 90. Design principles for the transition of the water system in the region. Source: made by author.

SYMBIOTIC SOLUTIONS

INTRODUCTION

This chapter sets out how the identification and categorisation process of the design solutions led to a pattern language. It bridges the conceptual framework, the analysis of the region, the vision, and the design.

The different components and interrelations of the pattern language are explained biefly in this chapter, as the main focus is to show a design implementation. For additional explanation of the pattern language, a Pattern Booklet for symbiotic design of the water system is provided separately.

SYMBIOTIC INTERVENTIONS

The symbiotic design interventions are found through an iterative research by design process, where anaylsis and design of the design location, combined with literature research, desk research and field work observations, led to a creative process. The design principle to obtain the symbiotic solutions forms one of the layers of symbiosis in the design, as explained previously in the methodology section (page 58). Within the three transitions, only symbiotic interventions are selected. Those interventions form solutions to multiple objectives from the vision combined, and are therefore multi-beneficial.

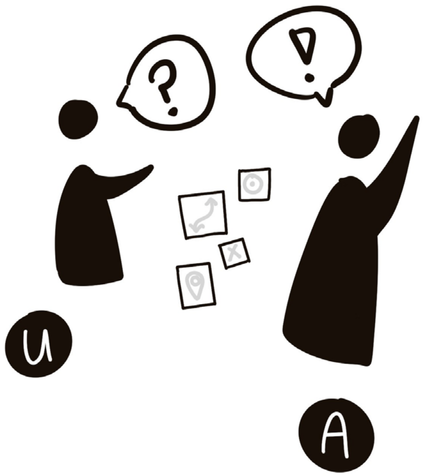
PROJECTS AND ACTIONS

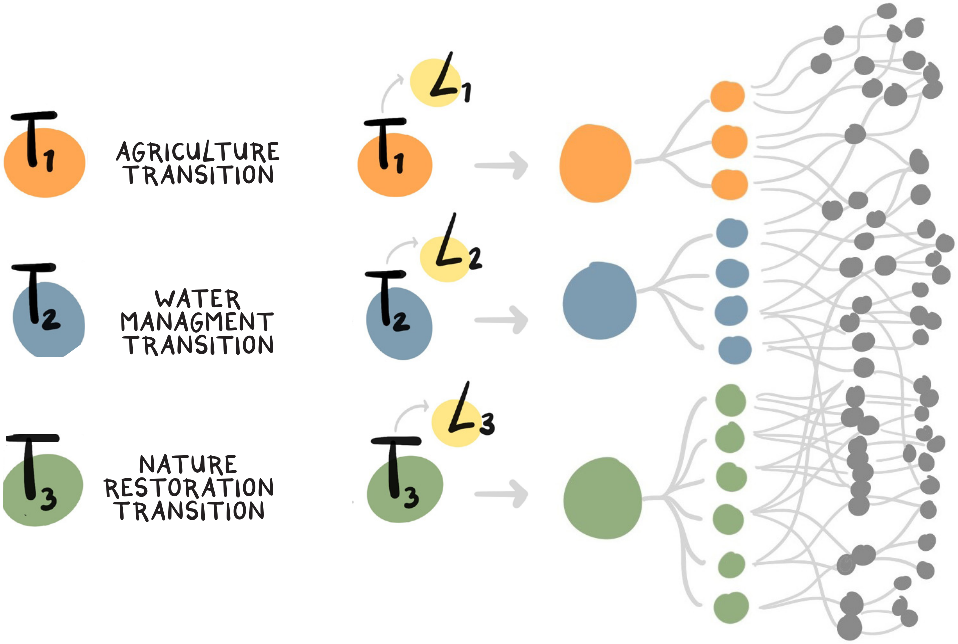
Possible spatial and non-spatial interventions to operationalise the design objectives from the three transitions were collected through precedent studies, desk research, literature study and fieldwork observations. The interventions are categorised in Projects (P) and Actions (A) to operationalise these projects. Projects are strategic interventions on the regional scale, and are to be implemented across regions. Those projects often require collaboration of multiple agents, and large investments. Action interventions are often local, small scale interventions that can be operationalised by one actor, sometimes with financial help of the municipality. Multiple actions together operationalise one (or more) projects.

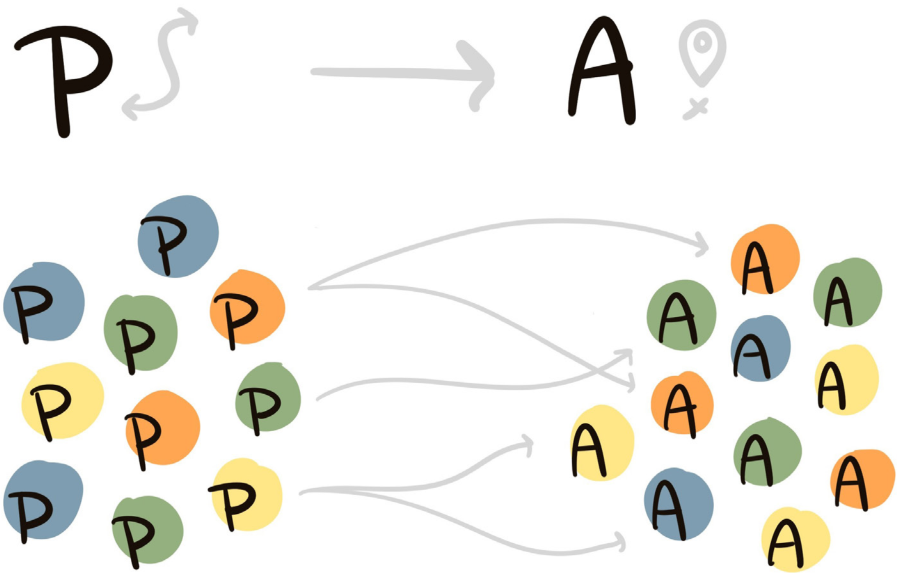
If a solution combines objectives through the three layers of the transitions, the intervention is likely to be favoured by all sectors (which would make it a sector symbiotic intervention). Those interventions are marked with the colour yellow.

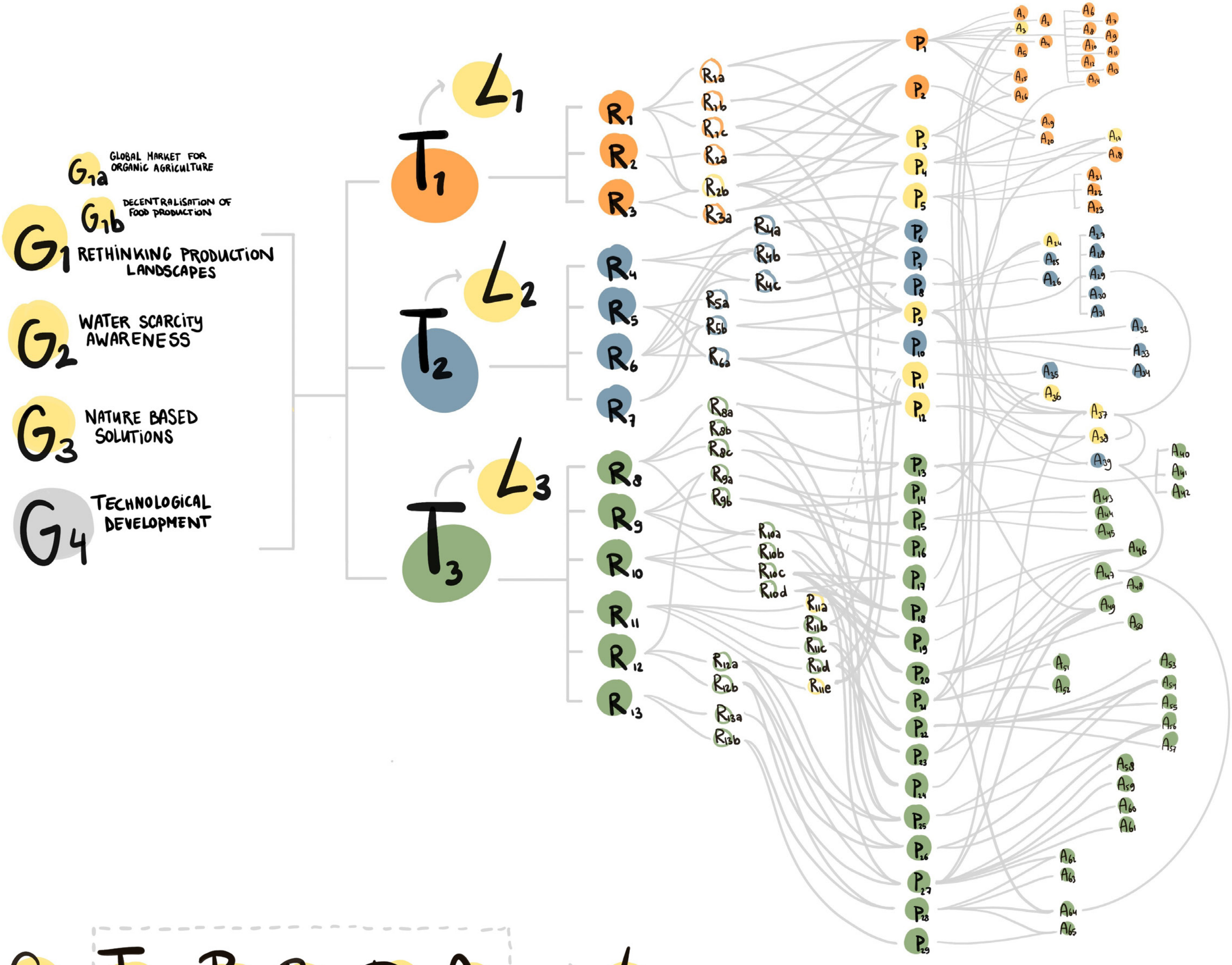
The categorisation of the patterns within and between the transitions led to a tree-like structure, which is to be used as a tool for the participatory design of a regional strategy. As a part of the symbiotic design methodology, the tool needs to be reproducible, communicative, generalisable, and understandable.

Because of these criteria, the intervention catalogue developed into a pattern language, where the design interventions are linked to the policies and political focus directions within and across the three transitions.




T1
AGRICULTURE TRANSITION
T2
WATER MANAGMENT TRANSITION
T3
NATURE RESTORATION TRANSITION
L1
L2
L3


P
A



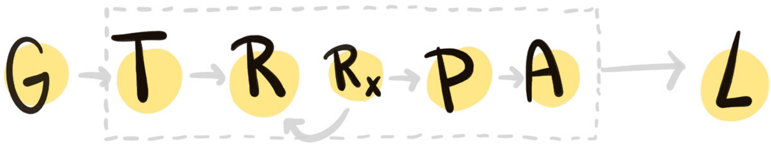


Figure 91. Pattern-web as a decision tree Source: made by author.
Figure 92. Different components of the pattern language. Source: made by author.

PATTERN LANGUAGE

The pattern language consists of different hierarchical levels that could follow after each other in a sequence, could be connected to each other in new ways, or could be implemented apart from each other. The pattern language is constructed for the symbiotic design of the three transitions, as a design and communication tool. It is influenced by global drivers (G), and designs for societal change in the form of leverage points (L).

PATTERN-WEB

Figure 91 shows the pattern-web that connects the different components and interventions of the pattern language. It can function as a decision-tree for policy-makers, designers or stakeholders to choose their preferred interventions from. It directs the user towards symbiotic design combinations in multiple ways.

To create a strategy, different pathways of interventions can be chosen, from the three transitions combined. These pathways are created by following a sequence of patterns connected in the pattern-web, through following their interrelations. The regional focus decisions (R) guide those pathways, and form their starting point.

WAY OF WORKING

One way of using the pattern language is from a top-down, strategic planning perspective. This means following the pattern language from the left to the right, starting at a certain global driver (G) or transition (T), and looking at the different political focus directions (R). This leads to policies (Rx) that are connected to possible operation patterns (P and A).

Another way to use it is from a bottom-up perspective, starting at the right side of the pattern-web. Projects and Actions can be initiated bij individual stakeholders, and the required political decisions can be discovered afterwards. In this way, local stakeholders can be included in the decision-making process, as they can add interventions, contribute to top-down plans in their own preferred way, and suggest policies or focus decisions that would be beneficial to them.

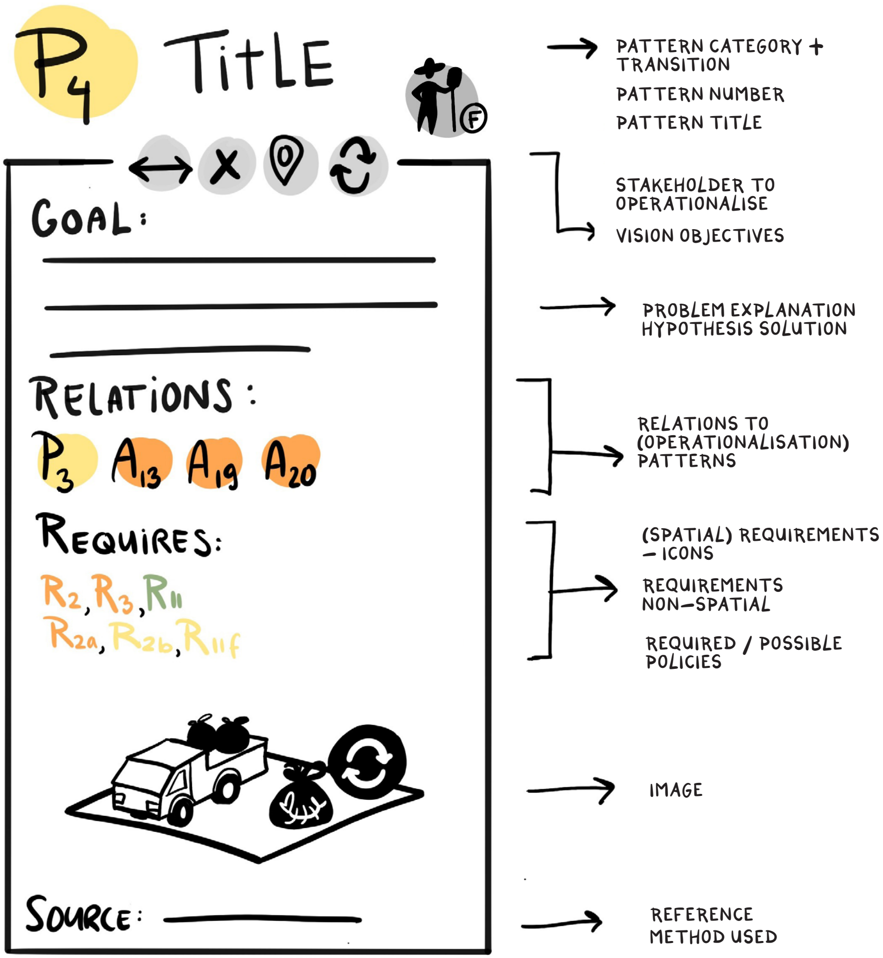


Figure 93. Framework for the patterns. Source: made by author.

PATTERN CARDS
OF THE OPERATION PATTERNS

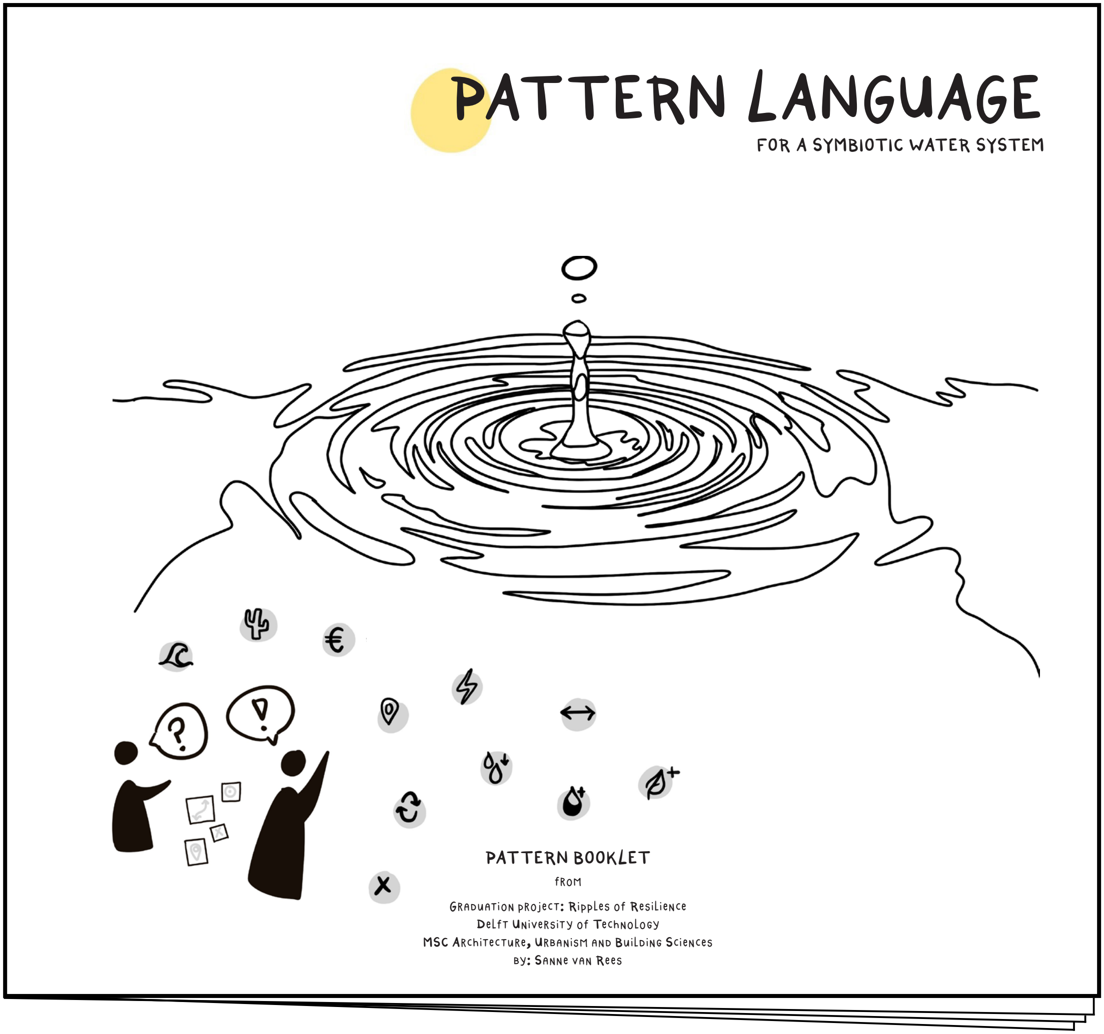
Figure 93 shows the framework used for the creation of the operation intervention pattern cards. On the top of the card, the category of the decision-tree is shown with a pattern letter (P or A), together with the number of the pattern and the title. The colour of the pattern number corresponds to the transition within the vision to which the pattern contributes. If the colour is yellow, the pattern contributes to more than one transition, making it a system symbiotic pattern. Below the title, the icons of the objectives to which the pattern contributes are shown, together with the actor(s) needed to operationalise the pattern intervention.

Next, a brief explanation of the problem the pattern addresses is given, together with a hypothesis for a solution, supported by literature sources, reference cases or fieldwork observations. If necessary, possible execution is explained as well. Afterwards, the possible connections to other patterns are shown, corresponding to the links of the decision-tree.

The possible regional focus decisions (R) that could lead to the project pattern are shown under requirements. Additionally, if the pattern is linked to another pattern as a requirement, this is shown as well. Furthermore, an indication of required investment of time, effort and money is given, as well as other non-spatial requirements. If the intervention requires a spatial contition in order to be effectively implemented, this is annotated with an icon that corresponds to the legend of an analytical map showing these preconditions spatially. This is explained further in the next chapter.

Next, a small drawing of the pattern illustrates the intervention. On the bottom of the pattern, sources or reference projects that were conducted for the creation of the pattern are shown, as well as the method used to obtain the solution presented on the pattern.

On the next page, an overview of the Pattern Booklet is given, for a quick impression.


PATTERN LANGUAGE
FOR A SYMBIOTIC WATER SYSTEM
PATTERN BOOKLET
FROM
Graduation project: Ripples of Resilience
Delft University of Technology
MSC Architecture, Urbanism and Building Sciences
By: Sanne van Rees

P4 CROSS-SECTORAL ORGANIC WASTE SYSTEM

GOAL:

Linear waste systems in agriculture and urban areas often lead to nutrient loss, pollution, and increased dependency on synthetic inputs. Implementing a cross-sectoral organic waste collection and reuse system focusing on composting, manure exchange, and inter-sectoral redistribution, addresses these inefficiencies by closing nutrient loops at the regional scale. By transforming local organic waste into valuable inputs such as compost, biochar, or organic mulch, the system promotes soil restoration, reduces reliance on chemical fertilisers, and supports organic farming practices. Additionally, facilitating manure exchange among farmers or between sectors like agriculture, landscaping, and golf courses reduces logistical burdens, prevents over-application and runoff, and helps combat desertification. This systemic approach supports circularity, enhances ecosystem resilience, and creates shared economic and ecological value across urban-rural interfaces (FAO, 2025).

RELATIONS WITH:

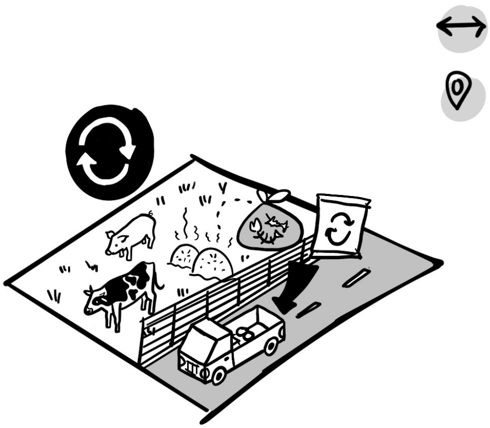
Possible Actions: A7, A8, A13, A15, A16, A19, A36, A42

To be combined with: P1, P2, P3, P5, P9, P11, P13, P22, P24

REQUIRES:

Focus: (R1), R2, R11

Policies: (R1a, R1b, R1c), R2a, R2b, (R8c), (R10c), R11e



SOURCE: (FAO, 2025)

OBTAINED THROUGH: Design intuition|Literature study

A54 HELOPHYTE FILTERS

GOAL:

Wastewater discharge can degrade aquatic ecosystems by introducing excess nutrients and pollutants. Helophyte filters are implementd in constructed wetlands that use rooted wetland plants (like Phragmites australis) that naturally treat wastewater by filtering and breaking down contaminants. When integrated into wadis or constructed wetlands, they enhance water quality and restore habitats for birds, fish, and other aquatic species. A notable example is the use of helophyte filters in the Horstermeer Polder, Netherlands, which improved water quality while supporting biodiversity recovery (Tanner, 2001).

SYMBIOSIS:

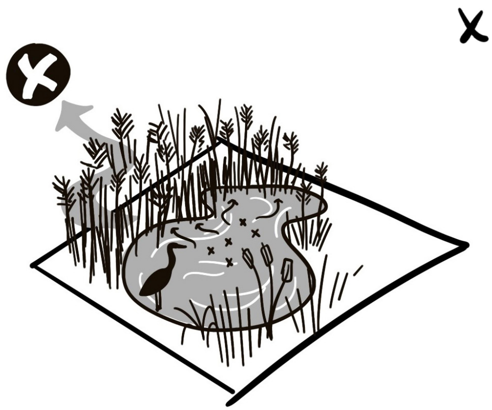
This intervention can be well compared with land transformation to natural area of former farmlands (P1), expanding protected nature (P19) or wetland areas (P25) and floodplains (P26), or local wastewater treatment, for instance in the form of agricultural return flow systems (P9/A39).

OPERATIONALISES:

P11, P13, P22

REQUIRES:

Research on the right filtering plants for the situation, investment in and the planting of the plants, and time for the plants to do the work.



SOURCE: (Tanner, 2001)

OBTAINED THROUGH: Literature study

FUTURE PROJECTION

INTRODUCTION

With the pattern language of symbiotic solutions at hand, it is time to design a strategy for the region. But how to incorporate future uncertainties and contrasting stakeholdler preferences?

The aim of this chapter is to explore sector specific preferred futures for the region, and compare them to identify symbiotic preferred interventions in the form of Sectoral Symbiosis and no-regret measures for a regional spatial strategy of the water system transition. Sectoral Symbiosis is defined in this research as *a symbiosis amongst the interests of the different stakeholders that are characterised by the three main sectors examined.* No-regret measures are defined as interventions that no sector would object to in a certain spatial location, because there is no other intervention preferred. The sector symbiotic measures and no-regret measures implemented in the region together form a spatial strategy.

To define them, a spatial design exercise is conducted in which three scenarios for the future transformation of the water system in region are constructed, according to the scenario framework of Figure 95. Each future scenario follows a narrative of combined perspectives from two sectors together by creating a combination of preferred interventions from the pattern language catalogue. To do this, the decision tree from the pattern language is followed from a top-down perspective, starting at integrating the preferred political focus directions of the two sector perspectives that are integrated in that scenario. Priorities in the political focus directions according to the scenario narratives lead to specific policies and regional project interventions chosen for each scenario. The regional project interventions are operationalised by different combinations of action interventions. The selection and spatial design implementation of pattern interventions for the scenarios is formed through a research-by-design process, resulting in a constant alteration of the scenario designs and pattern language. The analysis of the sub-basin and the pattern implementation is an integrated process, which results in a basemap for the interventions to be applied in. Some interventions have spatial implications that need to be met in order for them to be implemented. Those implications are annotated on the patterns in the form of preconditions. Those are integrated in a spatial precondition map on the scale of the sub-basin.

After constructing the scenarios, they are overlayed and compared to discover symbiotic and conflicting preferred interventions. The symbiotic interventions form the basis for a symbiotic strategic spatial strategy for the region, and are therefore a part of the answer to the main research question.

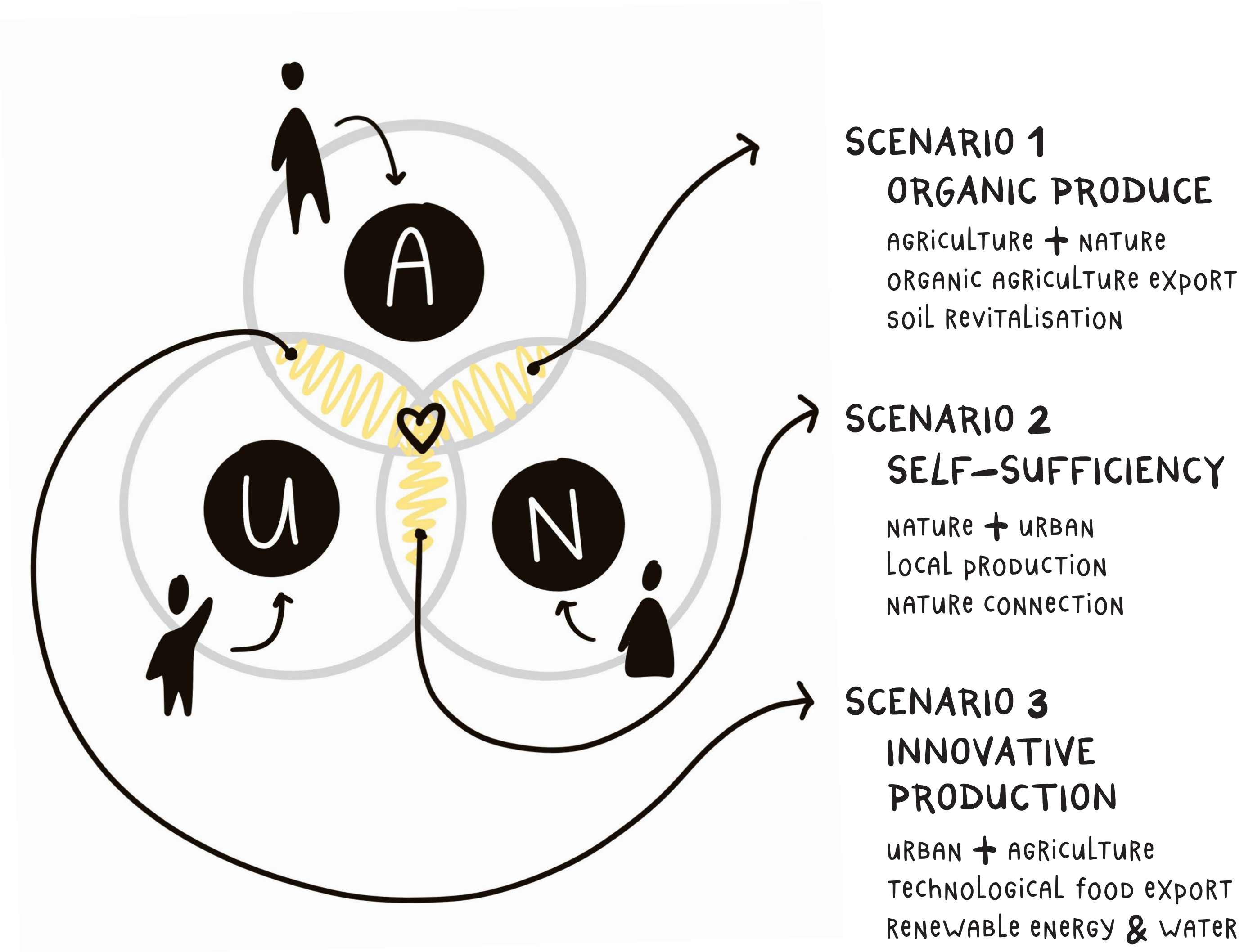


Figure 95. Scenario framework, made by author.

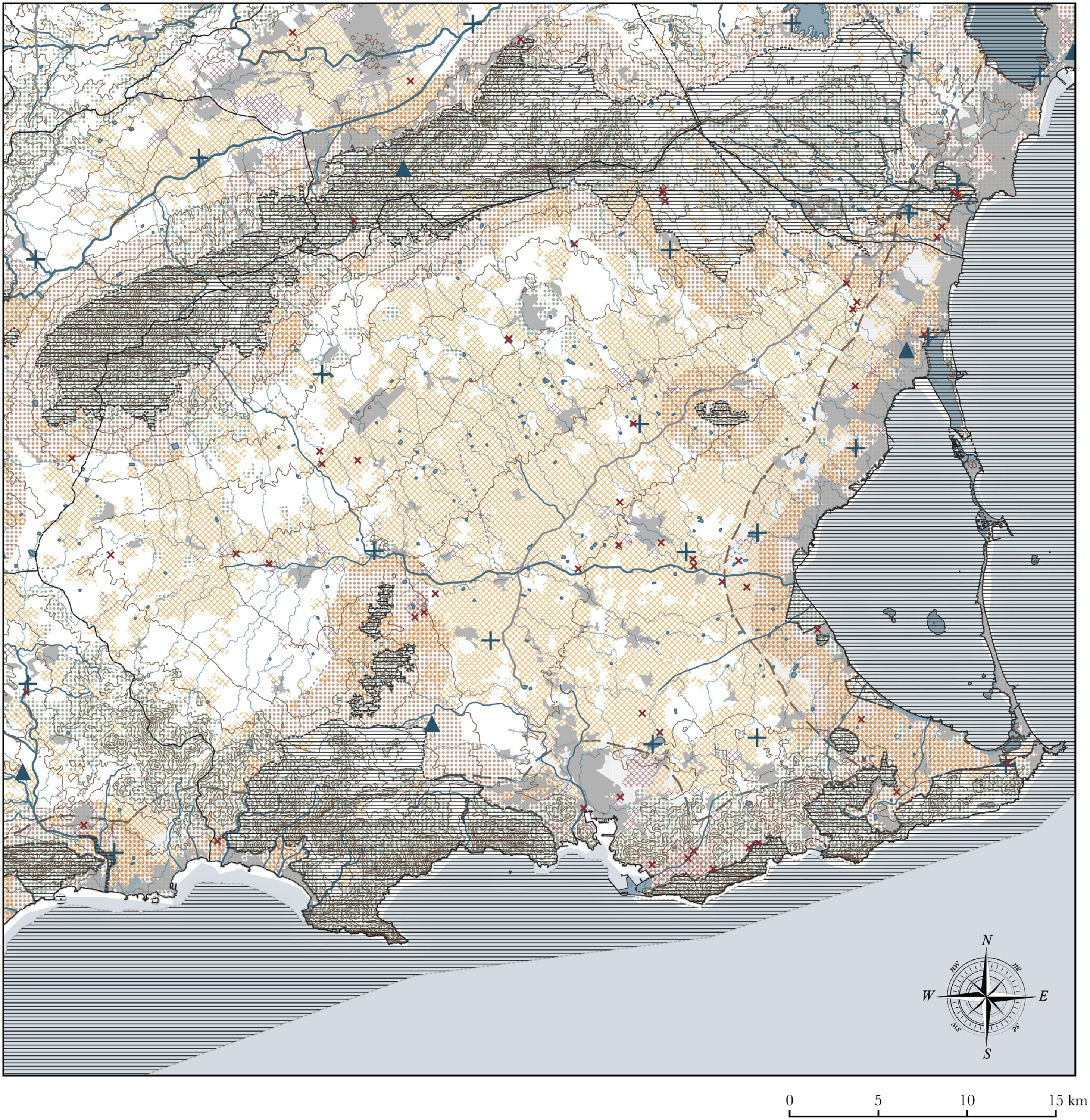
SCENARIO FRAMEWORK
TRANSFERRABILITY

SECTOR SYMBIOTIC SCENARIOS

The three scenarios are constructed according to the scenario framework of Figure 95, where sectoral symbiosis is the goal. By taking into account the regional challenges and global socio-economic, socio-ecological, and climatic pressures that came forward from the integrated analysis, different strategic approaches to the water system transition for the region can be envisioned. By integrating the perspectives and preferences of two sectors within the water system per scenario, different interdisciplinary scenario narratives are explored.

In the first scenario, Agriculture and Nature sector perspectives are integrated to form a future scenario design called Organic Produce. In the second scenario, the Nature and Urban preferences are integrated in the design called Self-Sufficiency. In the third scenario called Innovative Production, the Urban and Agriculture perspectives are integrated.

The scenario specific paragraphs in this chapter explain the narratives and spatial design implementation of the pattern language interventions more in detail.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SPATIAL PRECONDITIONS

BASEMAP FOR PATTERN IMPLEMENTATIONS

During the research-by-design process of constructing the scenarios, spatial preconditions were identified for certain interventions. The preconditions are shown on the pattern with icons that collaborate with the spatial precondition map of Figure 96. This map shows the factors contributing to the successful implementation of certain patterns.

For instance, the design solution A2, terracing, requires a sloped terrain in order to be effective. On the map, this is indicated with a close proximity of elevation lines, suggesting a spatial allocation to the pattern implementation in the design.

The spatial precondition map functions as a basemap for the scenario design exercise of applying the pattern solutions spatially to the region. Some design choices are more implicitly based on the analysis of the region, and do not require a spatial condition icon. For instance, desalination plants and wastewater treatment plants that are already operative in the region are shown on the basemap too, as they already (partially) fulfill some of the pattern interventions, which effects the spatial design implementation of those interventions.

Legend

- SRB outline
- Sub-basins
- Municipalities
- Rambla
- Segura river
- TST
- Wastewater treatment plants
- Desalination plants
- Drainage network
- Salines and seawater
- 5km buffer around the coast
- Urban area
- Industry
- Permanently irrigated land: monocultures
- Nitrate pollution
- Countour lines
- Protected areas outline
- Protected areas
- Sclerophyllous vegetation, Transitional woodland-shrub, Natural grasslands, Coniferous forest
- 2km buffer around Natura 2000 sites

SPATIAL PRECONDITION ICONS

- = PROXIMITY TO THE SEA
- = PROXIMITY TO URBAN CORE
- = POLLUTED AREA
- = SLOPED TERRAIN
- = PROXIMITY TO (PROTECTED) NATURAL AREA

Figure 96. Basemap for the scenario design exercise on the sub-basin scale. Source: made by author.

SCENARIO DESIGN PROCESS

The design process is explained by building up the first scenario design according to the priotitised pathway pattern selection process. The sub-basin is divided in three territorial lenses: seen through the lens of the agriculture and food industry sector, the lens of the natural landscape, and the lens of (urban) water management. Transitions within these domains shape land development related to the water system. By combining interventions that connect these lenses in the scenarios, different pathways for the water system transition are selected. Figure 97 shows the pathway of interventions selected for scenario 1 (Organic Produce). On the basis of the scenario narrative, a priorisation of global drivers (G) is made, from which certain policies (R) are selected. Seen from the top-down planning approach of the pattern language, these policies would result in the possibility of several project interventions (P) to apply in the region. Those projects include multiple possible action interventions (A) to choose from. Figure 98 shows the example of the first project pattern card with three (simplified) operational action patterns. The spatial implementation of the patterns is visible in Figures 99-101.

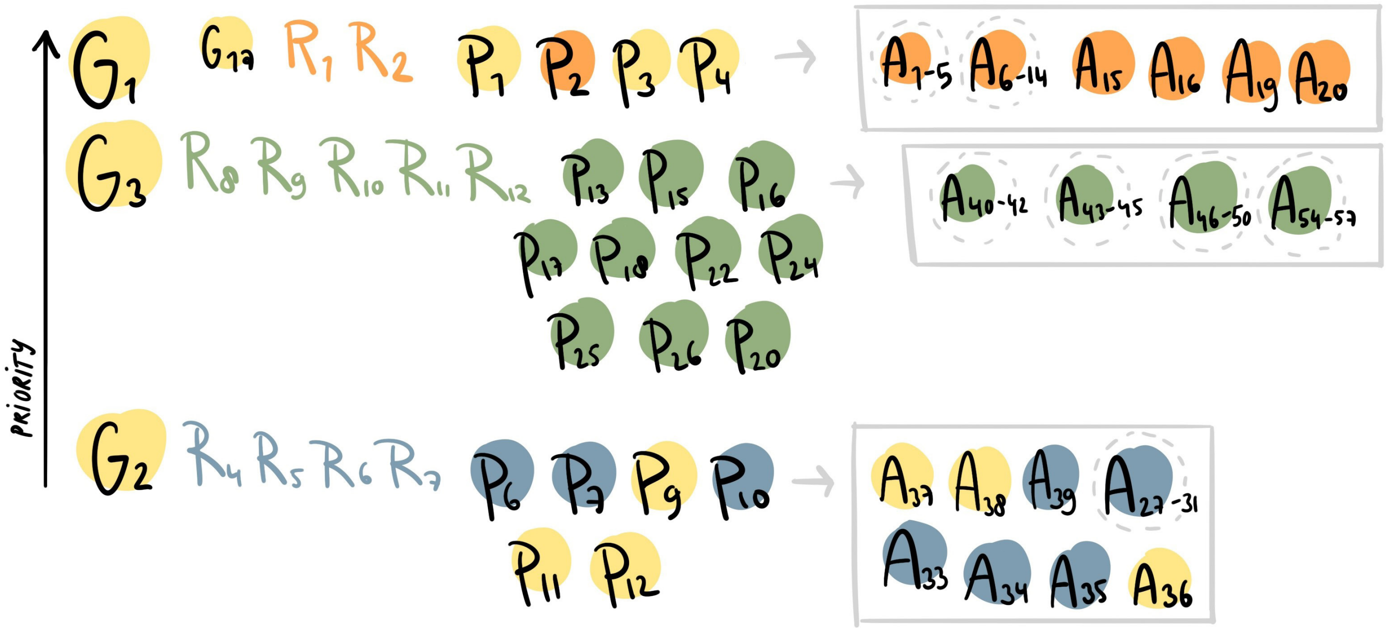


Figure 97. Selection of scenario based patterns for scenario 1. Source: made by author.

P1 TRANSITION TO ORGANIC AGRICULTURE

GOAL:

Transitioning from intensive conventional agriculture to organic farming practices in arid regions can enhance socio-ecological resilience by improving soil health, increasing biodiversity, and reducing water-related risks. Organic agriculture, characterised by the exclusion of synthetic chemicals and genetically modified organisms, relies on natural processes and resources (Iberdrola, 2021). This approach aligns with the European Union's Farm to Fork Strategy, which aims to have at least 25% of EU agricultural land under organic farming by 2030, promoting sustainable food systems and environmental stewardship (European Commission, 2020). The anticipated benefits include higher crop yields, reduced costs for fertilisers and pesticides, and improved water retention in soils, collectively contributing to the mitigation of desertification and flood risks. Implementing this transition involves a series of coordinated actions focused on depolluting natural substrates, enhancing local biodiversity, and fostering sustainable agricultural practices.

RELATIONS WITH:

Operationalised by: A1-A5 + A6-A14

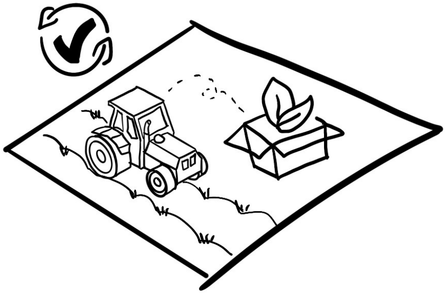
Related to: A17, A18

To be combined with: P2, P3, P4, P9, P13, (P5), (P12), (P18), A15, A16, A19, A20, A21-A23, A27-A31, A37, A38, A39, A40-A42,

REQUIRES:

Focus: R1

Policies: R1a, R1b, R1c

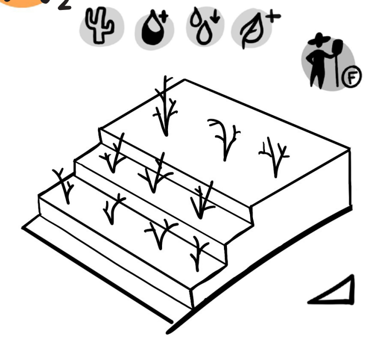


SOURCE: (Iberdrola, 2021), (European Commission, 2020)

OBTAINED THROUGH: Design intuition|Literature study

A1 CHANGE TO DROUGHT-TOLERANT CROPS

A2 TERRACING AGRICULTURE



A3 LAND TRANSFORMATION TO NATURAL LANDSCAPE

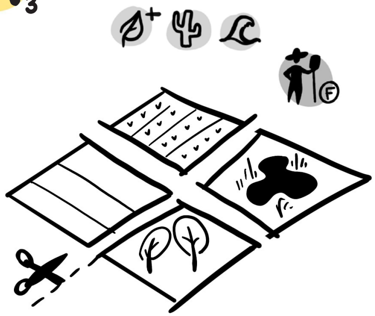


Figure 98. Example of (simplified) patterns selected for scenario 1 from the pattern booklet. Source: made by author.

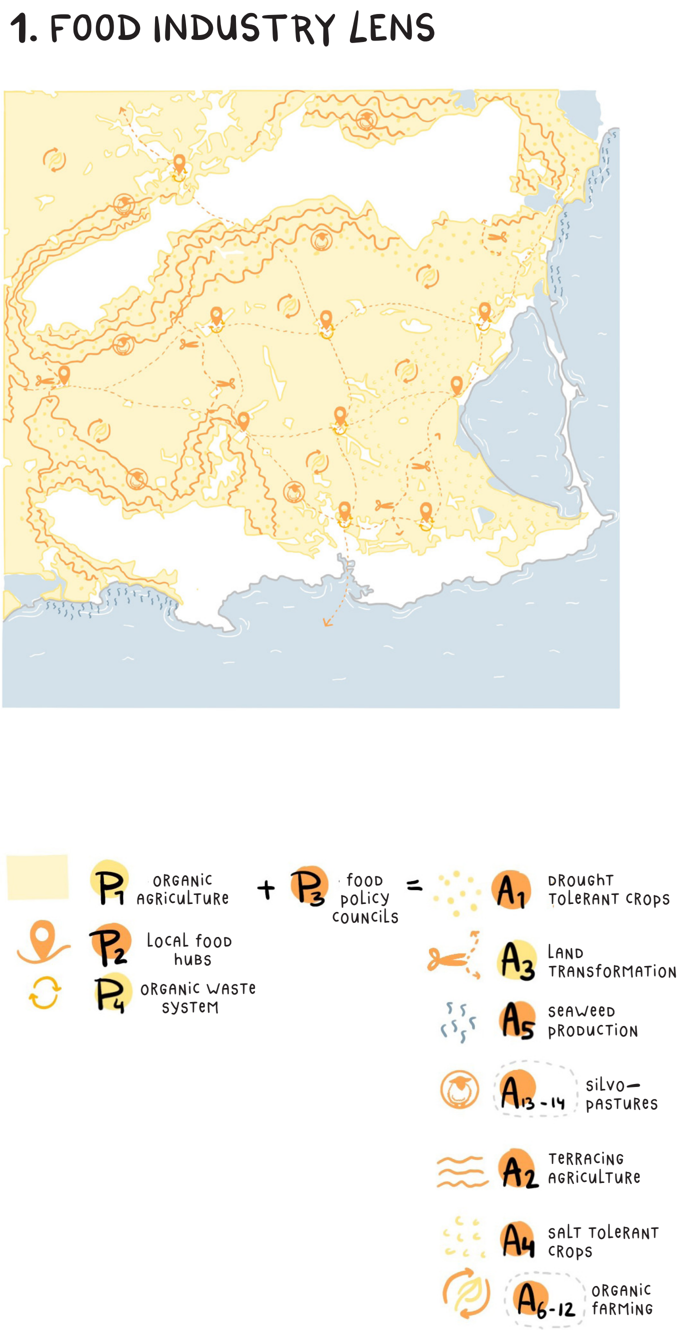


Figure 99. Scenario 1 Organic Produce: interventions of the territorial lens: agriculture and food industry. Source: made by author.

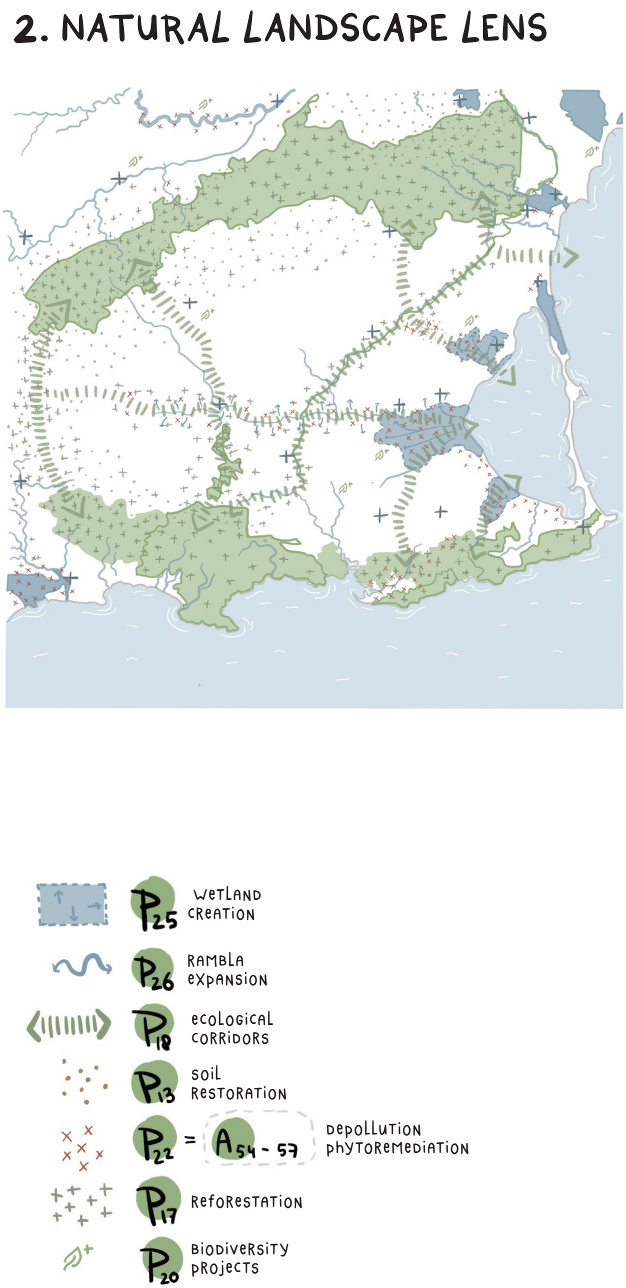
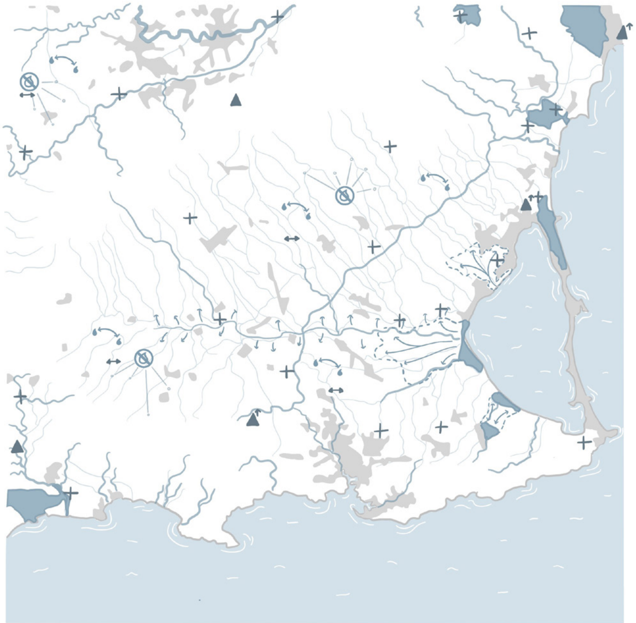


Figure 100. Scenario 1 Organic Produce: interventions of the territorial lens: natural layer. Source: made by author.

3. WATER MANAGEMENT LENS



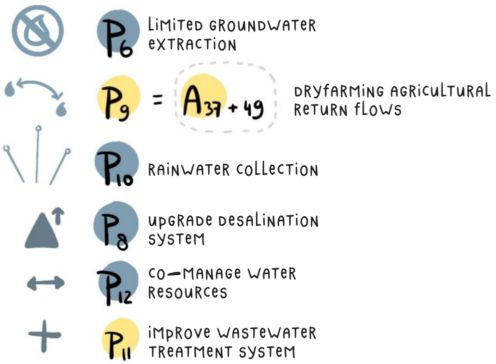
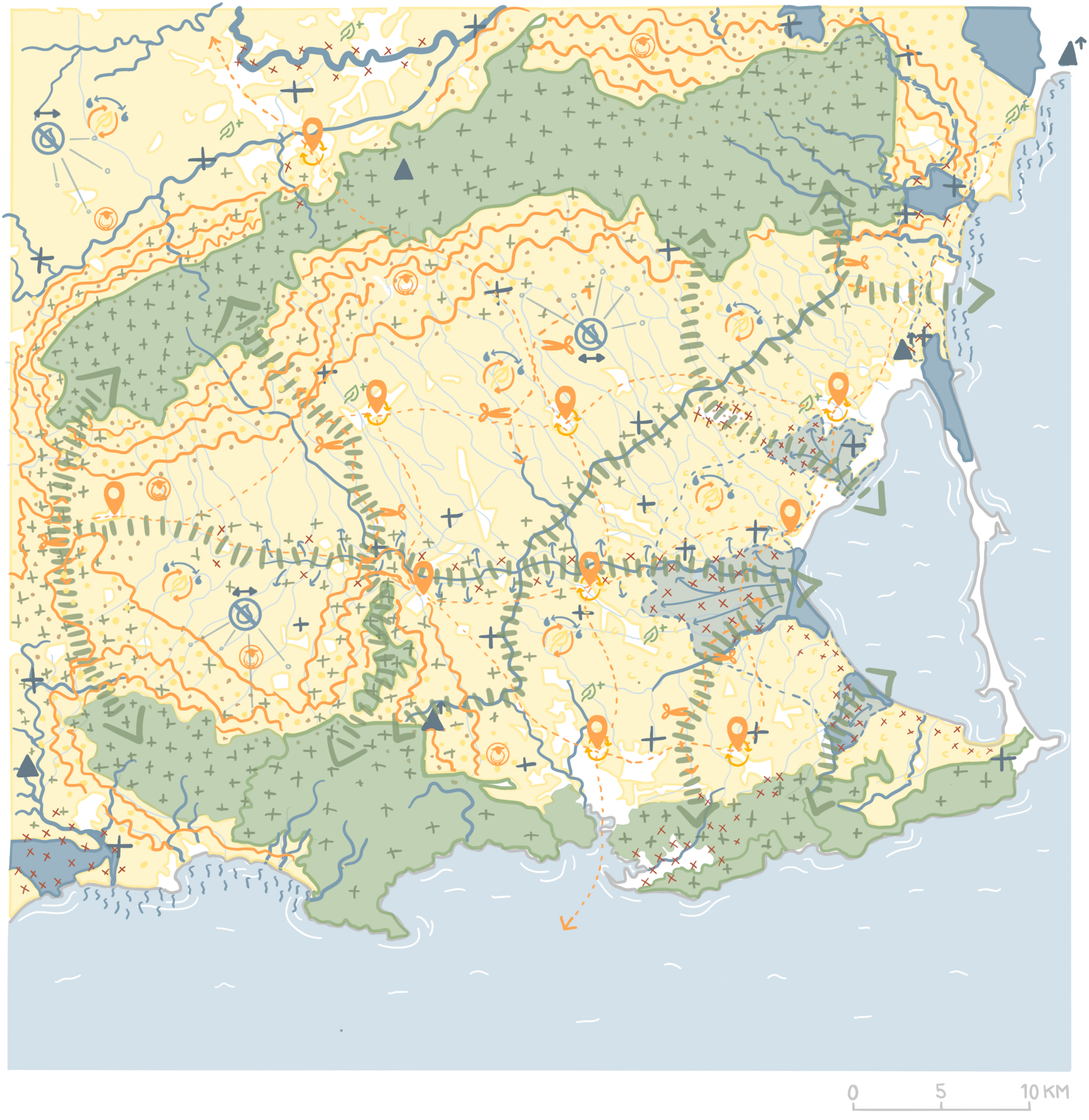


Figure 101. Scenario 1 Organic Produce: interventions of the territorial lens: (urban) water management. Source: made by author.

TERRITORIAL LENSES

Figures 99-101 show the spatial pattern implementations through the three territorial lenses, in order of priority for scenario 1. The interventions from the pattern language are connected to the legend items of the maps. The main pattern for this scenario is P1 (organic agriculture), which is operationalised by the pattern groups A1-5 and A6-14. In Figure 99, the spatial application of the P1 patterns as a first layer is shown. Together, the layers form the spatial strategy map of the first scenario, which is shown on the next page.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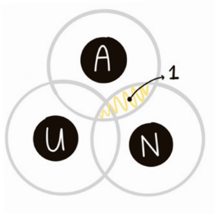
ORGANIC PRODUCE



SCENARIO 1

The first scenario is created by combining the interests of the Nature and Agriculture sectors. The political focus of this scenario is on transforming the agricultural production industry of the region into an organic production industry, thereby working together with the natural landscape and water system. This collaborates with the farm-to-fork strategy of the EU Green Deal, on which the first regional strategic design pattern (P1) is based.

SCENARIO NARRATIVE

By 2100, the Segura River Basin will have undergone a fundamental shift in its agricultural production identity, driven by global demands for organic food and environmental regulation. The region, once known for its monocultural, water-intensive exports, has embraced a new identity as the Green Garden of Europe. While the export mentality persists, the produce has transformed to meet international standards for organic agriculture, with strict certifications and zero-tolerance policies for chemical inputs. This transition has not only responded to global market pressures, but has started bottom-up as well, by growing societal awareness and a rising environmental movement. Key to this shift has been the region's commitment to ecological restoration and justice. Protected areas are carefully managed, and urban or agricultural activity is restricted within designated buffer zones to prevent further degradation and ecological disturbance.

At the same time, water governance has been significantly decentralised. Rainwater harvesting, dry farming, and indigenous water harvesting techniques are subsidised and encouraged through public support schemes. A centralised rainwater network collects and distributes stormwater to agricultural communities, which manage return flows in circular systems. Farmers themselves take an active role in this new system, as cooperatives and food policy councils have emerged as key platforms for participatory governance. These councils co-design regional food strategies that align production with both ecological needs and community well-being. Additionally, they invest in collaborative farming and local knowledge-sharing practices. Farmers, policy-makers, and ecologists meet through regular workshops, farmer-led markets, and open-source online platforms. The polluter pays principle has also been adopted: farms that continue to use polluting practices face higher costs, whereas those transitioning to organic methods benefit from financial incentives and access to shared resources.

The Organic Produce scenario envisions a region that uses the natural landscape as a tool for regenerative production. It transforms the Segura River Basin from a symbol of unsustainable intensification to a key example of symbiotic coexistence between agriculture and ecology, where sustainable food production contributes to a thriving landscape.

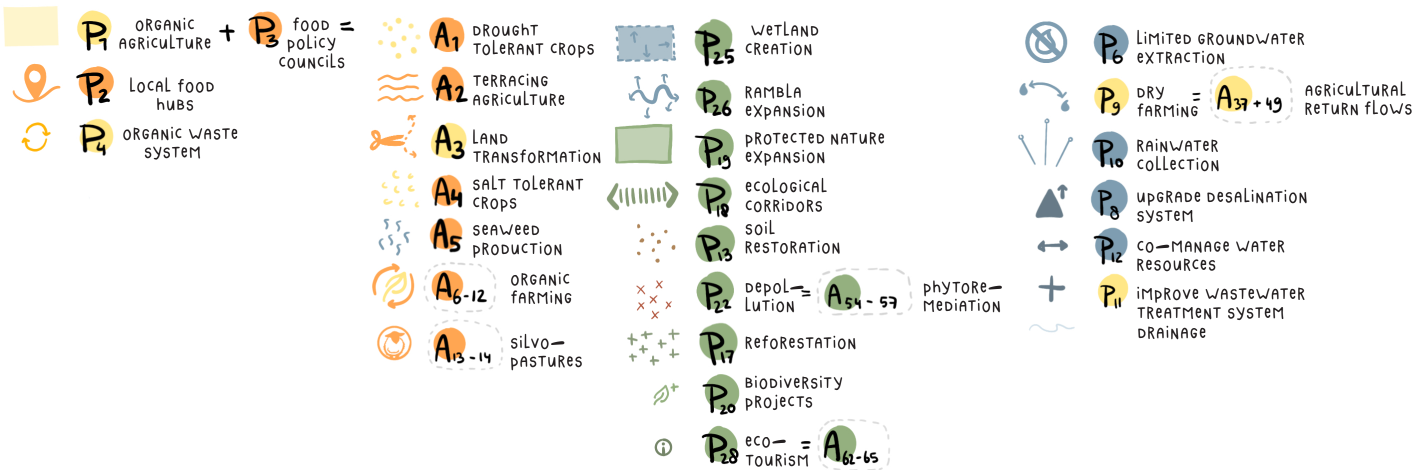
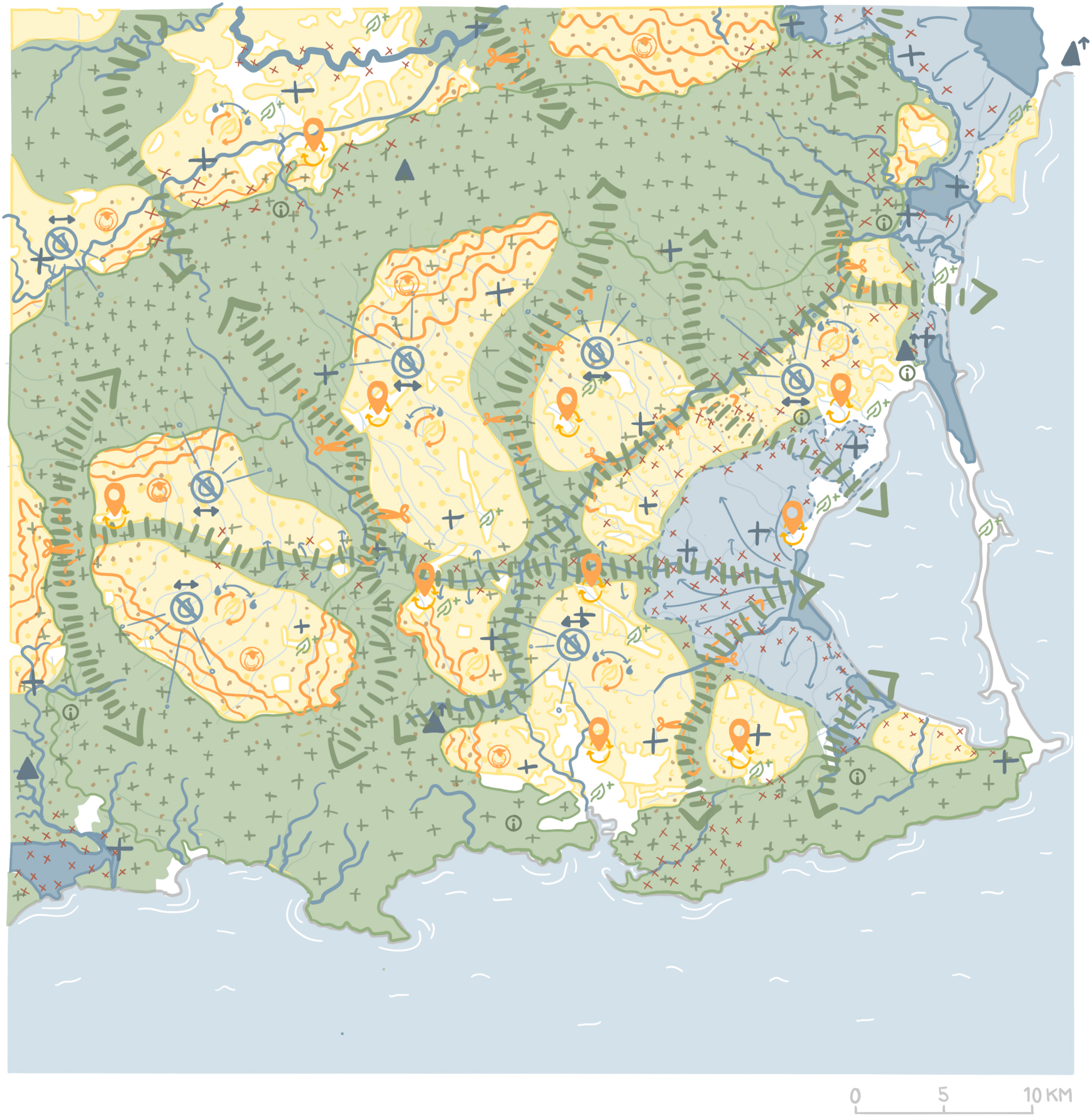


Figure 103. Map of the patterns applied in the sub-basin according to scenario 1. Source: made by author.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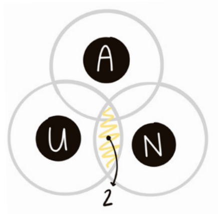
SELF-SUFFICIENCY



SCENARIO 2

The second scenario (Food self-sufficiency) is created by combining the interests and perspectives of the Nature and Urban sectors. The focus of this scenario is on local food production, distribution, and consumption, to ensure nature revitalisation and water security for future generations through significant water use reductions and the incorporation of efficient water use technologies.

SCENARIO NARRATIVE

By the year 2100, the region will have transitioned from an export-oriented agricultural production region to a self-sufficient region in terms of food production and water use. Driven by increasing political and societal awareness of water scarcity, strict regulations are introduced to limit groundwater extraction and diminish reliance on external water transfers. The enforcement of the polluter pays principle and the incorporation of the rights of nature result in rising water costs for water-intensive export crops. These shifts make traditional agricultural practices in the region economically unsustainable. As a result, large-scale agricultural land is gradually abandoned or transformed into more sustainable uses. Local and regional actors have repurposed former monocultural farmlands for ecological restoration, ecotourism, and local food systems, supported by decentralised governance structures. The region shifts away from its role as the "garden of Europe" and instead gains recognition for its restored landscapes, biodiversity, and circular economy practices. Rural livelihoods are reoriented around ecosystem services, ecotourism, and small-scale, water-efficient farming. These transitions reduce water demand while enhancing the ecological integrity and cultural identity of the territory, securing long-term socio-ecological resilience.

PATTERN SELECTION

In Figure 104, an overview is shown of the different patterns that are selected for this scenario, on the basis of the pattern-web (Figure 91).

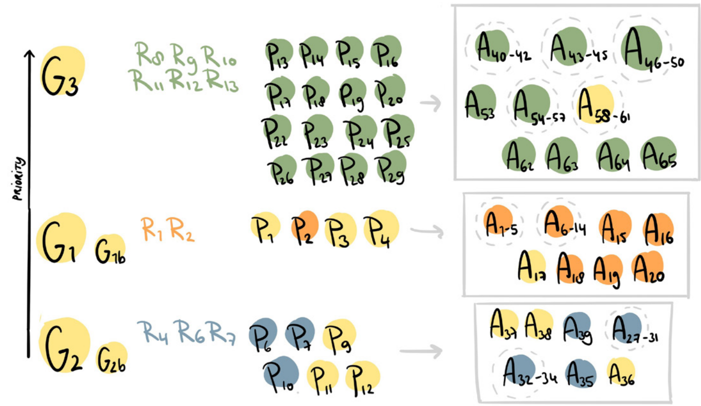


Figure 104. Selection of scenario based patterns for scenario 2. Source: made by author.

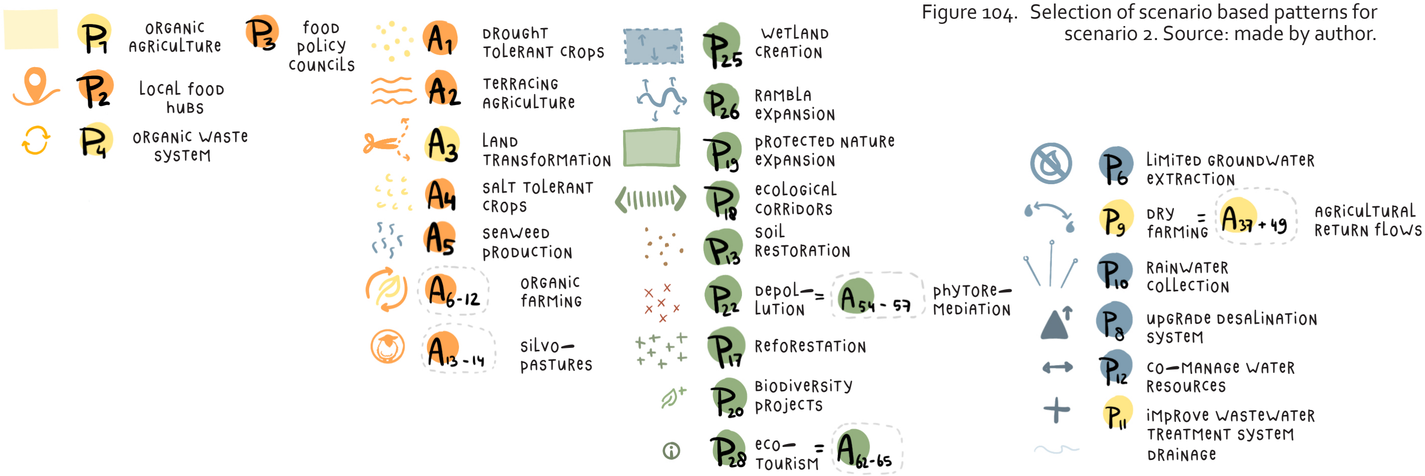
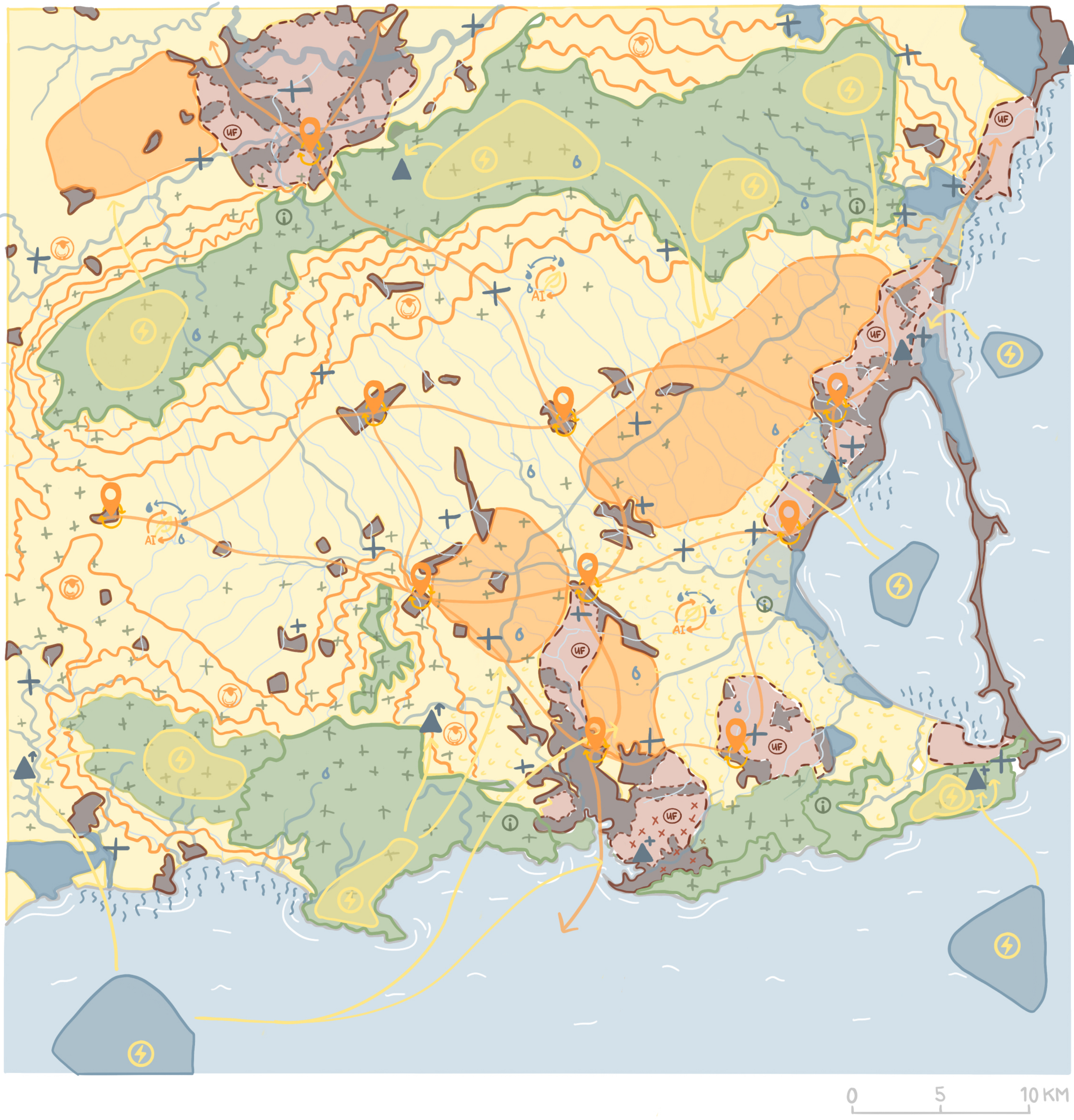


Figure 105. Map of the patterns applied in the sub-basin according to scenario 2. Source: made by author.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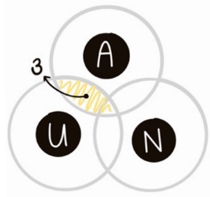
INNOVATIVE PRODUCTION



SCENARIO 3

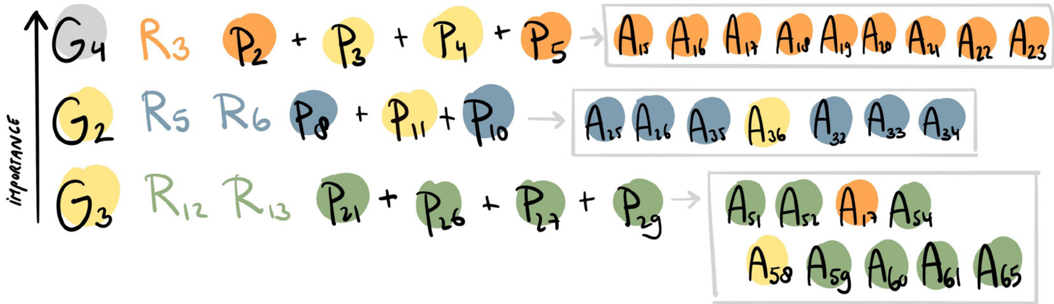
The third scenario, Innovative Production, is created through the combination of the interests of the Urban and Agriculture sectors. The focus of this scenario is on technological developments in the food production and renewable water and energy production industries, enabling a continuation of agricultural and urban processes.

SCENARIO NARRATIVE

By the year 2100, the region will have transformed into a technological food production pioneer. The focus lies on the integration of advanced water and food production systems that enable the continuation of economic activities while reducing environmental pressures. Driven by global investment and regional ambition, the region becomes a hub for water-efficient technologies, renewable energy systems, and alternative food production methods such as hydroponics, aquaponics, and AI-controlled vertical farming. Desalination plants are added or expanded to supply the region with renewable water sources, decreasing dependency on traditional water extraction and alleviating stress on aquifers and reservoirs. Although ecological restoration is not the primary objective, indirect environmental benefits emerge: improved water quality, reduced soil degradation, and a modest increase in biodiversity due to lower pollution levels from conventional agriculture. The region is internationally recognised for its leadership in circular food and water innovation.

PATTERN SELECTION

In Figure 106, an overview is shown of the different patterns that are selected for this scenario, on the basis of the pattern-web (Figure 91).



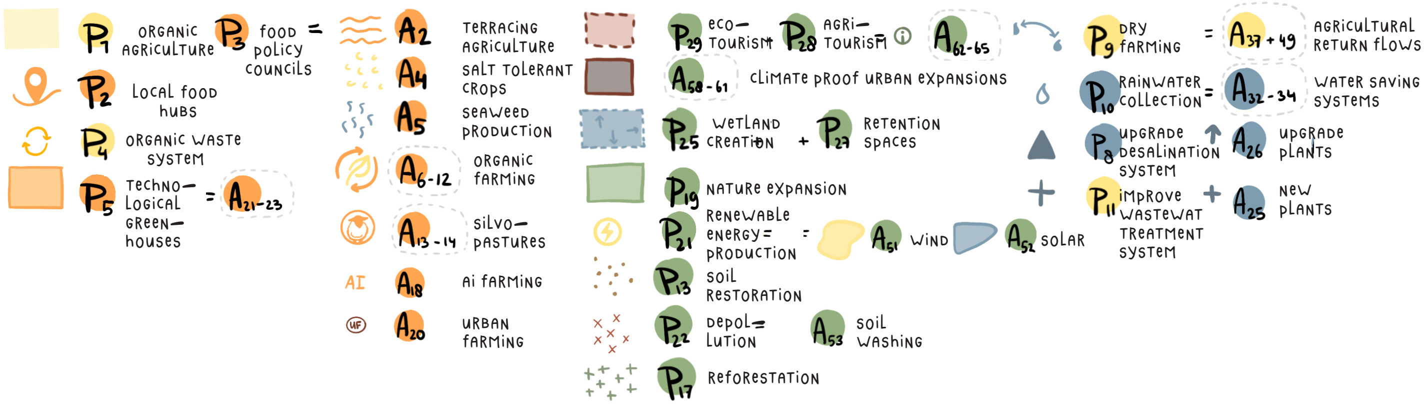
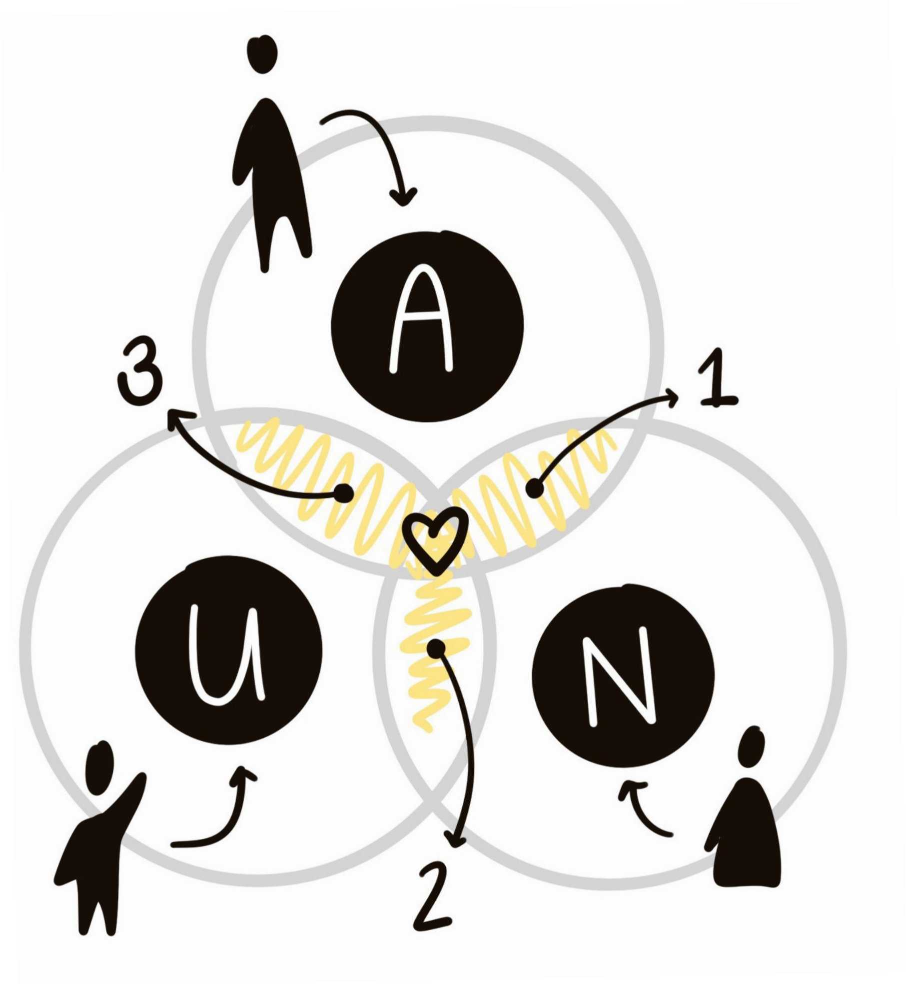


Figure 106. Map of the patterns applied in the sub-basin according to scenario 3. Source: made by author.

Figure 107. Selection of scenario based patterns for scenario 3. Source: made by author.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SCENARIO SYMBIOSIS
INTRODUCTION

From reviewing the scenarios can be concluded that the priorisation of different regional focus decisions (R) to achieve a symbiotic set of pathways between two sectors at a time, lead to different spatial design outcomes for the region.

By overlapping the scenarios spatially, no-regret measures can be discovered. No-regret measures would work in all scenarios, without hindering the operationalisation of a scenario-specific focus decision.

Additionally, sector symbiotic interventions can be discovered. These interventions are implemented in all three scenarios, because they operationalise a focus decision.

And lastly, by comparing the spatial implications of the three scenarios, areas of conflict can be identified. Areas of conflict are locations where different patterns from the scenarios are competing spatially. This means that in a certain area, according to scenario 1, a specific intervention is crucial, where according to scenario 2 and/or 3, a different (set of) patterns would be chosen to implement.

By identifying the no-regret measures, sector symbiotic interventions and areas of conflict for the sub-basin, a strategy for symbiotic design can be created. The no-regret measures and sector symbiotic interventions can be integrated in the strategy on the sub-basin scale right away, where the areas of conflict would need extra attention.

The overlapping of the scenarios is done by overlapping two scenarios at a time, identifying synergetic interventions per sector. The conclusions give insights in the priorities of the sector reviewed. This can inform the decision-making and design process during the design of the symbiotic pathways of the strategic projects. From these overlaps, the areas of conflict can be derived.

Next, all scenarios are overlapped spatially, focusing on the no-regret measures and sector symbiotic interventions.

The integration of the three sector specific synergetic maps results in a map of the region that shows the areas of conflict. Those areas form the locations of interest for strategic projects to design location-specific symbiotic pathways. Integrating these symbiotic pathways with the no-regret measures and sector symbiotic interventions, forms a symbiotic strategy for the water system transition in the region.

Figure 110. Map of the synergies and conflicts when comparing scenario 1 and 3 spatially. Source: made by author.

AGRICULTURE SECTOR
GLOBAL ORGANIC PRODUCTION V/S TECHNOLOGICAL FOOD HUB

When overlapping scenario 1 (Organic Produce) and scenario 3 (Innovative Production), synergies in interventions that were chosen to be applied are found mainly within the agriculture transition. Both scenarios focus on improving the agriculture industry to maintain its importance for global food production.

However, most interventions aplied are contradictory to each other. In scenario 1, the focus within water management is on water demand reduction, while in scenario 3, the focus is on water supply increase. Furthermore, scenario 1 focusses on connecting and protecting the natural landscapes, where scenario 3 prioritises technological development and urban expansions.

Contrasting interventions in terms of spatial claims are therefore found between creating nature connections and promoting the expansion of water supply infrastructures with the necessary additional green energy production sites. Other conflicts are found between implementing nature based flood control measures and alterations to restore the ecological flow of rivers (scenario 1), against developing the lowlands further in terms of technologically beased agricultural production and eco-tourism (scenario 3).

From this comparison can be concluded that the agriculture sector would perfer to maintain the global importance in the food production industry, and would only want to transition to natural areas if this is required by the law, or if it would be beneficial for their yields and produce.

Figure 111. Map of the synergies and conflicts when comparing scenario 2 and 3 spatially. Source: made by author.

URBAN SECTOR

TECHNOLOGICAL FOOD HUB V/S LOCAL SELF-SUFFICIENCY

When comparing scenario 2 (self-sufficient production) and scenario 3 (innovative production), spatial conflicts arise over transitioning agricultural area to natural areas for the creation of ecological corridors (scenario 2) and maintaing the agricultural areas, but improving them technically (scenario 3). Furthermore, according to scenario 2, food is produced for local consumption only, which results in a spatial conlfict in the harbour area with the food export industry of scenario 3. Thirdly, scenario 1 prioritises the creation and expansion of wetlands to provide flood control and increase the water supply, where scenario 3 would prioritise agricultural production and expansion of desalinated water infrastructures in those locations.

However, synergies between the two scenarios are found spatially in agricultural sites located around villages, where organic farming, dry farming, smart farming and drip irrigation can be used.

Seen from the urban sector, the preferred pathway to transition the agriculture industry is two-fold. Either a focus on local food production would lead to water security through a reduction in demand, or a technological revolution could optimise the system, providing enough water for all.

It is hard to tell which option would be preferred, as both pathways come with future uncertainties that could ruin the system. Improving the system technically according to scenario 3 would require national investments in food production technologies to be implemented in the area, as well as new renewable energy production sites and the expansion of the energy network. Possible new regulations against technically produced food, possible electricity fall outs or cuts in the available budget are uncertainties that could influence this pathway. On the other hand, a focus on local food production only would mean a loss in regional economic profit, which could result in a socio-economic decline of the region and hinder in the operationalisation of the other interventions from the pathway.

Therefore, a balance between the two preferred pathways from the urban sector has to be found, where renewable water production could form a centralised water supply network, supported by a decentralised network of rainwater collection and agricultural return flows that is locally managed. Together with implementing measures that result in a reduction of water demand, water security can be achieved through creating a new, symbiotic pathway.

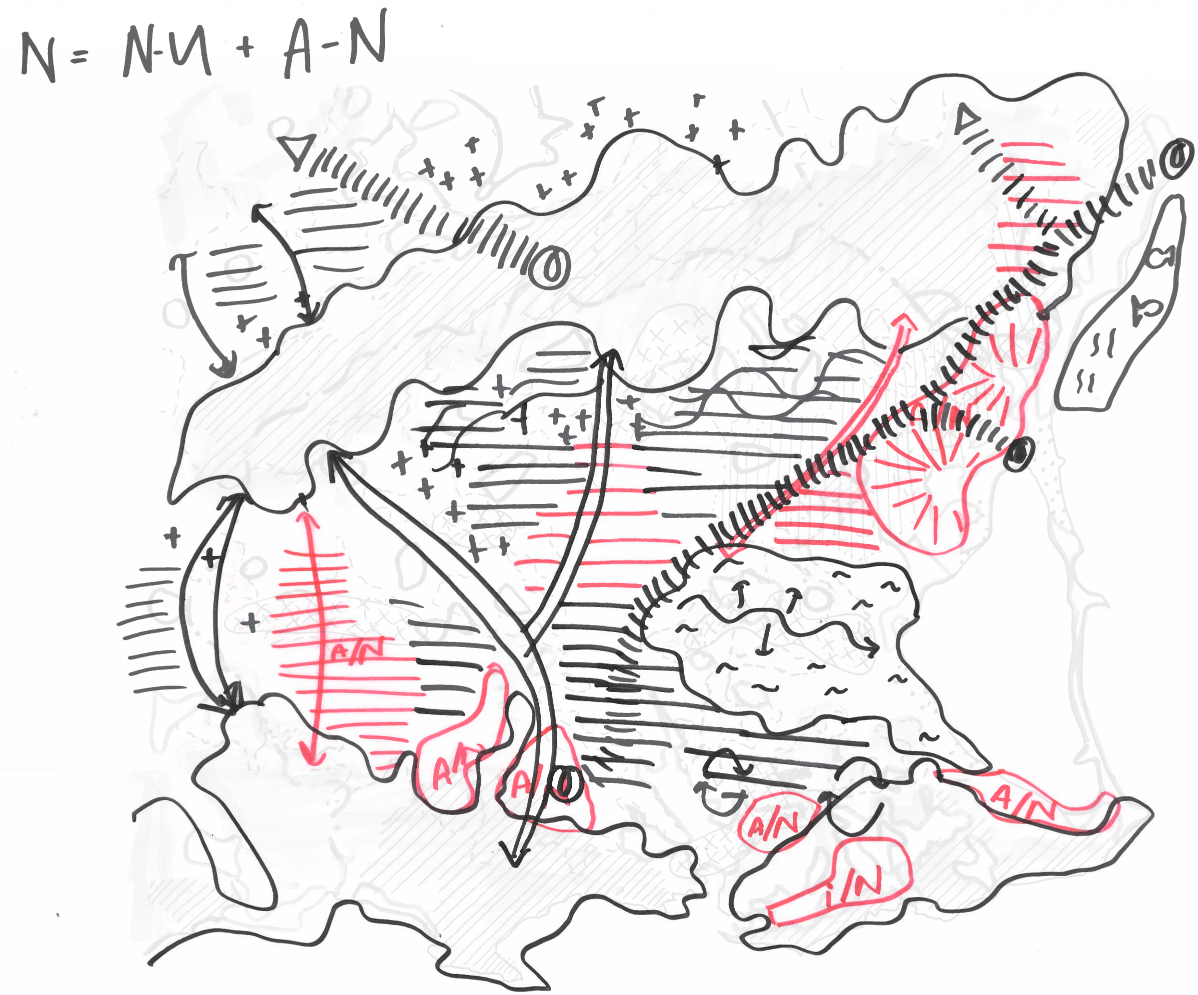


Figure 112. Map of the synergies and conflicts when comparing scenario 1 and 2 spatially. Source: made by author.

NATURE SECTOR

LOCAL SELF-SUFFICIENCY V/S GLOBAL ORGANIC PRODUCTION

Between the two scenarios that include the nature sector (scenario 1 and 2), interventions that cause conflict in spatial implementation are related mainly to the focus on local agricultural production (scenario 2) versus global organic food production (scenario 1), which requires a larger amount of land for agricultural production.

However, as both scenarios prioritise nature's needs, synergies are found in creating ecological corridors, expanding protected nature areas, creating wetlands for water supply and flood control, restoring desertifying areas, and implementing organic agriculture and dry agriculture principles.

In conclusion, the nature sector would prefer pathways that prioritise nature-based solutions for flood control and sustainable food production, where there is simultaneously a focus on nature restoration and connection. Therefore, as long as revitalising the natural landscape and fair water distribution are prioritised, and pollution is prevented, ecological systems can be in harmony with water supply networks and the agriculture industry.

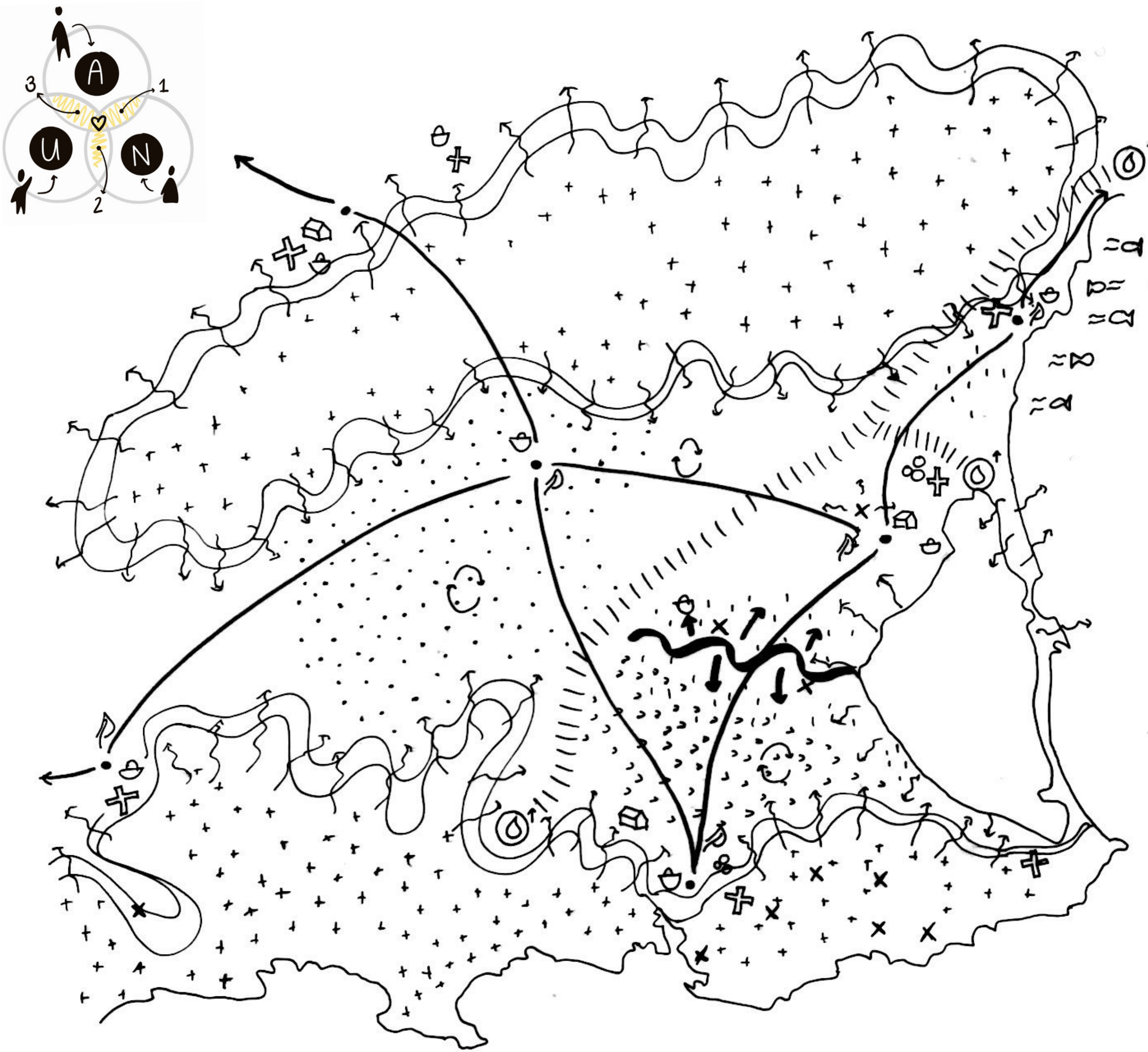
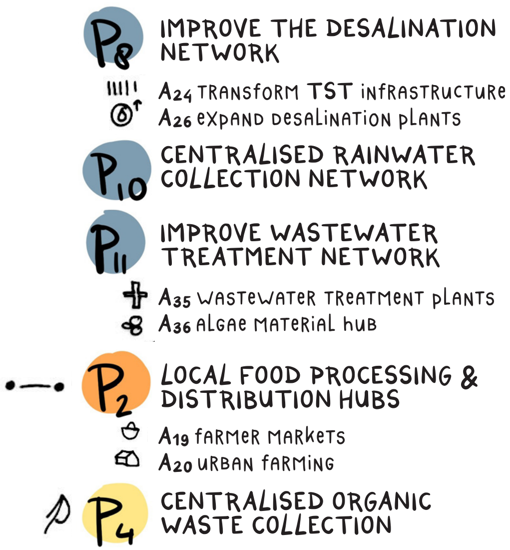


Figure 113. Map of the no-regret measures when comparing all scenarios spatially. Source: made by author.

SECTOR SYMBIOTIC MEASURES

SCENARIO SYNTHESIS



When overlapping the scenarios, a map of no-regret measures for the sub-basin can be created (see Figure 113). This map shows the spatial implementation of a selection of patterns that work in all three scenarios. Some projects are incuded as a priority in all scenarios. These projects are therefore called sector symbiotic interventions. The sector symbiotic projects for the sub-basin are:

P8) improve the desalination network

P10) implement a (centralised) rainwater collection network

P11) improve the wastewater treatment and reuse network

P2) local food processing and distribution hubs

P4) implement a centralised system for organic waste collection

The five sector symbiotic intervention patterns are highlighted from the pattern booklet on the next page.

However, the amount of actions implemented. the level of importance of the project and the phasing of the interventions can differ per scenario. The other interventions drawn on the map are included as no-regret measures, because they could be included in each scenario, without sacrificing any of the scenario specific priorities.

P2 LOCAL FOOD PROCESSING & DISTRIBUTION HUBS

GOAL:

Conventional agri-food systems often rely on long supply chains that contribute to high emissions, energy use, and food waste, while disconnecting producers from consumers. Establishing local food processing and distribution hubs near production and consumption areas enhances the sustainability and resilience of regional agri-food systems. These hubs reduce greenhouse gas emissions and water use for cooling by minimising transportation distances and enabling efficient, small-scale food processing and distribution. Economically, they lower logistics and packaging costs, generate local employment, and retain value within the regional economy. When integrated with farmers' markets, cooperatives, or community-supported agriculture schemes, they help improve food security and community well-being by reinforcing producer–consumer connections and supporting shorter, more transparent supply chains. This intervention aligns with the Farm-to-Fork strategy of the EU Green Deal (European Commision, 2020).

RELATIONS WITH:

Operationalised by: A19, A20

Related to: P3, P4, P1, P5

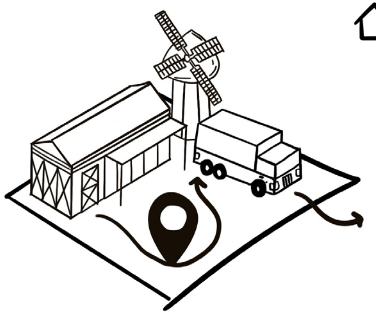
To be combined with: P3, P4, P5, P1, A15, A16, A21, A65

REQUIRES:

Focus: R2

Policies: R2a, R2b, (R3a)

Spatial conditions: close to urban transportation cores, located in agricultural areas.



SOURCE: (European Commission, 2020)

OBTAINED THROUGH: Design intuition|Literature study

P4 CROSS-SECTORAL ORGANIC WASTE SYSTEM

GOAL:

Linear waste systems in agriculture and urban areas often lead to nutrient loss, pollution, and increased dependency on synthetic inputs. Implementing a cross-sectoral organic waste collection and reuse system focusing on composting, manure exchange, and inter-sectoral redistribution, addresses these inefficiencies by closing nutrient loops at the regional scale. By transforming local organic waste into valuable inputs such as compost, biochar, or organic mulch, the system promotes soil restoration, reduces reliance on chemical fertilisers, and supports organic farming practices. Additionally, facilitating manure exchange among farmers or between sectors like agriculture, landscaping, and golf courses reduces logistical burdens, prevents over-application and runoff, and helps combat desertification. This systemic approach supports circularity, enhances ecosystem resilience, and creates shared economic and ecological value across urban-rural interfaces (FAO, 2025).

RELATIONS WITH:

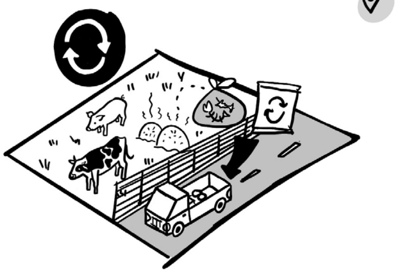
Possible Actions: A7, A8, A13, A15, A16, A19, A36, A42

To be combined with: P1, P2, P3, P5, P9, P11, P13, P22, P24

REQUIRES:

Focus: (R1), R2, R11

Policies: (R1a, R1b, R1c), R2a, R2b, (R8c), (R10c), R11e



SOURCE: (FAO, 2025)

OBTAINED THROUGH: Design intuition|Literature study

P8 REGI… DESALI… NETW…

GOAL:

Desalination is a promising… production, that is already pres… all areas are connected to the… plants are not yet operating at… the desalination network provi… supply of renewable water, r… environment and improving… However, desalination is a cos… the ecological environment, ar… well as infrastructure adjustm… Therefore, it is required to inte… strategy that is connected to… ecological restoration transition…

RELATIONS WITH:

Operationalised by: A24, A25,…

Related to: P7, P21, P6, P16, P1…

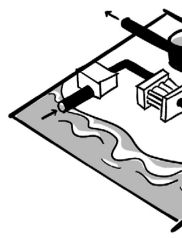
To be combined with: P11, P10…

REQUIRES:

Connection to: P21, P7

Focus: R5

Policies: R5a



OBTAINED THROUGH: Li… study, Fieldwork observation…

Figure 114. Sector symbiotic patterns from the pattern language. Source: pattern booklet, made by author.

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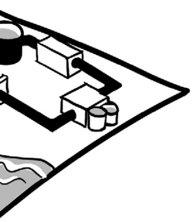
g form of renewable water ent in the region. However, not desalination network, and the their full capacity. Improving ides opportunity for increased relieving water stress on the water security in the region. tly practice, has an impact on nd requires a lot of energy, as nents to expand the network. egrate this solution in a bigger o the renewable energy and ns.

A26
11
, P9, P1, P5, P7, P21



terature study, Precedent
ns

P10 CENTRALISED RAINWATER COLLECTION

GOAL:

The region faces significant water shortages exacerbated by outdated and leaky water infrastructure and high evapration rates, leading to structural water deficits and inefficient use of available rainfall. Centralised rainwater collection systems, integrating both large-scale reservoirs and numerous small-scale catchment projects, can significantly enhance water availability and supply reliability. By capturing and storing rainwater from rooftops, urban surfaces, and natural catchments, these systems reduce dependency on overexploited groundwater and surface water sources. Implementing centralised rainwater harvesting can be synergistically combined with upgrading outdated sewage and stormwater infrastructures to reduce leakages and manage urban runoff more effectively.

RELATIONS WITH:

Operationalised by: A32-A34, A28, A39, A47, A58, A59

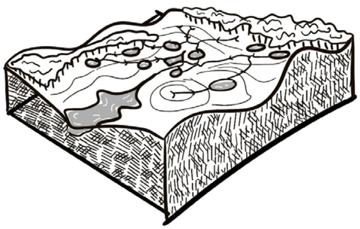
To be combined with: P11, P22, P25, P27, P9, P12

REQUIRES:

Such systems require investments in interconnected storage tanks, pipelines, filtration units, and smart monitoring technologies to optimise water capture, storage, and distribution. Collaboration between municipal water authorities, urban planners, and local communities is crucial to design and maintain these infrastructures.

Focus: R6, R5, (R7), R4, (R12)

Policies: R5b, (R6a)



OBTAINED THROUGH: Design intuition

P11 REGIONAL WASTE WATER TREATMENT

GOAL:

In semi-arid regions, insufficiently treated wastewater poses environmental and public health risks while valuable water resources are lost. Wastewater treatment systems use physical (screening, sedimentation), biological (microbial degradation), and chemical (disinfection, nutrient removal) processes to clean water before safe discharge or reuse. Enhancing the regional wastewater treatment network by constructing new plants and upgrading existing facilities can increase the availability of water, support circular water management by reducing freshwater demand, and mitigate environmental degradation by preventing pollution from contaminants. Especially on-site treatment systems like septic tanks, constructed wetlands, and composting latrines has potential in contributing to sustainability as they do not rely on energy and chemical intensive processes, and return nutrients to the surrounding environment (Muga & Mihelcic, 2007).

RELATIONS WITH:

Operationalised by: A35, A36, A37

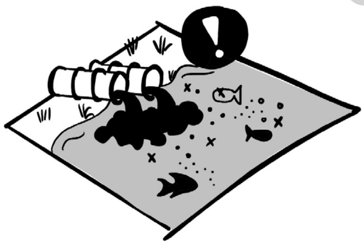
To be combined with: P8, P10

REQUIRES:

Coordination among municipalities, industries, and agricultural users is essential to optimise reuse applications and infrastructure investments.

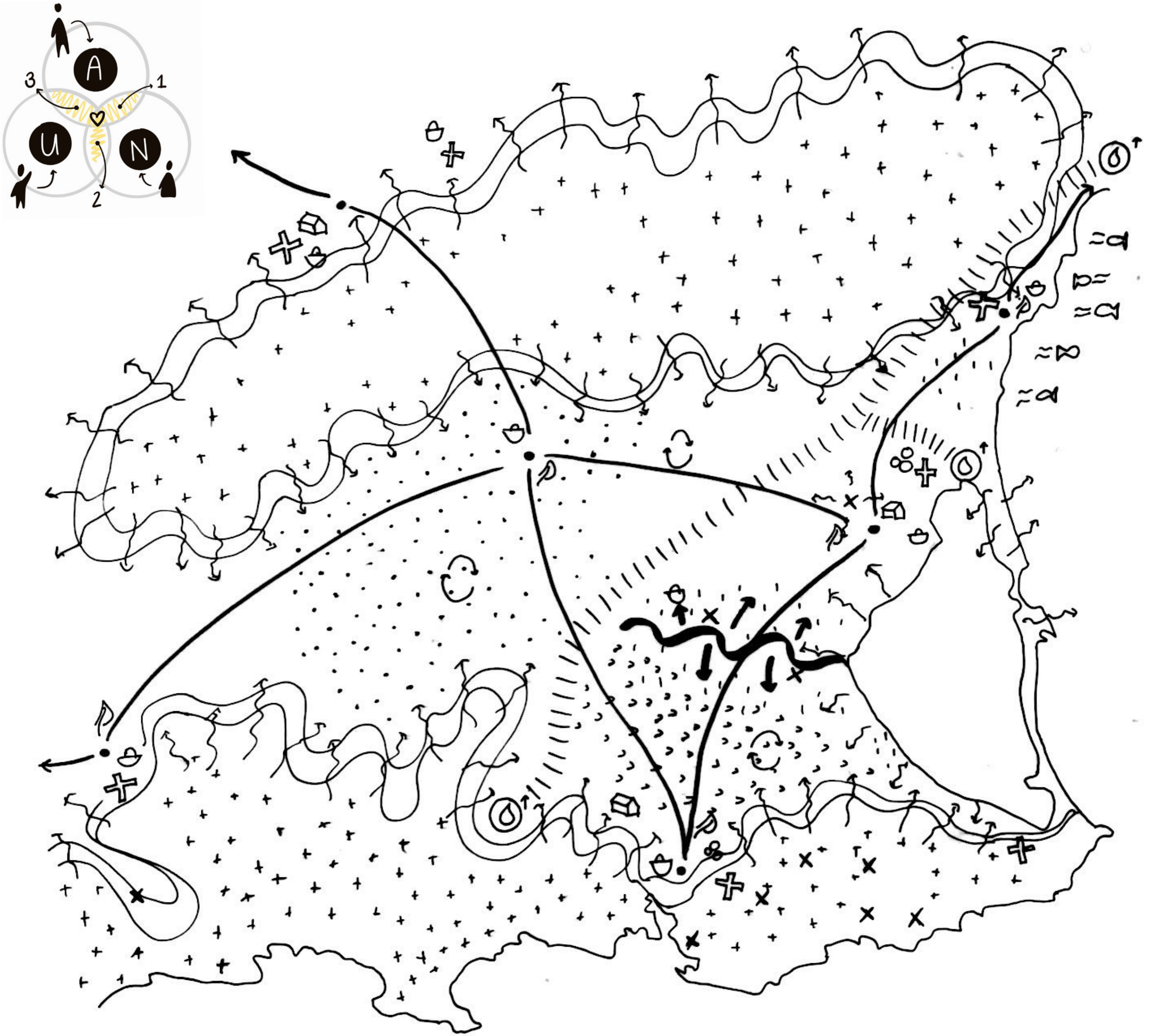
Focus: R5, R6, R4

Policies: R6a



SOURCE: (Muga & Mihelcic, 2007).

OBTAINED THROUGH: Literature study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NO-REGRET MEASURES

SCENARIO SYNTHESIS

However, the amount of actions implemented. the level of importance of the project and the phasing of the interventions can differ per scenario. The other interventions drawn on the map are included as no-regret measures, because they could be included in each scenario, without sacrificing any of the scenario specific priorities.

P7 **TRANSITION TO ORGANIC AGRICULTURE**

A1 drought tolerant crops
A2 terracing
A3 transition parcals to nature
A4 salt tolerant crops
A5 seaweed farming
A6 vegetated parcel divisions
A8 organic mulching
A9 crop rotation
A10 natural pest control
A13 silvopastures
A18 AI farming

P3 **FOOD POLICY COUNCILS**

A37 agriculture return flows
A16 knowledge platform

P13 **SOIL TREATMENT**

A2 terracing

P16 **WATER EXTRACTION ACCORDING TO WEATHER**

P17 **REFORESTATION**

P20 **BIODIVERSTIY PROJECTS**

A47 ponds
A49 urban green strips

P22 **SOIL & WATER DECONTAMINATION**

A55 phytoextraction
A56 phytostabilisation

P23 **RIPARIAN BUFFERZONES**

P26 **EXPAND RAMBLAS**

P27 **WATER RETENTION AREAS**

A58 rain collection roofs
A59 wadis
A60 permeable pavement
A61 urban vegetated floodquays

P28 **ECOTOURISM**

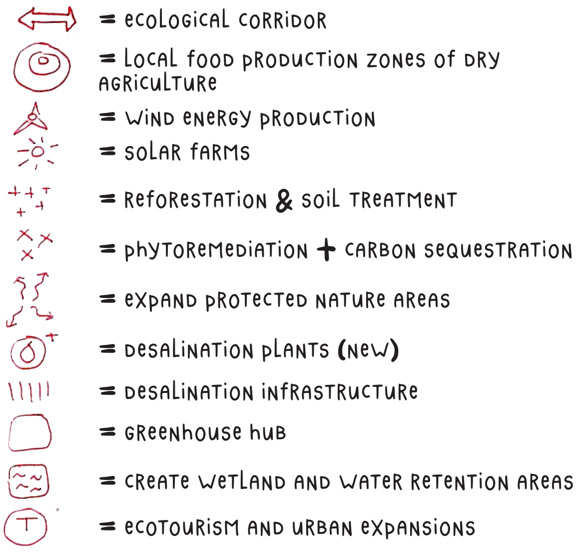
A63 elevated paths
A64 amphibious parks
A65 informative route

Figure 115. Map of the interventions causing spatial conflict when comparing all scenarios spatially. Source: made by author.

SPATIAL CONFLICT
CONFLICTING SCENARIO INTERVENTIONS

On top of the no-regret measures, a spatial map of conflicting actions for the sub-basin can be created (see Figure 115). This map shows in red the spatial implementation of the operation patterns that cause spatial conflict between two (or all three) scenarios. The main interventions causing spatial conflict are:

P5) Create a technological greenhouse hub
A25) New desalination plants and infrastructure
P21) Renewable energy production sites
P18) Create ecological corridors
P23) Riparian bufferzones in agricultural and urban areas
P28) Ecotourism + P29) Agrotourism
P25) Expand and create wetlands



CONCLUSION

In this chapter, several strategic design futures for the water system transition in the Campo-de-Cartagena sub-basin within the Segura River Basin are explored, through the construction of three integrated perspective scenario narratives, following the scenario framework presented in Figure 95.

A research-by-design process was used for the spatial design of the scenarios, which created a workflow for improving and expanding the pattern language, and applying the patterns spatially. For the selection of patterns to be implemented, the pattern-web structure was followed from a top-down regional planning perspective, by prioritising different political focus decisions, and connecting them to operational interventions in the form of regional projects and local actions.

The first scenario, Organic Produce, combined the preferences of the Agriculture and Nature sectors, and resulted in a strategy for the region focussing on transitioning the food production industry to organic agriculture. The second scenario called Self-Sufficiency combined the preferred interventions of the Nature and Urban sectors, and resulted in a spatial design exploration of a transition that is focussed on local food production and consumption, combined with priotitising nature's protection. The third scenario, Innovative Production, showed an exploration of the combination of the preferences of the Urban and Agriculture sectors, where a technological development of the food industry was prioritised.

The different scenario narratives resulted in different pattern selections. Overlapping the scenario designs spatially resulted in a map of symbiotic, no-regret, and spatially conflicting patterns. The symbiotic and no-regret measures combined formed the basis of a symbiotic spatial design strategy of the water system transition in the region, showing the key interventions of the pattern language.

The spatially conflicting patterns from the scenarios form points of collision between preferred pathways. Extracting these locations from the spatial strategy map, and investigating them on a smaller scale, results in zoom-in designs that aim for the construction of a symbiotoic adaptive pathway that solves these local conflicts. The construction of these local strategic projects is explained further in the next chapter.

STRATEGIC ACTION

INTRODUCTION

In this chapter, the regional symbiotic spatial design strategy of the water system transition, consisting of symbiotic and no-regret measures applied spatially to the design region, is completed. This is done by zooming in to the areas of spatial conflict that arose from overlapping and comparing the scenario interventions spatially, and creating local strategic projects that design a symbiotic adaptive pathway specifically to fit the context of those locations. To do this, first, the areas of spatial conflict are defined and extracted as separate study cases, to design a strategy for on a smaller scale. Each strategic project is analysed on a local scale, and the conflicting interventions from the scenarios on that specific location are set out. This gives insight in the direction in which the design solutions should be focussed.

Afterwards, the pattern language is applied through a research-by-design process, this time approached from a bottom-up perspective. Starting with the local intervention actions that could be operationalised by agents of the local scale, new combinations or relations between patterns, as well as new symbiotic solution interventions are sought through a creative research and design process, resulting in a fourth symbtiotic scenario for the zoom-in location. During this process, the pattern language is expanded further with these new ideas and pattern relations, resulting in an iterative process of constant alteration. The newly created pattern connections form symbiotic adaptive pathways within the pattern language, that are context specific to the location of the strategic project, but could be of general interest to broader strategies. These symbiotic adaptive pathways are phased over time to show the implementation of the strategy on the local scale, and connect the pathway to broader policies of the regional strategy. Integrating the symbiotic adaptive pathway pattern selections with the spatial stategy consisting of symbiotic and no-regret measures, results in a completed symbiotic spatial design strategy for the broader region.

This chapter shows how this method is applied, by zooming in to the first strategic project location.

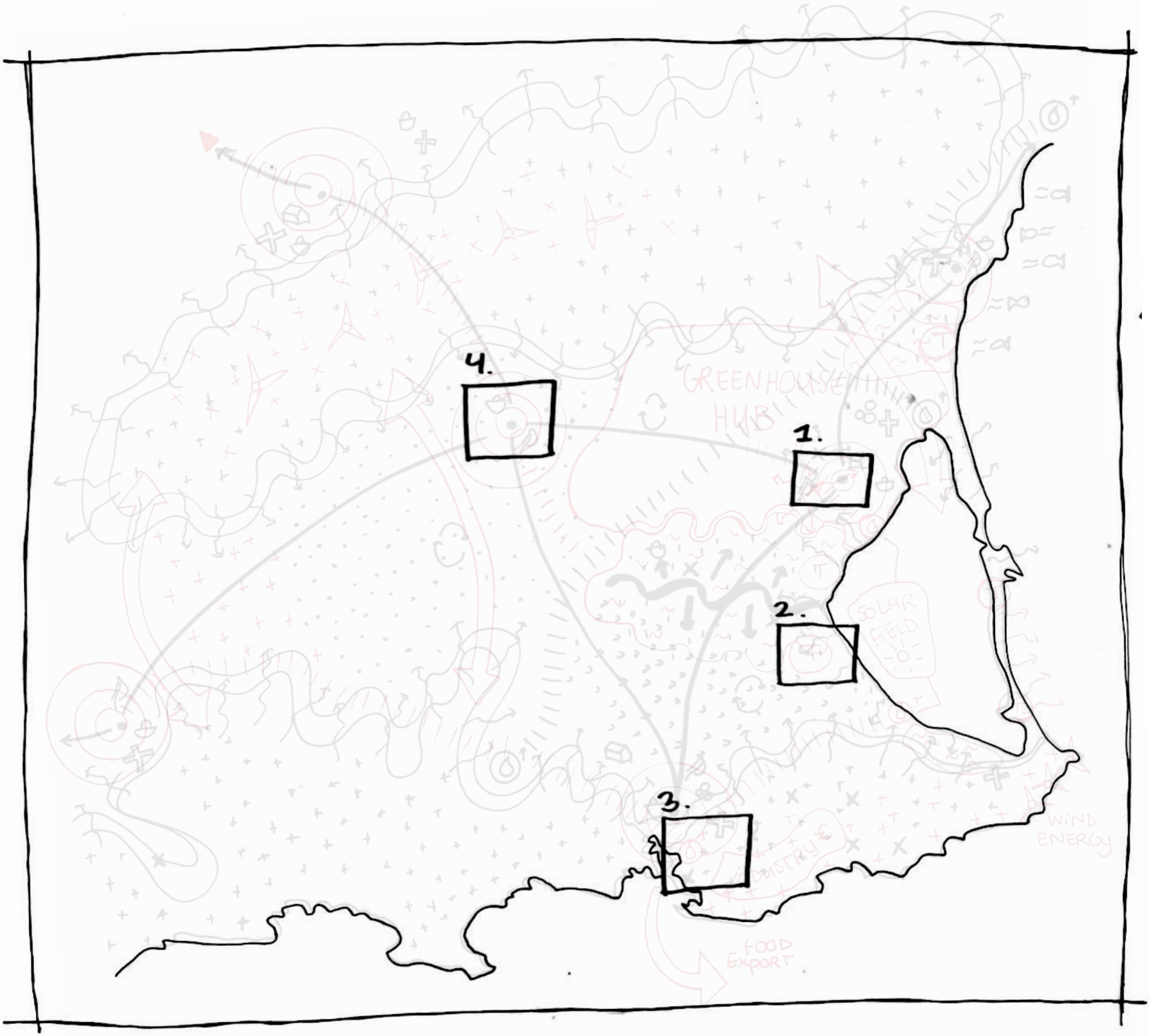


Figure 116. Areas of spatial intervention conflict from overlapping the scenarios.
Source: made by author.

AREAS OF CONFLICT
INTRODUCTION

From the overlapping of the scenarios came forward that certain areas in the region have conflicting pattern choices and spatial implementations according to the different priorities of the scenarios. These areas of conflict are shown in Figure 116. The areas of conflict are translated to strategic projects in this chapter, by creating a symbiotic pathway of interventions for each area of conflict. Together with the no-regret measures, the symbiotic pathways create a strategy for the region.

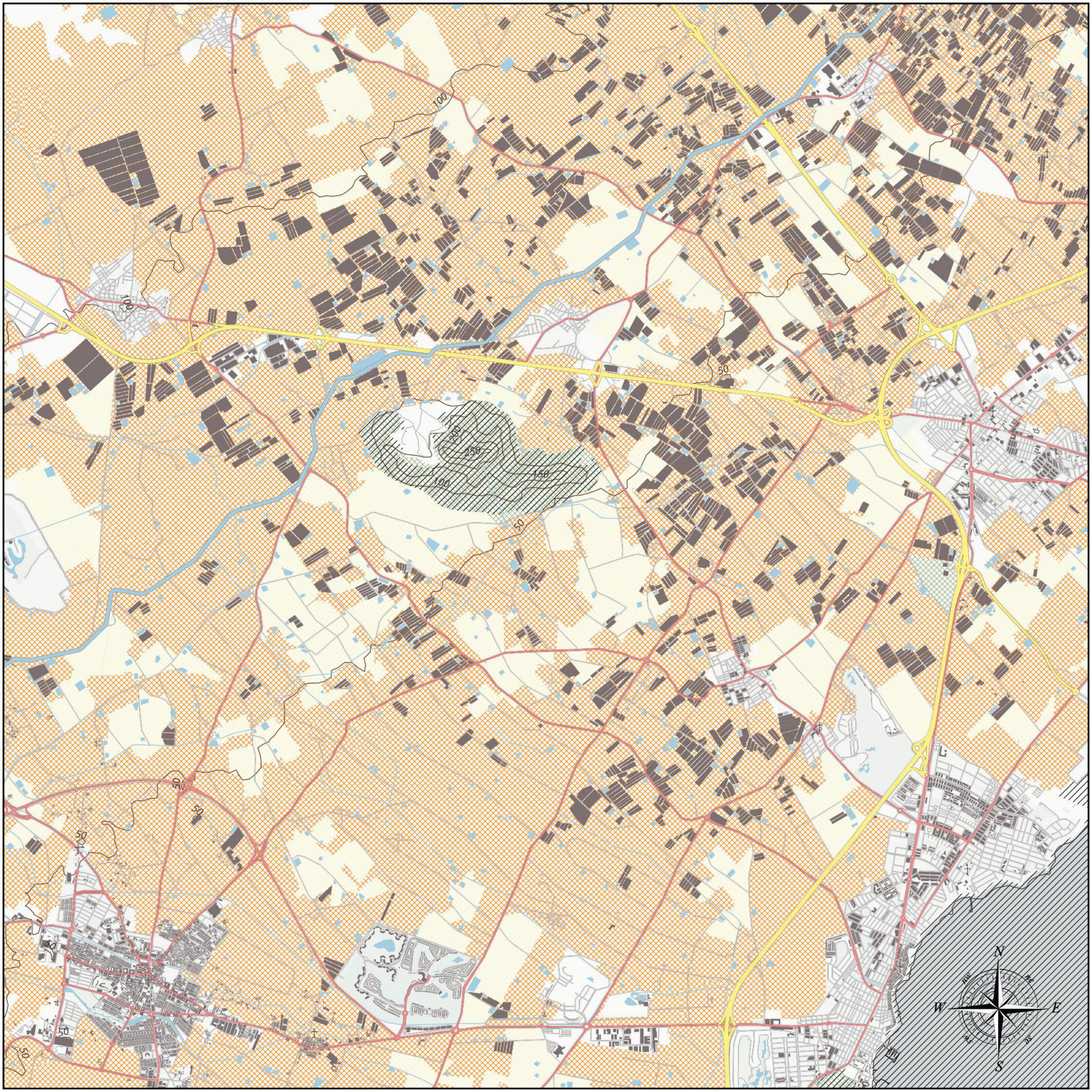
FROM AREAS OF SPATIAL CONFLICT TO STRATEGIC PROJECTS:

1. PILOT GREENHOUSE HUB = COMBINING TECHNOLOGICAL INNOVATION IN THE FOOD INDUSRY & JUSTICE FOR NATURE

2. ECOTOURISM WETLAND = COMBINING DEPOLLUTION, ECOLOGICAL FLOW RESTORATION AND HABITAT PROTECTION & TOURISM

3. TRANSITION OF THE HARBOUR = COMBINING RENEWABLE WATER AND ENERGY PRODUCTION & CLIMATE RESILIENT URBAN DEVELOPMENT

4. DETACHED SYSTEMS = COMBINING FOOD AND WATER SELF-SUFFICIENCY AND CO-MANAGEMENT & INDIGENOUS TECHNIQUES IN DETACHED AGGLOMERATIONS



0 1 2 3 km

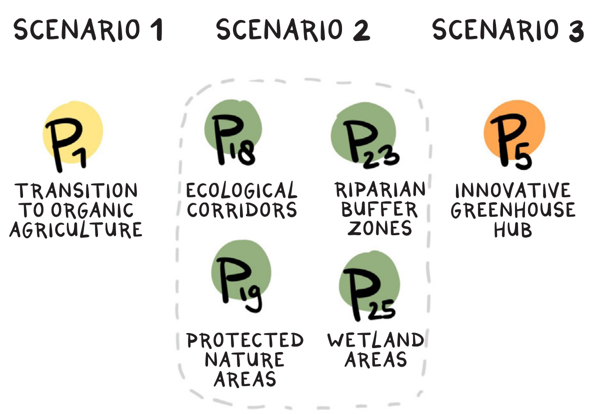
STRATEGIC PROJECT

GREENHOUSE HUB - PILOT VERSION

The first strategic project is located in an intensive irrigated area full of greenhouse agriculture. The location of the project is shown in Figure 116. Figure 117 shows a zoomed-in map of the location, where the current land uses are shown, in combination with the morphology and transportation routes of the area.

CONFLICTING PATTERNS

In this area, the patterns that clashed from the different scenarios were:



Legend

Buildings
Canal Tajo-Segura

Road network
Motorway or highway
Main road
Road, residential, living street, etc.

Waterways
Stream
River

Water
Protected areas

Corine Land Cover 2018
212: Permanently irrigated land
222: Fruit trees and berry plantations
321: Natural grasslands
Elevation

Figure 117. Location strategic procject 1: cumulative analysis map. Source: made by author, based on (CHS, 2025) and (CORINE, 2022).

Additionally, related to the water transfer infrastructure located in the area, three contrasting paterns were found as well:

1. Close the transfer and improve the desalination network in that area (P14 + P8, scenario 1)
2. Close the transfer and expand natural Ramblas in that area (P14 +P26, scenario 2)
3. Adaptive management through the TST and improve the desalination network alongside it (P16, P8, scenario 3).

In Figure 118, a systemic section of the current practices in the area is shown. Figure 119 Figure 120 and Figure 121 show systemic sections and the pattern selections applied in the area for the different scenarios.

SYMBIOTIC PATHWAY

These sequences of pattern choices can be seen as alternative pathways to achieve the vision. The sections show different outcomes of the vision, according to the scenarios. However, as certain stakeholders perfer one outcome (or pathway) over the other, a symbiotic design for the future is not yet achieved when following either of these pathways. To create a symbiotic pathway in areas of conflict, a more thorough analysis and context specific design is needed.

Figure 122 shows the systemic section for a fourth scenario that is created for this location specifically. In this scenario, a middle pathway is created between the different scenarios. This is done by selecting, prioritising, and combining several aspects of the patterns, implementing other patterns, or implementing the patterns only partially. During this process, new relations are made between the patterns that could (but not necessarily have to) be shown on the pattern cards. Additionally, new patterns emerge from the design process.

The symbiotic relations that are found are explained through imaginary tiles that show pattern combinations for the design location.

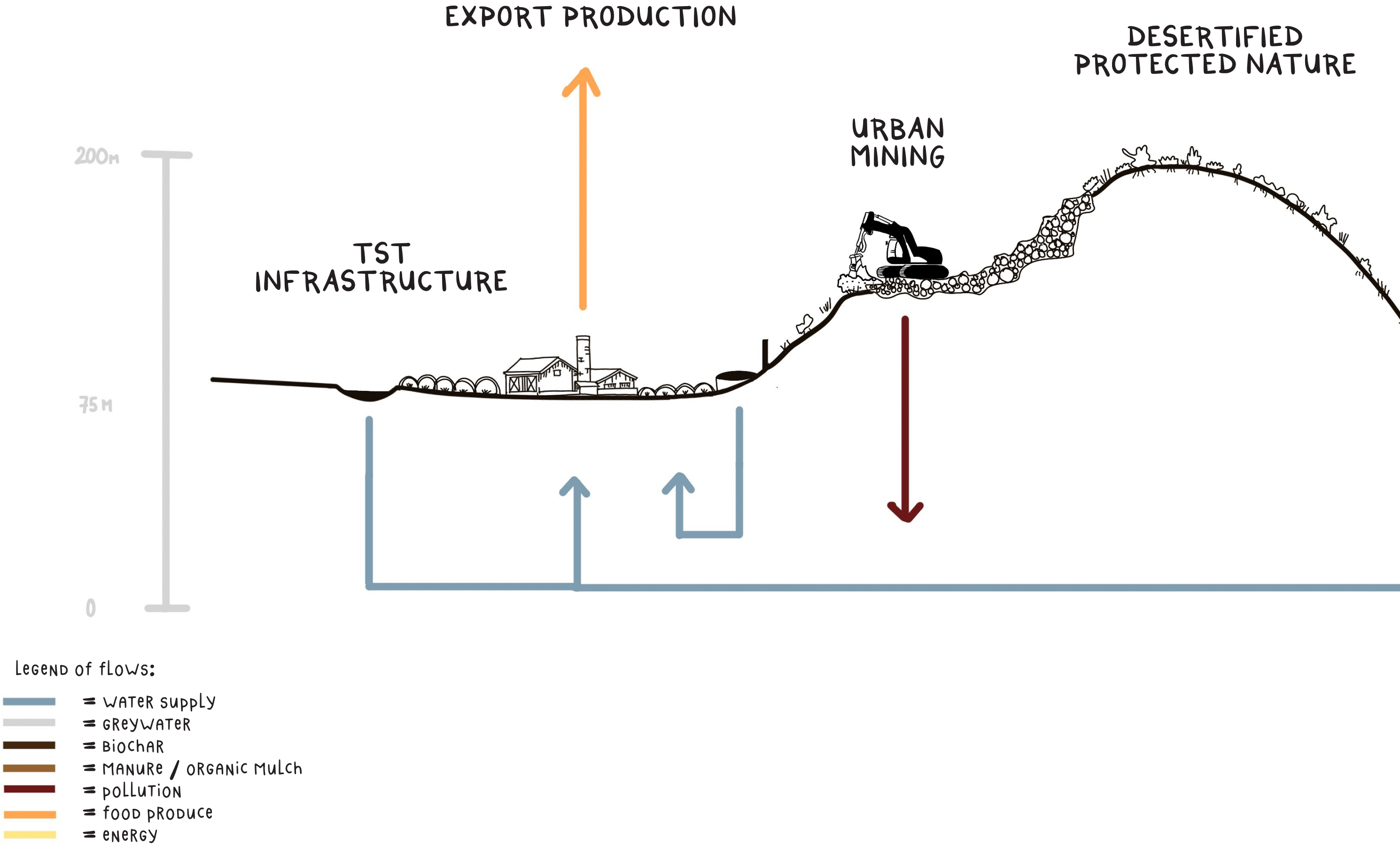
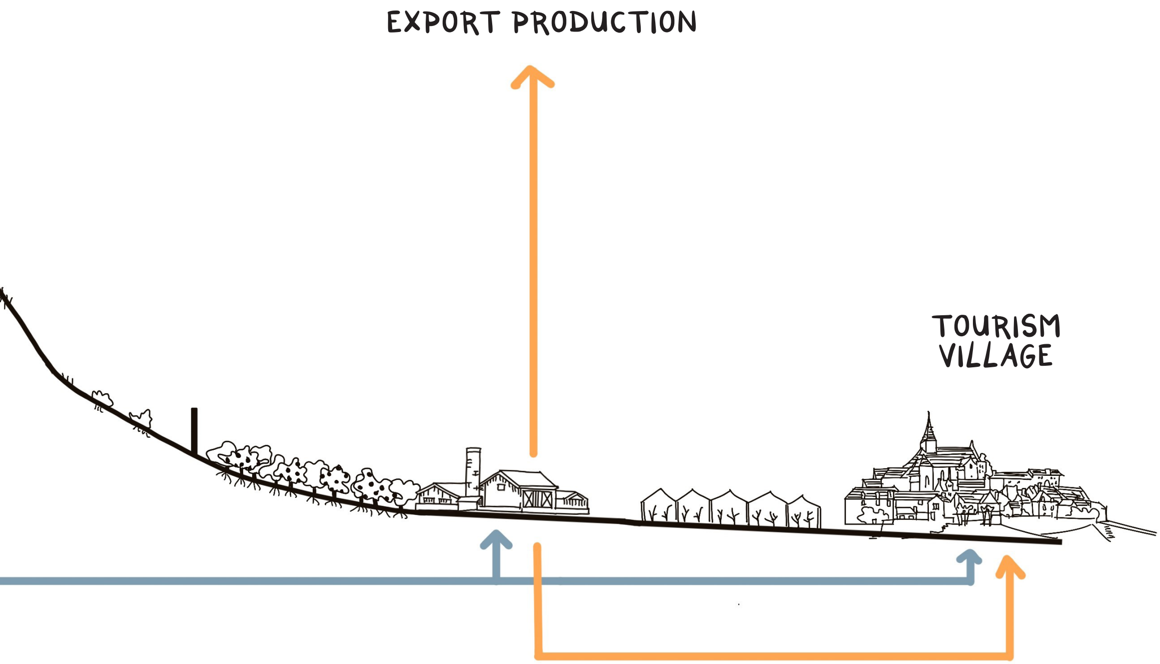


Figure 118. Section of the current practices and systems in location 1. Source: made by author.

CURRENT SITUATION

Currently, the area is characterised by intensive irrigation in the form of greenhouse agriculture where vegetable crops are being producd, irrigated fruit trees and vegetable crops that are covered by plastic foils. The water used for irrigation is supplied by the TST (in the section drawn on the left). A village is located nearby (on the right in the section), and in the middle of the area, a 200 metre high hill with sparce vegetation marks the territory. The hill is marked as a Natura 2000 site, but is currently subjective to urban mining, waste dumping and soil erosion.



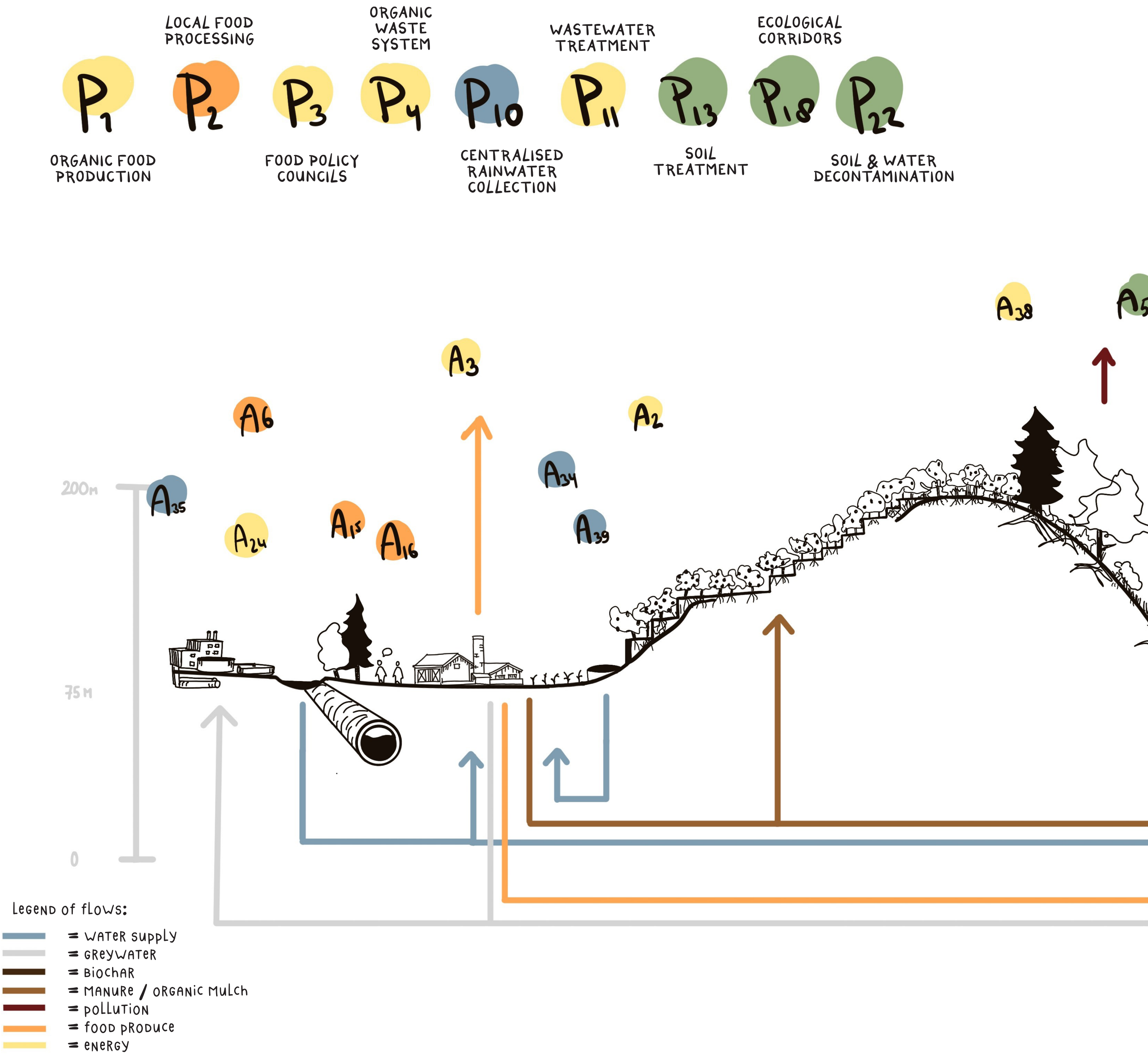
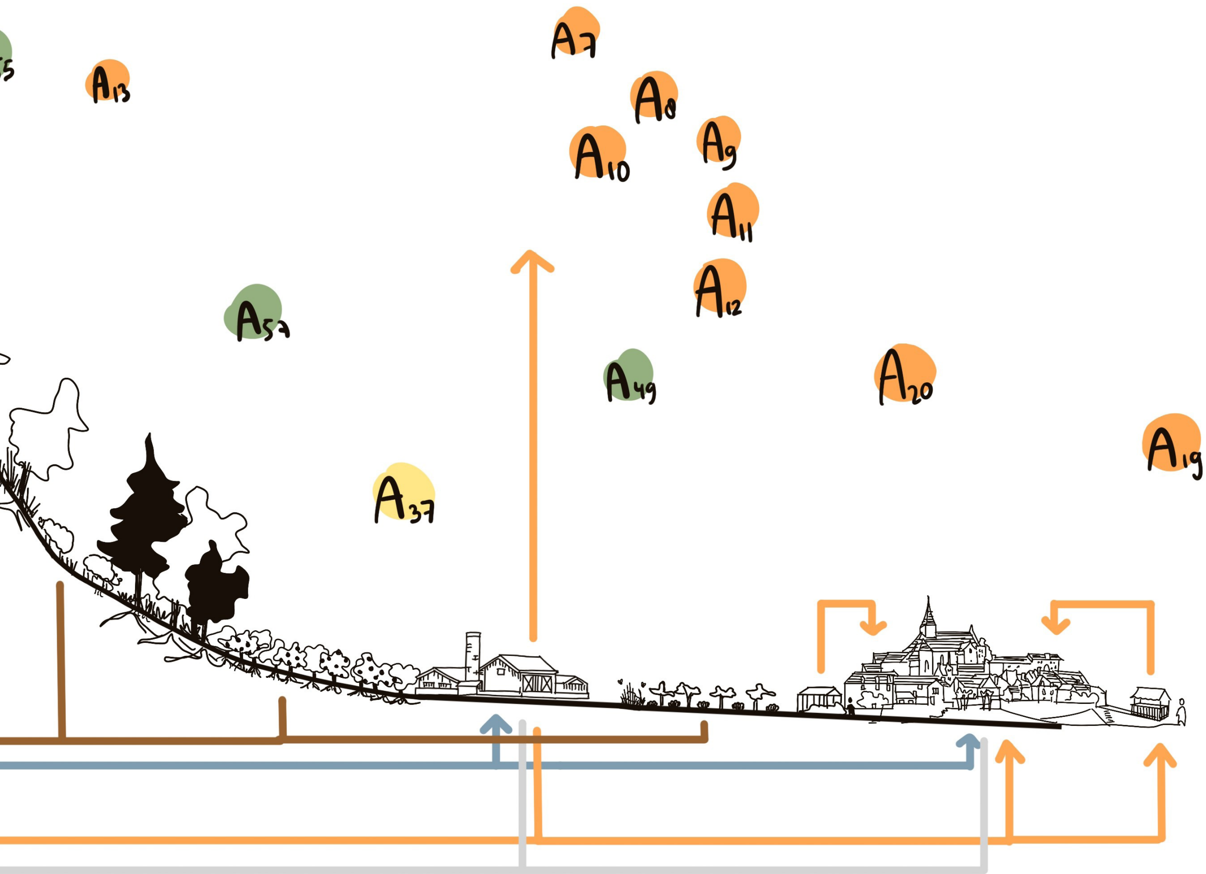


Figure 119. Section of the pattern selection for scenario 1 applied in location 1: practices and systems. Source: made by author.

SCENARIO 1

According to scenario 1, the location needs to transition to organic agriculture production. The section shows the pattern selection for this location according to scenario 1, and the implementation of the patterns in the area.



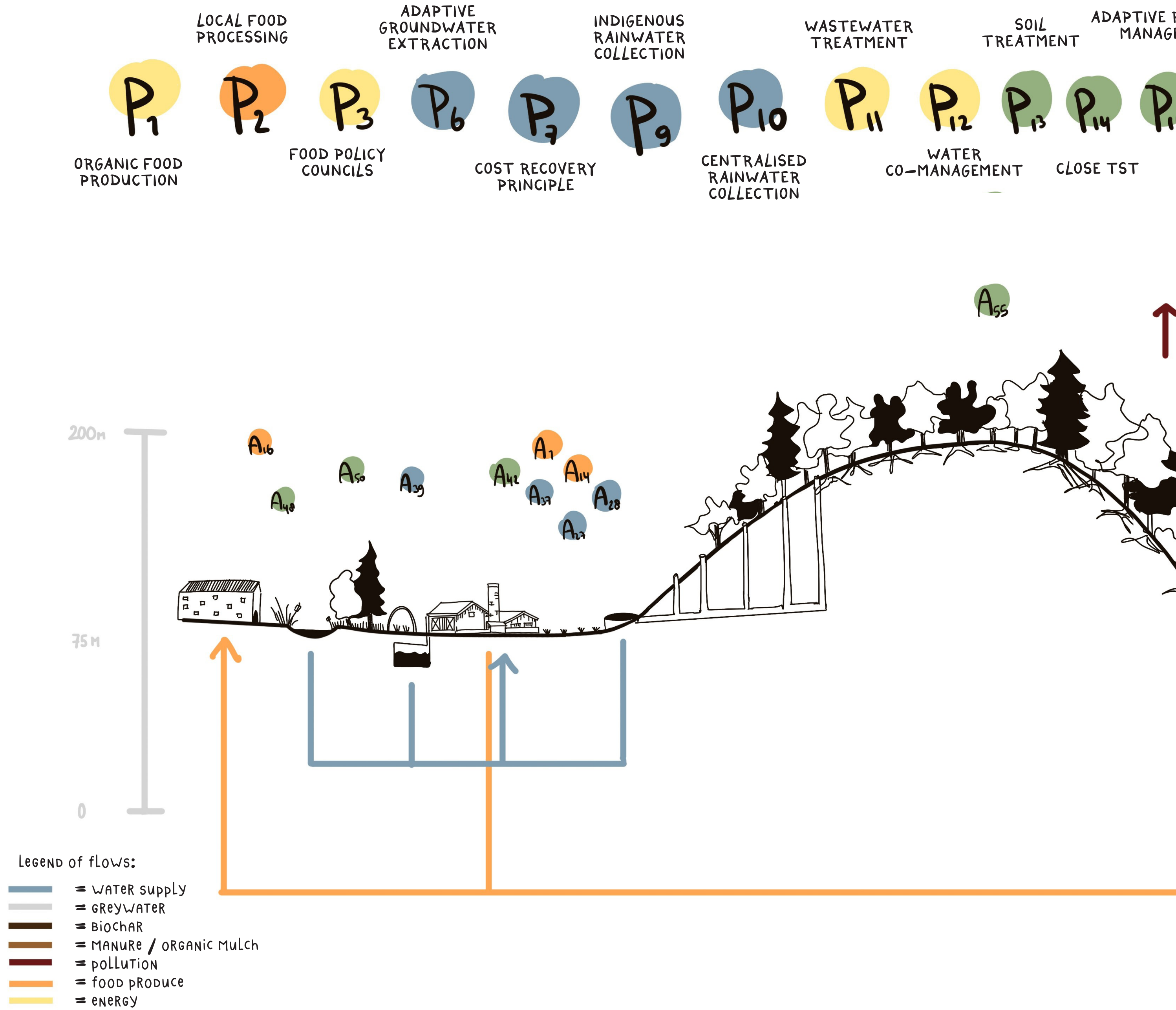
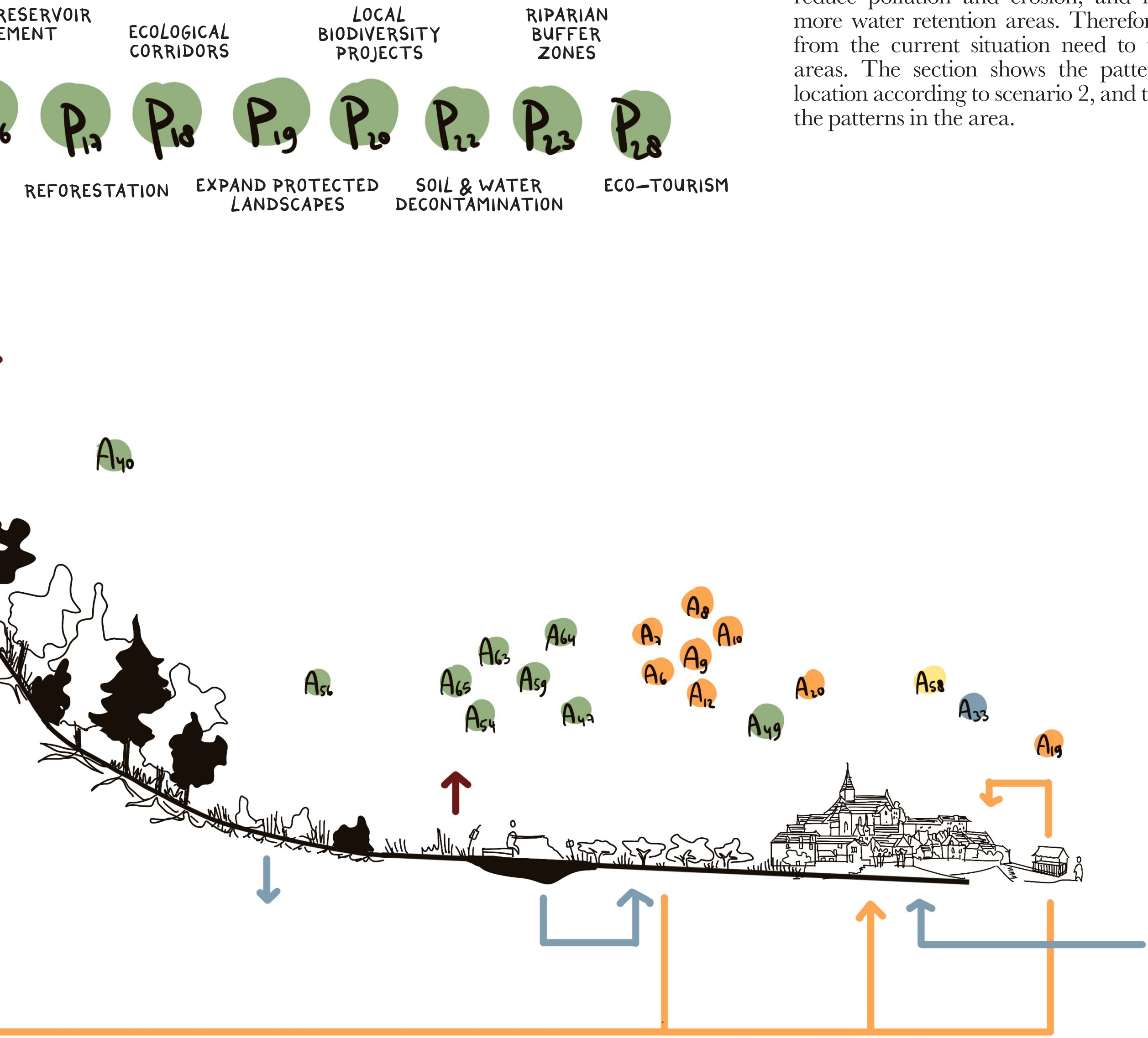


Figure 120. Section of the pattern selection for scenario 2 applied in location 1: practices and systems. Source: made by author.



SCENARIO 2

According to scenario 2, the location needs to form an ecological corridor with natural areas nearby, needs to reduce pollution and erosion, and needs to incorporate more water retention areas. Therefore, agricultural areas from the current situation need to transition to natural areas. The section shows the pattern selection for this location according to scenario 2, and the implementation of the patterns in the area.

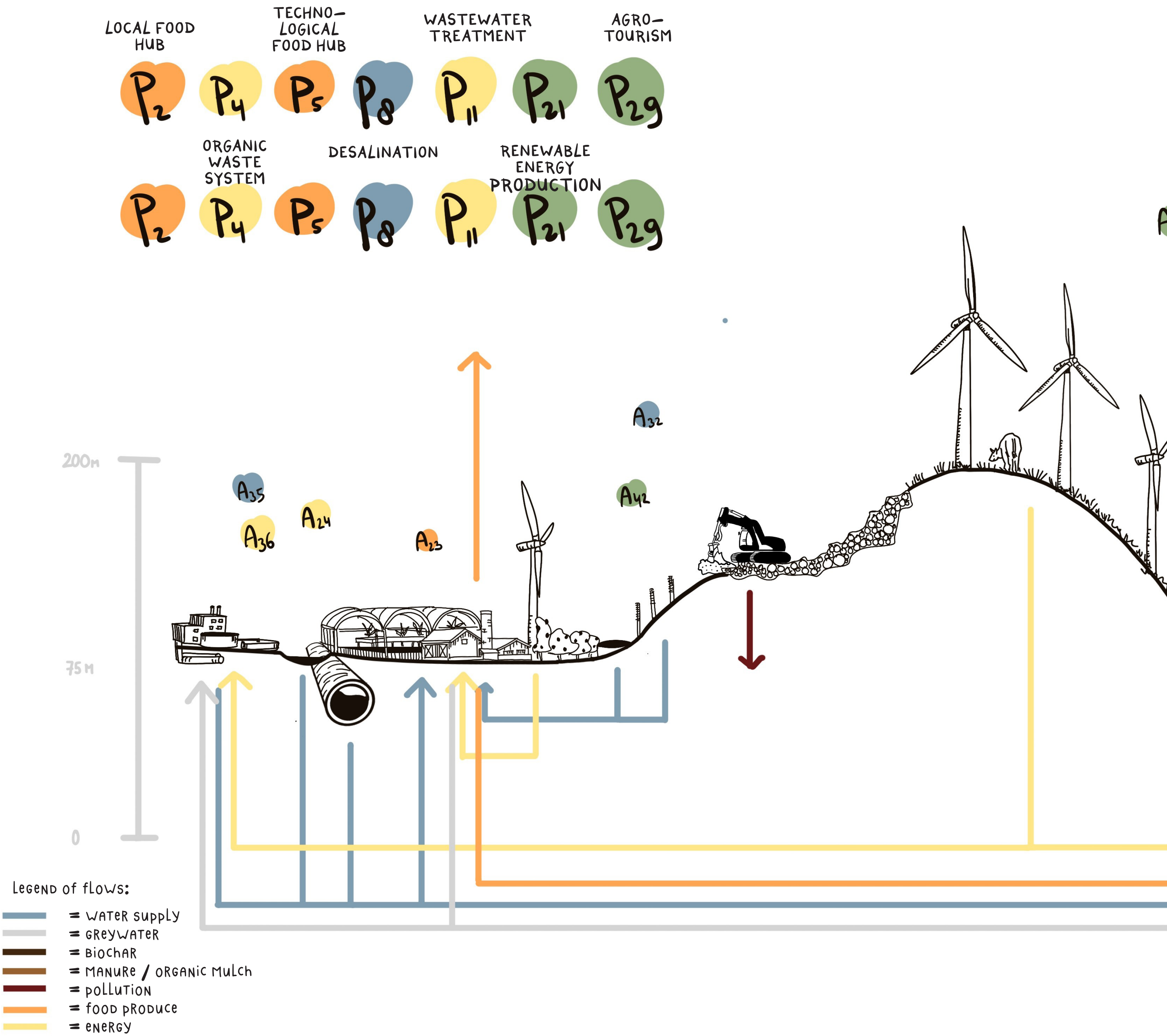
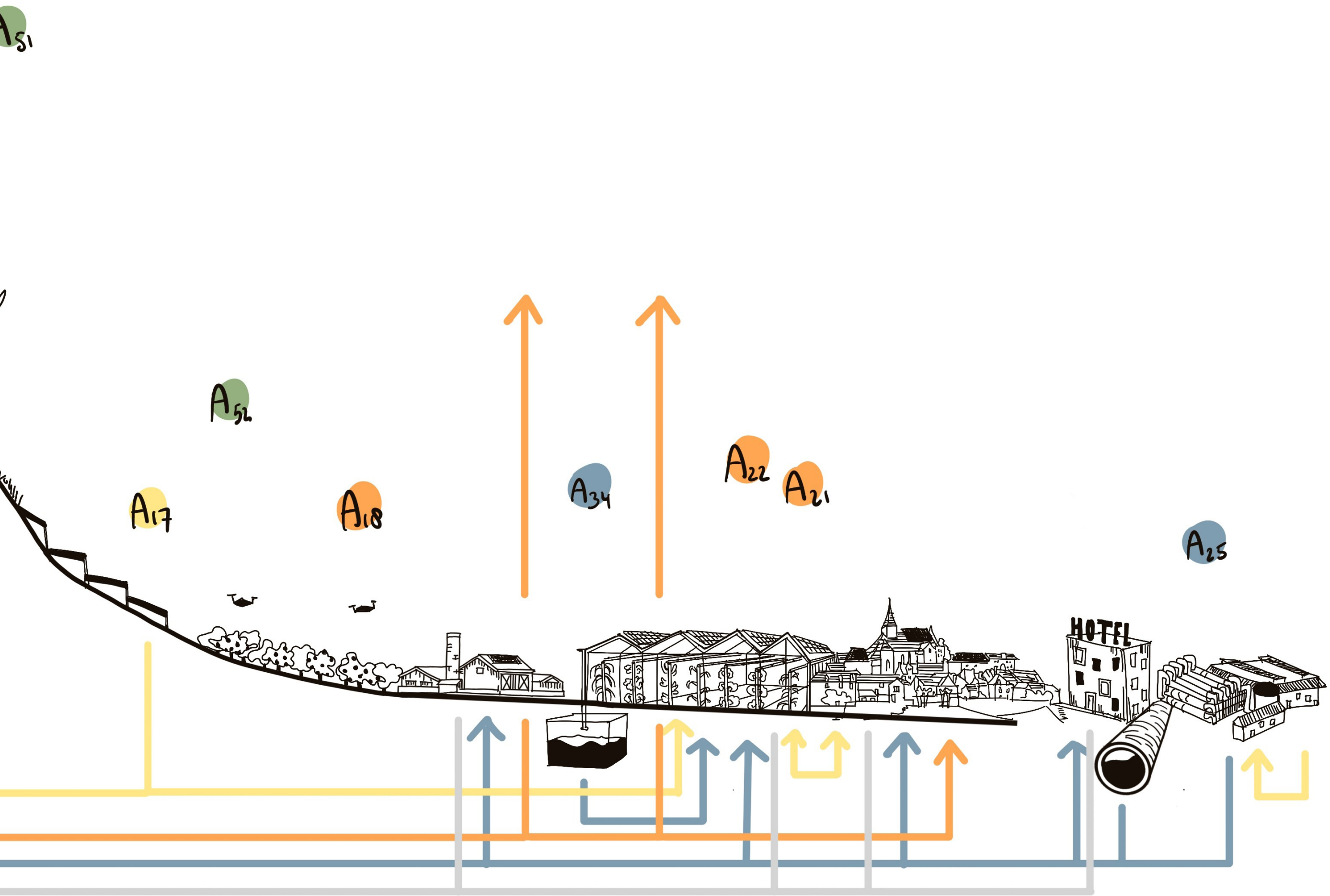


Figure 121. Section of the pattern selection for scenario 3 applied in location 1: practices and systems. Source: made by author.

SCENARIO 3

According to scenario 3, the location needs to innovate and transition into a technological food production hub that supports the export industry. For this transition, additional water supply sources and renewable energy supply is required. The section shows the pattern selection for this location according to scenario 3, and the implementation of the patterns in the area.



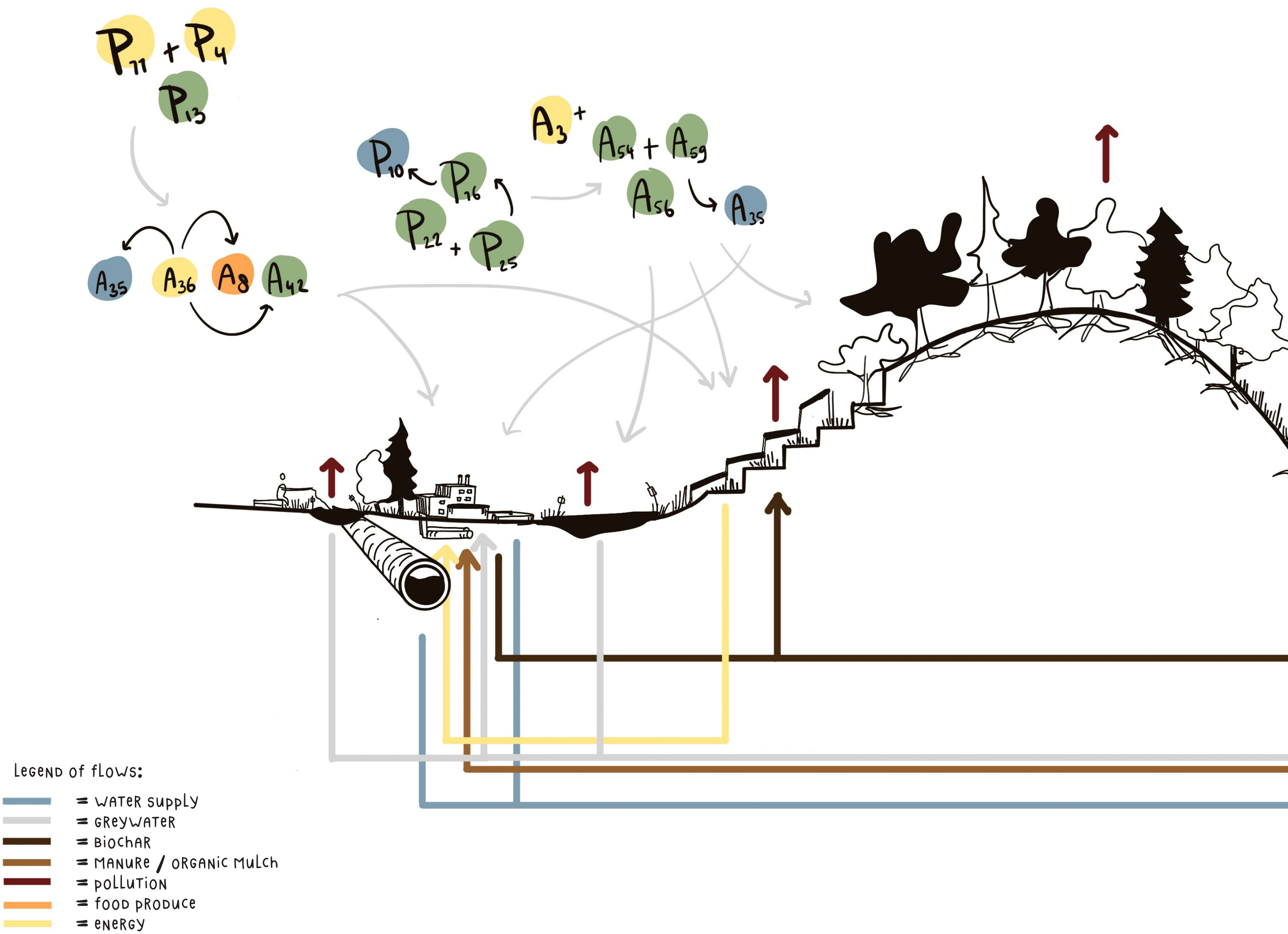


Figure 122. Section of the pattern selection for scenario 4 - symbiotic pathway - applied in location 1: practices and systems. Source: made by author.

SCENARIO 4

In Figure 122, a combination of the patterns is made, prioritising different patterns than each scenario specifically, to form a middle-ground version in the form of a symbiotic pathway. This symbiotic pathway can be seen as a fourth scenario, which incorporates elements from all three scenarios. The section shows the altered pattern selection for this location, and the implementation of the patterns in the area.

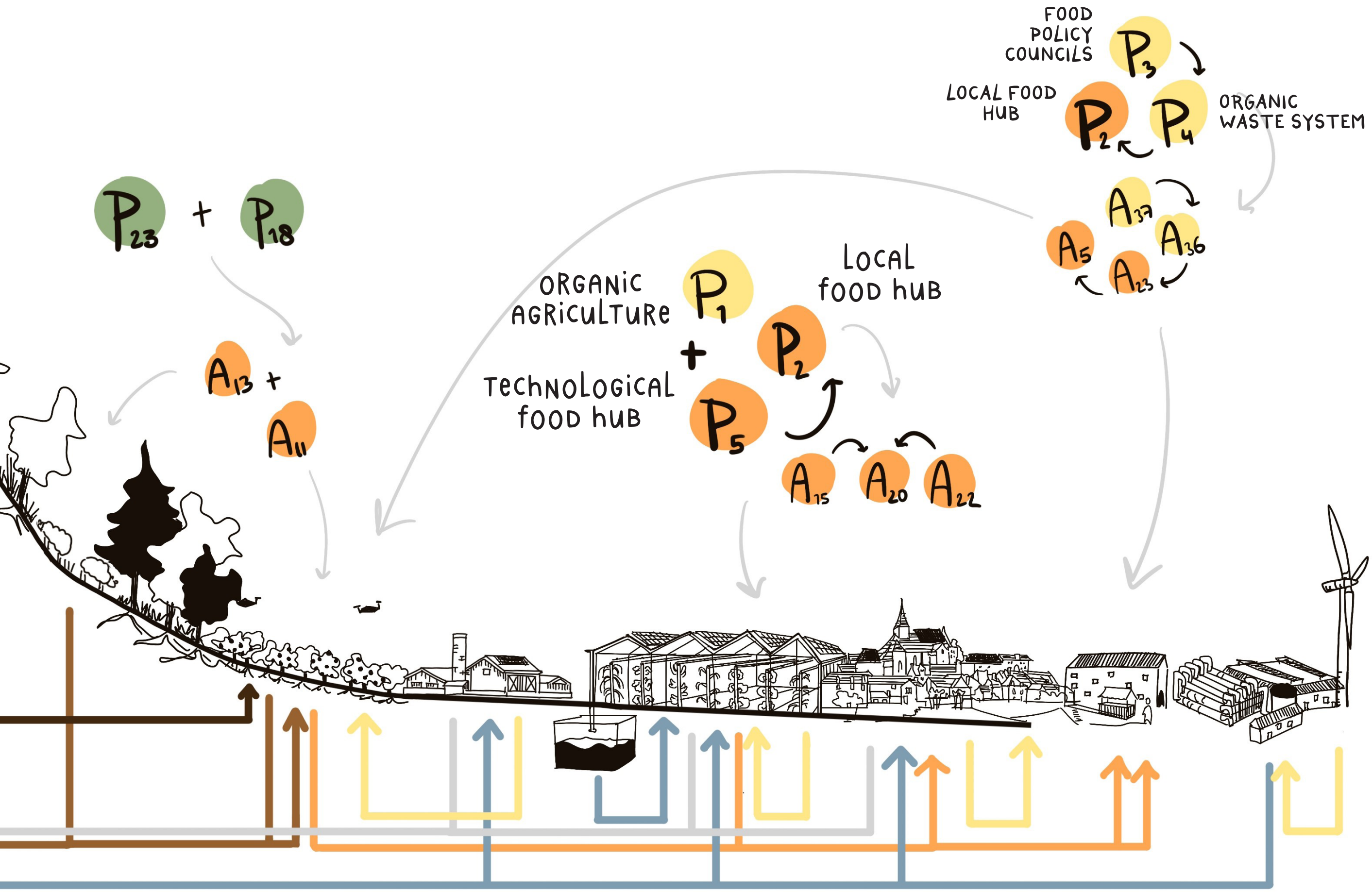
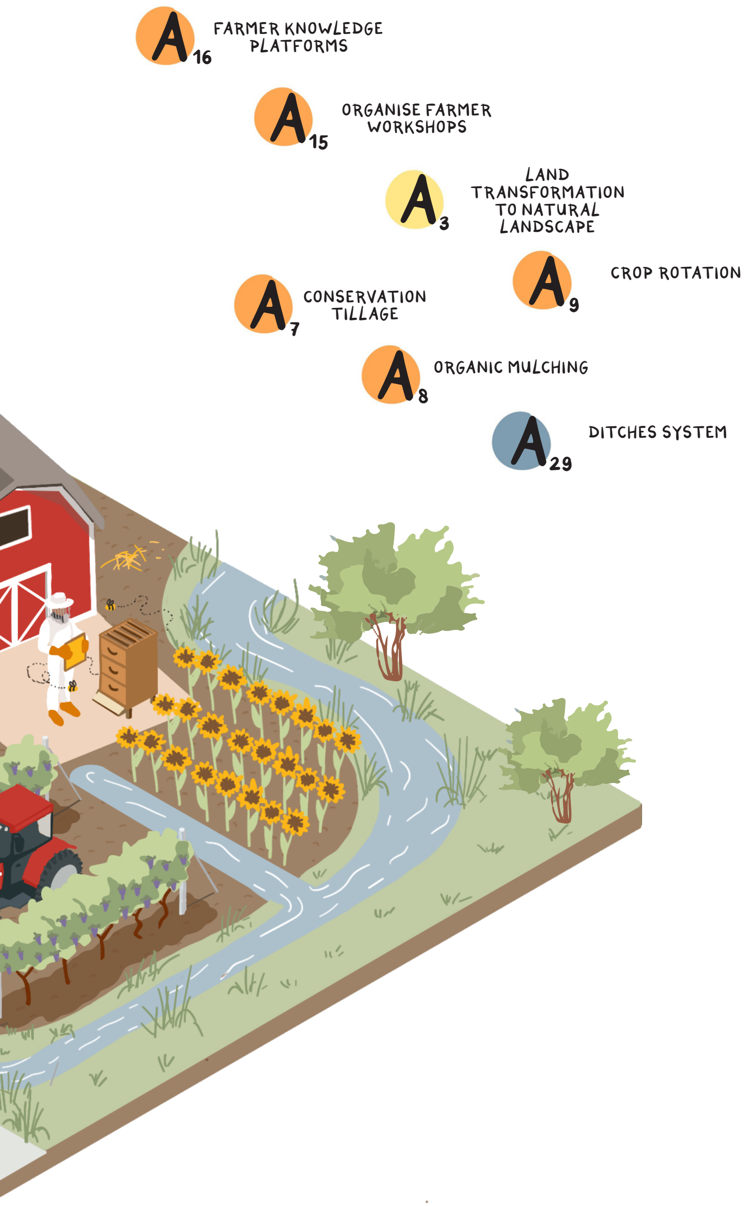


Figure 123. Symbiotic project 1: organic small farms. Source: made by author.

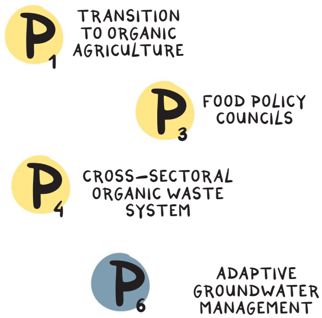
ORGANIC SMALL FARMS



Within scenario 4, several symbiotic projects are created with the new pattern combinations.

The first project is created by establishing a food policy council to encourage local farmers to start the transition to organic agriculture. Large monocultural farmlands are divided into small farms where subsidies support dry farming and organic produce. This is done through a collaborative and participatory process, where several rules are established. Restrictions for groundwater extractions, requirements for land division and crop rotation, and subsidies for organic farming, smart farming, and rainwater collection systems are used as tools to support this transition. Next to this, riparian buffer zones are implemented by law, to protect natural areas from agricultural pollution, prevent desertification, and restore groundwater aquifers. This forces intensive farms to move to another area, or sell the land.

Additionally, an organic waste collection system is set in place, where manure and mulch is collected, distributed and used locally.



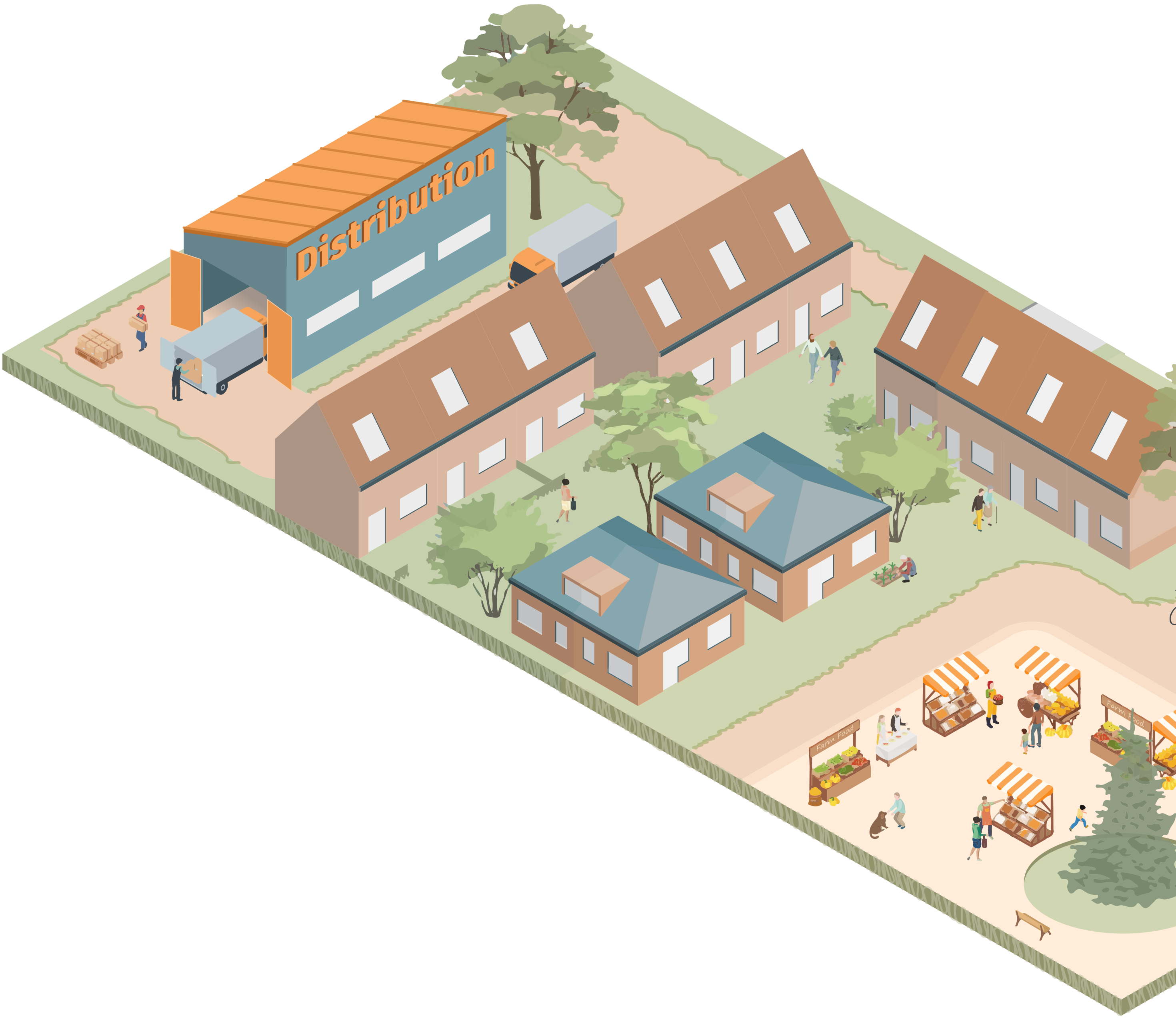


Figure 124. Symbiotic project 2: local food distribution. Source: made by author.

SYMBIOTIC PROJECT 2

LOCAL FOOD DISTRIBUTION

The second project builds on the first project, and facilitates the transition to the third. It does so by connecting the farmer and the consumer through establishing local food markets where organic produce from nearby farms is sold to the inhabitants and tourists in villages closeby. For this project, local food packaging and distribution hubs are put in place. In this way, the market slowly changes towards organic produce, contributing to the agricultural transition,

A19 REGULAR LOCAL FARMER MARKETS

A60 PERMEABLE PAVEMENTS

P2 LOCAL FOOD PROCESSING & DISTRIBUTION HUBS

P29 AGRITOURISM

P4 CROSS-SECTORAL ORGANIC WASTE SYSTEM

P27 WATER RETENTION IN URBAN LANDSCAPES

Figure 125. Symbiotic project 3: urban (smart) farming. Source: made by author.

SYMBIOTIC PROJECT 3

URBAN (SMART) FARMING

A 23 AQUAPONICS

A 22 HYDROPONICS

A 21 VERTICAL FARMING

A 18 AI FARMING

A 20 URBAN FARMING & ALLOTMENT GARDENS

Next, the food policy councils invest in smart farming techniques that reduce resource consumption. Technological greenhouse hubs are installed in urban areas as pilot projects. Farmers who lost their jobs due to the agriculture transition find new jobs here. When connected to a research insitute, the hub creates an interesting hotspot for agritourism.

Here, local residents and tourists can learn about innovative technologies as vertical farming, hydroponics and AI farming. These techniques are tought through workshops in urban farming settings, where allotment gardens serve an educational function, next to providing local communities with organic food and economic support.

The smart farms and urban area expansions due to the developments are connected to a wastewater treatment plant that is transformed to an algae material hub. This hub cleans urban and agricultural wastewater, and uses organic waste to create biochar, which can be used to enrich desertified soils. Additionally, biofuel is created as a part of this process, which can be used for the transportation of the food produced.

With the knowledge obtained from the workshops, local farmers are stimulated to join the organic agriculture transition themselves, and farming communities can be formed. These communties can co-farm by managing resources as manure, collected rainwater and renewable energy together.

P 3 FOOD POLICY COUNCILS

P 5 TECHNOLOGICAL GREENHOUSE HUB

P 29 AGRITOURISM

P 21 RENEWABLE ENERGY PRODUCTION

Figure 126. Symbiotic project 4: ecotourism and clean corridors. Source: made by author.

ECOTOURISM AND CLEAN CORRIDORS

A 57 PHYTODEGRADATION

A 56 PHYTOSTABILISATION

A 54 HELOPHYTE FILTERS

A 37 AGRICULTURE RETURN FLOW SYSTEMS

A 38 DRIP IRRIGATION

Simultaneously, investments are made in ecological restoration, combined with nature-based flood control and decontamination. Areas previously occupied by intensive monocultures are transformed in green-blue corridors that protect ánd clean the water and soils, while connecting nature sites. In this way, biodiversity hotspots are created that are suitable for ecotourism purposes that bring people in contact with nature, while providing the economic means to invest in restoration efforts.

By allowing flood-prone areas to rewilden, wetlands that function as water buffers are created, while protecting surrounding areas from sudden floods. These wetlands can be enriched with water filtering plants and trees that remove agricultural pollutants from the water and soil through phytoremediation and helophyte filters. The agricultural return-flow systems from local organic farmer communities can be connected to the wetland for a natural wastewater cleaning system.

Eventually, a symbiotic relationship between the human (food production) and natural system is created for the area.

P 25 EXPAND WETLANDS

P 26 EXPAND RAMBLAS & FLOODPLAINS

P 28 ECO–TOURISM

P 22 SOIL & WATER DECONTAMINATION

P 18 ECOLOGICAL CORRIDORS

PHASING OF INTERVENTIONS

To coordinate the implementation of these symbiotic projects over time, a suggestion is made that includes three phases of the transformation of the area, based on a prioitisation of certain interventions, and the estimated time required for those interventions to be implemented. An overview of the phased interventions and required policies is given in Figure 127.

PHASE 1

In the first phase, agricultural areas along the protected natural area transition to organic agricultural production and natural land. This is done through a participatory process of creating a strategy for the area with local food policy councils and farmers, who are provided with subsidies to sell their land for full transformation to natural area with the offer of an urban farming job, or transition to organic agriculture practices and partial land transformation. Once this process is in motion, phase 2 can begin.

PHASE 2

In the second phase, land transformations to natural area are set in motion, where a focus lies on improving natural flood control, restoring and depolluting the soils previously occupied by intensive agriculture practices, and improving local biodiversity. This is done through the involvement of NGO's, municipal bodies, local communities, and activists, with the help of national budgets.

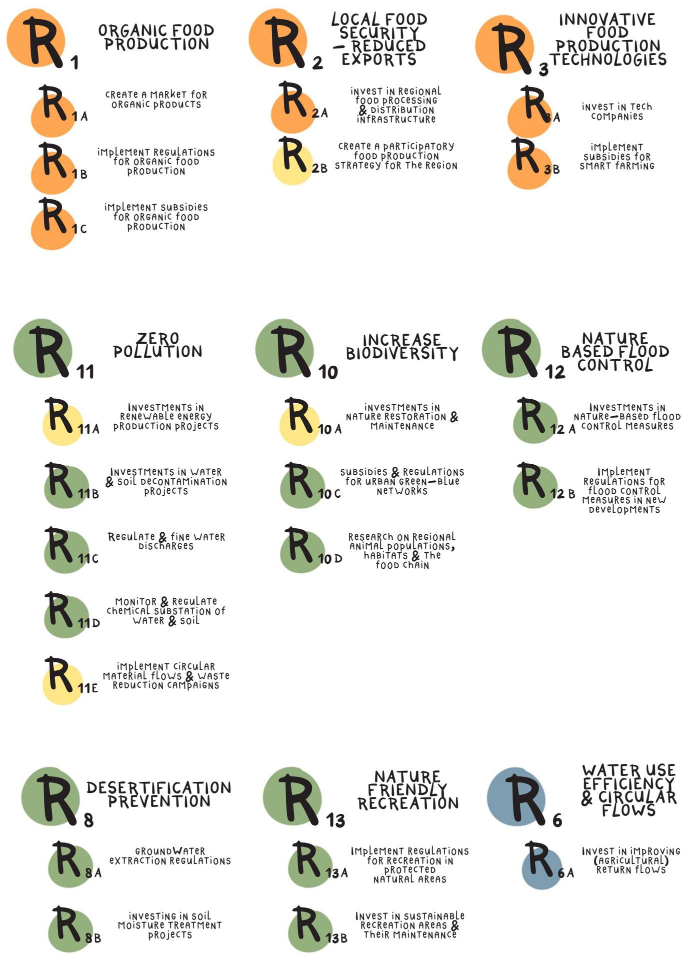
PHASE 3

During the third phase, the regional food policy councils have gained popularity and created evolved plans for the food produciton industry in the region. With the help of additional budgets for improving the food production system, urban farming is brought to a new level in the form of pilot projects for innovative technological food production.

POLICY RECOMMENDATIONS

In order to realise these symbiotic relations of the strategic project, several policy adjustments can be recommended when following the connections in the pattern-web.

The policy recommendations connected to these projects from the pattern-web are derived from the pattern booklet:



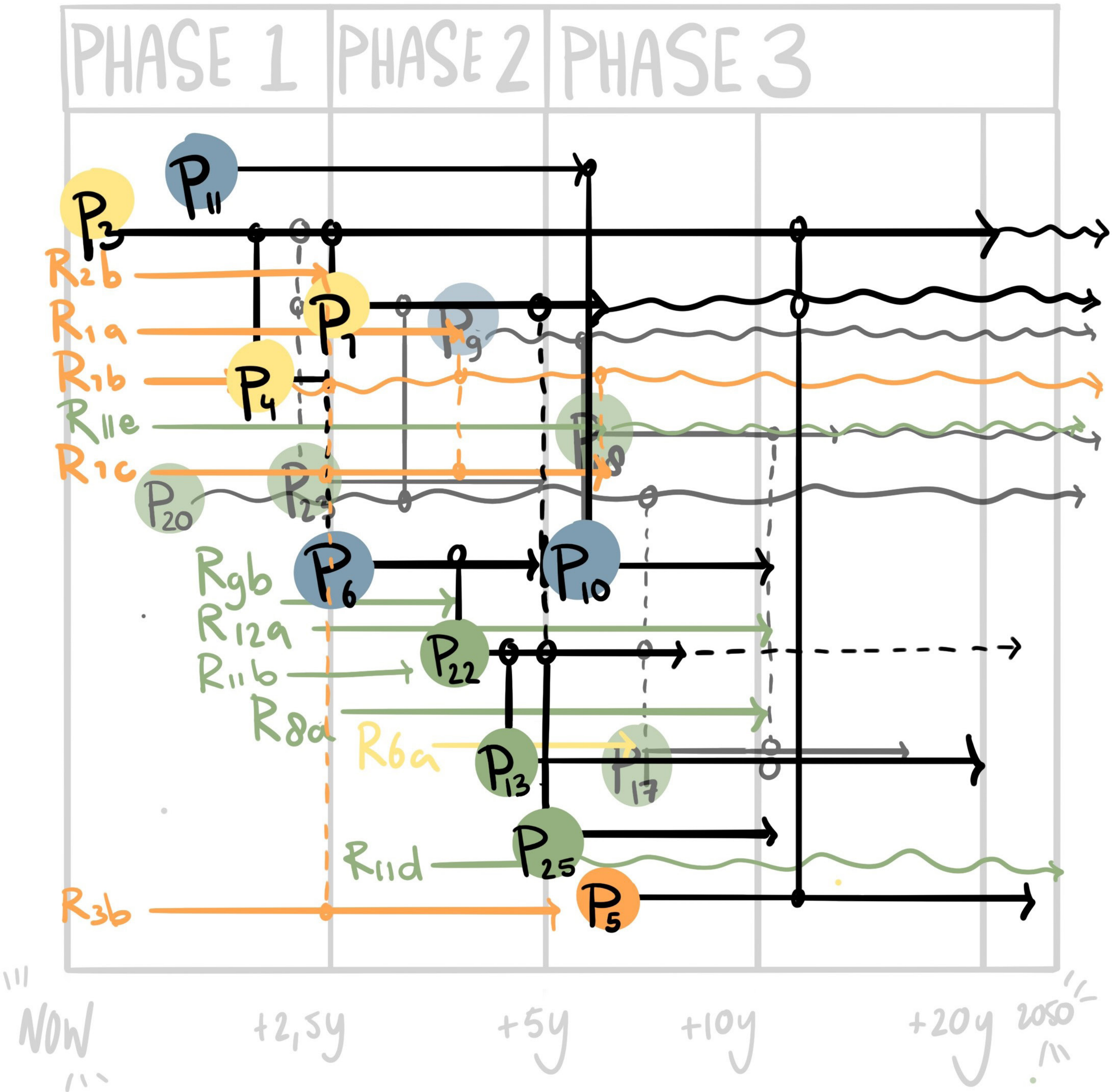
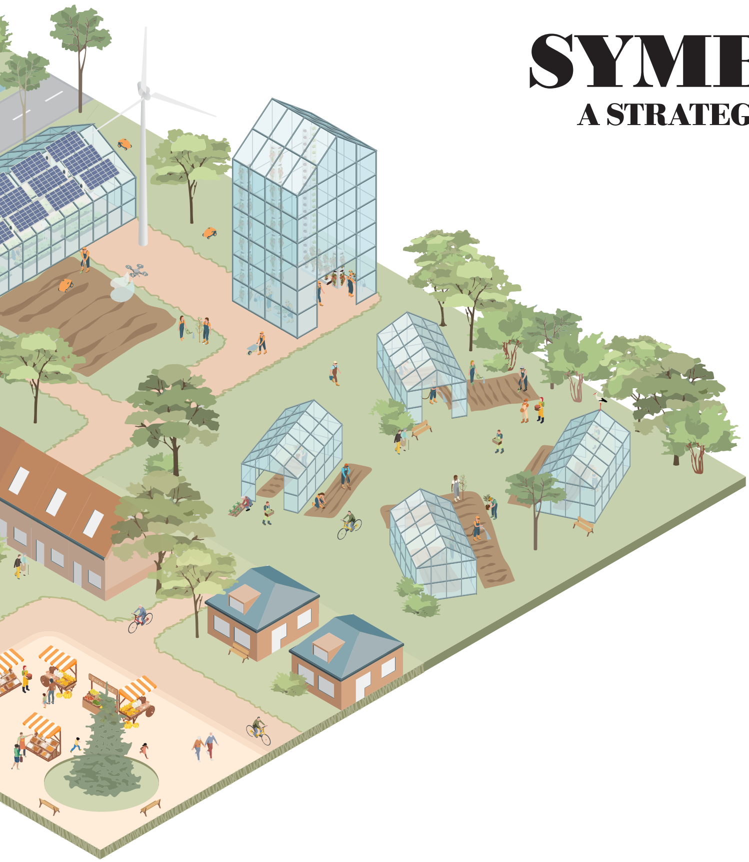


Figure 127. Phasing of interventions of the symbiotic pathway for strategic project 1. Source: made by author.

Figure 128. Total of symbiotic projects for strategic project 1. Source: made by author.



SYMBIOTIC STRATEGY

A STRATEGY OF SYMBIOTIC PATHWAYS FOR THE REGION

How the first strategic project called "Pilot Greenhouse Hub" comes together, is visualised in Figure 128. It forms one of the symbiotic pathways to complete the regional strategy on the sub-basin scale, when combined with the no-regret measures. Expanding this strategy further could lead to a symbiotic water system transition strategy on the full basin scale, or even larger regions.

This thesis shows that a symbiotic design method offers a promising approach to navigating the complexity of water system transitions in arid regions. By focusing on relationships between people, sectors, and ecosystems, the design strategy moves beyond fragmented solutions toward integrated, context-sensitive transformation. When diverse actors align around shared goals, systemic change becomes possible. The project facilitates this, by combining participatory methods and bottom-up initiatives with top-down governance, while using different tools to work through the scales and deal with stakeholder preferences and future uncertainties. The pattern language plays a key role in this, serving as a practical and expandable tool that helps people from different backgrounds understand each other, collaborate, and act. In this way, the project illustrates how designing for symbiosis can turn complexity into opportunity.

CONCLUSION

DISCUSSION

This thesis demonstrates that a symbiotic design approach can offer a viable and integrative strategy for addressing the complex challenge of water scarcity in arid agricultural regions like the Segura River Basin. By designing for collaboration between land use development, water management, and ecological restoration, the research presents an alternative to fragmented and extractive water management models. It highlights how territorial, ecological, and socio-political systemic interrelations must be understood and designed holistically to build climate-resilient, socially just, and environmentally regenerative futures. A key contribution to the literature on systemic design lies in creating a symbiotic spatial design methodology that enables the operationalisation of systemic change across scales through context-based design.

Positioned between theoretical frameworks and spatial design practice, the thesis is grounded in systemic design, territorial metabolism, socio-ecological resilience theory, and symbiotic design thinking. While these theories offer critical lenses for understanding complex systems, none individually provided a sufficient framework for addressing the full scale and layered nature of the water system transition in the Segura River Basin .Therefore, this research proposes an integrated methodology that expands upon existing frameworks and bridges top-down strategies and bottom-up agency. It addresses ecological degradation, infrastructural lock-ins, and socio-political conflict in a systemic and participatory framework for action.

The findings confirm the relevance and urgency of resilience theory for addressing ecological and hydrological vulnerabilities, but also challenge its limited spatial articulation by embedding it in a design framework. Similarly, while territorial metabolism provides a powerful tool for understanding flows of water, energy, and resources across territories, it often remains at the level of analysis and lacks concrete methods for design intervention. This thesis extends the framework by integrating it into a systemic design method that addresses resource extraction, allocation, and use through the different systemic layers.

Systemic design forms the theoretical backbone of the methodology, particularly its emphasis on mapping complexity, cross-sectoral integration, and design-led change. This thesis contributes to the systemic design literature by proposing a symbiotic strategic design method that aims for a mutually beneficial, socially supported transition strategy by actively integrating ecological, socio-political, and infrastructural systems, as well as multiple stakeholder perspectives.

A novel contribution is made through the introduction of symbiosis as both a conceptual and operational principle. Unlike traditional sustainable transition theories , symbiosis promotes co-evolution and mutual benefit between human and more-than-human systems. This concept proved especially useful for rethinking anchored socio-technical lock-ins and opening up new pathways for regenerative water management.

Moreover, this thesis demonstrates the value of scenario development and pattern language creation through a research-by-design process. The use of a decision tree structure within the pattern language, combining spatial, and non-spatial interventions such as policies, provides a new strategic planning tool. It holds generalised solutions for context-specific issues that are supported by literature and previous success cases, while supporting creative formulation of adaptive pathways through local stakeholder perspectives. This participatory dimension challenges purely technocratic or top-down models of transition and highlights the need for design approaches that aim for a shared vision and are grounded in place-based contexts.

This thesis contributes to the broader fields of urban planning, water governance, and sustainability transitions, by offering a systemic and design-driven response to complex socio-ecological challenges. Its core contribution lies in demonstrating how symbiotic design thinking can inform integrated spatial strategies across scales and sectors. In the context of urban policy making and spatial planning, the thesis calls for a shift from fragmented, sectoral approaches toward integrative frameworks that align ecological regeneration with spatial transformation, and enable societal change. By bridging scenario development, adaptive policy pathways, and a strategic design pattern language, it proposes new tools for symbiotic planning that remain flexible under future uncertainty.

Within the discourse on water governance and management, this work critiques dominant top-down paradigms and offers a counter-model rooted in territorial specificity, bottom-up participation, co-management, and multi-scalar coordination. It promotes governance approaches that are adaptive, inclusive, and ecologically responsive. In sustainability transition theory, the thesis reinforces the value of transdisciplinary and research-by-design methods, while extending these approaches with a spatial logic that makes systemic change understandable and actionable. It also engages with principles of spatial justice and the rights of nature, arguing for the redistribution of spatial benefits and burdens and for the legal and ethical recognition of ecosystems as stakeholders in planning processes.

While this thesis proposes a novel framework for symbiotic water system transitions, several limitations must be acknowledged regarding its scope, context, methodology, and application.

First, the scope of the research was necessarily selective. The focus has been primarily on the agricultural transition, with complementary attention to climate-adaptive urban design and the expansion of protected natural areas. Other layers of the system, such as the role of tourism, transportation, energy transitions, and circular economy strategies, have not been explored in depth. Additionally, although this research begins to frame nature as a stakeholder, more critical and theoretical work is needed to fully explore what it means to grant nature agency in design processes beyond landscape expansion.

Second, there are contextual limitations due to my background as the author and the short timeframe of the project. As a Dutch urban planning student unfamiliar with the Spanish language and socio-political system, certain assumptions were made based on generalisable global trends or Dutch planning models, such as the research and design approach through the lens of the Network Approach.

Third, stakeholder participation was not directly embedded in the research. While the proposed methodology encourages multi-actor, multi-scalar involvement, no participatory workshops or interviews were conducted due to the time limit and language barrier. Therefore, the alignment of proposed interventions with the actual needs, desires, and resistance of local actors remains untested.

Fourth, the methodological and design outputs remain theoretical. The symbiotic design methodology, pattern language, and strategic framework have not yet been implemented or repeated in other contexts, which limits their immediate validation or real-world impact. The transferability of the pattern language to other arid, agriculturally intensive regions remains promising but would benefit from further generalisation and testing.

Finally, there are ethical limitations. A sustainable transition inevitably comes with trade-offs, and not all stakeholders may benefit equally. Some actors may experience losses in land, profit, or influence. These tensions are not fully resolved in this thesis but are acknowledged as part of the systemic complexity that the design approach aims to address.

In summary, the theoretical contribution of this thesis lies in its synthesis and extension of existing theories into a symbiotic spatial design method that is operational, participatory, and context-based. It addresses a notable gap in the literature between theory and practice by offering a transdisciplinary, integrative, and actionable approach capable of guiding water system transitions that are ecologically regenerative and socially grounded. Therefore, the research provides a methodological and conceptual contribution that informs more just, resilient, and context-based systemic transition strategies that are relevant not only for academic debates but also for planners, policymakers, and designers working toward climate-resilient futures.

CONCLUSION

This research set out to address the persistent issue of water scarcity in the Segura River Basin (SRB), driven by both climatic and anthropogenic pressures. By developing a symbiotic regional design strategy grounded in socio-ecological resilience and territorial metabolism theory, the thesis aimed to offer new pathways for a sustainable, adaptive, and inclusive water system transition.

Through a research-by-design process, the project developed a multi-scalar, multi-layered approach that integrates systems thinking, spatial design principles, scenario building, and adaptive policy pathways. This resulted in three key outputs: a symbiotic design methodology , a pattern language, and a symbiotic strategy for the water system transition in the SRB. These outputs collectively demonstrate how symbiotic systemic design can address the complexity of water-related challenges by weaving together spatial, ecological, political, and social dimensions.

The analysis revealed that water scarcity in the region results from a complex interrelation between environmental degradation, infrastructural dependence, and socio-political conflicts. Key leverage points for the water system transition were identified as global mindset changes, targeting three layers of the water system transition (sustainable food systems, circular water networks, and restored ecological landscapes). These findings laid the groundwork for constructing a vision for the region's future and identifying pathways for systemic change. The vision was created by translating the multi-layered analysis into spatial and non-spatial design objectives for symbiotic systemic solutions, based on global trends and frameworks. Integrating the objectives and different stakeholder views led to the vision framework for a resilient water system in the region.

A range of symbiotic solutions (solutions that combine multiple objectives from the vision) was identified through a precedent study, fieldwork observations, and design intuition through a research-by-design process. Interrelations between the solutions are found within sustainable agri-food systems, circular and renewable water flows, ecological restoration and preservation efforts, and climate-resilient urban development. The categorisation of these solutions led to the key output of this thesis: the pattern language for symbiotic design of the water system transition in arid regions of agricultural production. During this process, a design exercise to test the pattern language on the SRB region from the top-down planning perspective took place, where three future scenarios were created following the integration of different combined stakeholder perspectives. The comparison of these scenarios led to the identification of symbiotic interventions (pattern interventions that are favoured by all stakeholders) and no-regret measures (interventions that are favoured by one sector, but not resisted by others). These measures formed the basis of the regional strategy for the water system transition, represented in a regional plan of synergetic strategy interventions. This strategy did not yet cover the whole region, as the scenario pathway comparison also revealed areas of spatial conflict where certain stakeholders would prefer other interventions than others.

To fill the spatial strategy gaps, the areas characterised by this spatial conflict were redesigned on the local scale. Within these projects, the pattern language was applied from a bottom-up perspective, leading to the identification of new patterns and pattern connections in the form of symbiotic adaptive pathways. The integration of the strategic projects with the symbiotic and no-regret measures resulted in a transformation strategy for the water system in the region.

The main research question "*How could symbiotic systemic design be used to develop pathways for the sustainable water system transition, contributing to water security and a socio-ecologically resilient future for the Segura River Basin?*" was answered by demonstrating how design can bridge analytical research, uncertain future developments, different stakeholder perspectives, and practical, context-based implementation. The proposed methodology enables both top-down strategy-making and bottom-up action, as well as inter-disciplinary collaborations. This aligns with the goals of water security and socio-ecological resilience in the SRB and broader sustainability frameworks.

Altogether, this thesis research demonstrates how using a research-by-design process and the implementation of a pattern language on the basis of a context-based, multi-layered analysis can inform the strategic design of systemic transformations in a symbiotic manner. Harmony in the form of socio-ecological resilience can be designed for when multiple systemic layers, stakeholder perspectives, and future uncertainties are considered and used as an advantage to integrate solutions across domains and spatiotemporal dimensions.

The work contributes to academic discourse by advancing symbiotic design as a systemic, actionable methodology for territorial transitions, bridging the gap between theoretical frameworks for sustainability transitions and design practice. It provides planners, policymakers, and local actors with concrete tools to guide the decision-making process of the water system transition in a complex, multi-stakeholder environment. The strategy encourages the integration of spatial design and regional policy frameworks, fostering collaboration across disciplines and sectors. It can be implemented or used as an inspiration by the municipalities in the SRB or the river basin authority (*Confederación Hidrográfica del Segura*). Similarly, the pattern language forms a source of inspiration for local stakeholders and individuals who mean to contribute to the water system transition. It is structured as a transferrable toolkit, where the vocabulary of tested interventions supported by research forms a language. This language creates a multi-faceted design structure to be used by spatial designers at the same time.

At the heart of this thesis lies a novel approach to multi-dimensional, inter-scalar designing of complex systemic transitions. It encourages other designers to use a similar holistic design methodology, where symbiosis is not only used as a metaphor, but as the core design principle, calling for mutual reinforcement between systems rather than competition or overexploitation. In order to facilitate sustainable transitions that are equitable and resilient, inter-disciplinary alignment, participatory decision-making, and adaptive design are necessary. Thereby, symbiosis is a method as well as a mindset.

Looking ahead, further research could test the methodology in other territories facing similar climate and resource challenges to improve the transferability and verify the design results. The pattern language could be expanded and evolved into a collaborative tool that is generalised to fit more than one context. Furthermore, additional research could refine the design outcomes through participatory design practices and expand them by incorporating more systemic layers and perspectives. Such steps could strengthen transferability, foster inclusive innovation, and contribute to global water resilience and sustainability transition efforts.

APPENDIX

REFLECTION

ON THE RESEARCH AND DESIGN PROCESS

INTRODUCTION

In this chapter, I reflect upon the process of creating this thesis and its outputs from an academic perspective. To do this, five questions from the graduation manual and two additional questions are answered.

ACADEMIC REFLECTION

What is the relation between your graduation project, your master track, and your master programme?

My graduation project focuses on creating a strategy for the water system transition to address water scarcity, a topic deeply embedded in the broader discourse on sustainability transitions. Transitioning socio-ecological systems, such as the water system, to circular, resilient, and sustainable futures is a key concern within Urbanism and the MEP studio. The project responds to climate change challenges by including both adaptation and mitigation measures. This collaborates with the core ambitions of Urbanism as a discipline that connects spatial, social, political, and environmental aspects of planning.

Within the MEP studio, the emphasis on systemic design and interlinkages within complex socio-ecological systems is reflected in my multi-layered and multi-scalar approach for symbiotic design and the search for leverage points for systemic change. Next to this, my thesis research emphasises the need for societal change as a requirement for long-term socio-ecological resilience, broadening the project's scope to a larger timeframe and connecting the output to a global scale.

Furthermore, the role of an urbanist as mediator between diverse stakeholders is represented in the thesis output of a pattern language that combines different perspectives and pathways to a shared vision in an accessible and collaborative planning and design tool.

How did your research influence your design/recommendations and how did the design/recommendations influence your research?

Throughout my project, I worked with an iterative research-by-design process, where research and design constantly influenced each other. Researching the different systemic elements and interrelations through the layers of the Network Approach, in combination with researching various theories and concepts, helped me to create relations and values in the form of new conceptual and methodological frameworks for symbiotic design.

At the same time, the design exercises from the scenario-building and the process of creating the pattern language gave new insights that changed the direction of the research. I constantly reflected critically on my work, resulting in the continuous evolution of the design and results. For example, when testing possible design methods, I realised that additional or adjusted frameworks were needed each time to fit the approach to my concept of symbiotic design and the complex context of the project. These discoveries led me to go back to the research, refine the frameworks, and adapt my methodology. Later in the project, when I was building scenarios and working on the pattern language, I discovered new patterns and connections between spatial elements that only became visible through drawing, testing, and combining ideas visually. These discoveries, too, led to new solutions for the pattern language to research.

How do you assess the value of your way of working (your approach, your used methods, used methodology)?

The iterative research by design approach allowed for a new symbiotic strategy grounded in theory but shaped by practical and spatial experimentation. I see substantial value in my approach, especially in how it addresses a knowledge gap found in academic literature on symbiotic strategic design approaches, where existing frameworks for systemic analysis are often separated from spatial implementation.

However, this process has come with limitations in both the research and design aspects. Constantly critically reflecting on and revising the methods and outcomes was highly time-consuming, meaning that I had to cut out some elements from the research, and had less time than anticipated for the design itself. Looking back, a more structured decision-making process early on in creating the methodology could have helped in balancing the depth of the research with a stronger design output.

Another critical limitation of my approach is that, although my pattern language is designed as a tool to support collaborative and participatory design processes, I was unable to include local stakeholder perspectives and engagement in my research due to a lack of time, a focus on integrating other design methods, and the language barrier. This limits the current applicability of my results in the local context. Including local perspectives would be a key next step to strengthen both the academic and practical relevance of the research.

Building on this argument, another limitation is that the symbiotic design method I developed is a new contribution to academic research and has not been tested or verified by other designers or planners. It has the potential to fill an existing gap in literature and practice, but remains speculative of success until further research, validation, or practical application.

How do you assess the academic and societal value, scope, and implications of your graduation project, including ethical aspects?

Academically, I think this thesis offers a novel contribution to the field of integrated systemic spatial design. By proposing a strategy for symbiotic design in the context of complex systemic transitions, the research aimed to bridge the gap identified between conceptual and policy frameworks and spatial design and implementation. The framework supports the design of multi-scalar and multi-stakeholder perspective strategies that address layered and interconnected systemic issues. However, further research is needed to validate the method. This could be done, for instance, through application in other regions or through integrating different disciplines and layers connected to the system, such as emphasizing the connection to the energy system, climate governance, or rural development.

In terms of societal value, the project output has direct practical value. The designed pattern language and symbiotic pathways can support regional planners, decision-makers, or other stakeholders in imagining, communicating, and implementing integrated strategies and actionable interventions. It could also be used as inspiration in other arid agricultural regions. However, the societal value depends on its participatory application. Without the right tools, communication, and collaboration, the strategy might lack the power to engage stakeholders. Especially farmers and agricultural businesses that are affected by the water-related policies would need strong convincing to participate.

From an ethical perspective, the project focuses on ecological integration and sustainability objectives, potentially at the expense of continued economic development for certain actors in the region. The focus is justified through the urgency of climate adaptation, underpinned by scientific evidence, but it raises questions about the fairness of the transition.

In terms of the scope, this project sets out a broad inter-scalar framework that could be adapted to other contexts or expanded to a wider scale. On the other hand, a narrower scope from the beginning could have allowed for more in-depth analysis and design, for instance, through participatory methods.

How do you assess the value of the transferability of your project results?

The outcomes of this thesis (the pattern language, the symbiotic systemic regional strategy for the water system, and the methodology for symbiotic design) were all created with the aim of transferability. The approach aims to provide tools that are not only context-specific to the studied region but are also applicable in other regions facing similar problems. The pattern language, in particular, was designed as a communicative tool that supports collaborations between stakeholders from different disciplines. The adaptive pathway strategy offers a flexible framework for decision-makers and designers to connect short-term urgencies and long-term transitions while incorporating future uncertainties.

However, the actual transferability of the methodology depends on several factors. The method relies on iterative research by design and strategic thinking, as well as interdisciplinary collaboration, and ideally, participatory input from local actors. These elements take time and would, when repeated by someone else, result in very different design outputs. Furthermore, the method has not yet been applied outside this research, and still requires testing, refinement, and verification through application in other territories.

To improve transferability, future steps could include structuring the method into a more detailed guide with clear steps for planners and designers. Furthermore, including stakeholder feedback would significantly improve its legitimacy and usability in practice.

PERSONAL REFLECTION

What have I learned about myself as a designer and researcher through this process?

During this thesis process, I learned to reflect on academic sources and methods critically. In the beginning of the process, I tried to find a research and design method to use that would bring me to the right results to fit with my aim of combining the concepts of symbiosis, socio-ecological resilience, and sustainable water systems. However, I did not find such a method, and therefore, I created a new methodology to fit with my conceptual framework. Because of this process, I learned to follow my intuition when designing and to create my own way of working, despite the many challenges it brought along the way. It has been challenging for me to embrace this way of working because there was no clear order of steps set out to follow. Secondly, especially when tackling complex and interrelated problems that are shaped by multiple processes and viewpoints, I prefer to work in a team, where constant deliberations and discussions result in team-based decisions. Because of a lack of confirmation when working alone, I reviewed options repeatedly, resulting in long periods of contemplation before making a decision. Therefore, insecurities about time management and the value of the result were constantly at the back of my mind. Still, eventually, I found a way to combine methods and stay with my original plan of output for my research (to develop a symbiotic strategy). It has not been an easy process for me, but I am glad it turned out this way, as I have learned to be more confident in following my research and design intuition.

Which moments or decisions shaped the direction of my project most significantly?

A turning point for me was when I realised, after taking a small break after P2, that the method that I had proposed then (the Maximisation Method) for constructing the scenarios and testing design interventions would not lead to the symbiotic principles that I was hoping to discover. This was also the feedback from my mentors during my P2 presentation, but I did not understand what it meant at the time. Eventually, after reflecting on my concepts, I realised that spatially maximising specific ideas and futures separately, and overlapping them later, would not result in a bottom-up approach where stakeholder views are incorporated simultaneously. Therefore, I revised my methodology and realised that I needed to create a new framework for symbiotic design, including a scenario framework and an approach where I searched for a way to combine methods to incorporate a symbiotic aspect.

However, within the time from P2 to P3, I got stuck in the analysis when revising my methodology, where I doubted my decisions. Because of this, I lost valuable time in the design process, which led me to question the value of my thesis output. At this moment, there was another turning point for my thesis. During the process of creating symbiotic frameworks, I found academic relevance in addressing a gap in the literature on symbiotic systemic design methods. I was motivated to follow my intuition and explore this idea, which helped me to lose my insecurities. The feedback from P3 helped me to embrace my approach further, as I realised then that I was making a Pattern Language. I had not considered using this method before, but it turned out to be a valuable tool for combining the aspects I was aiming for. This made me realise that the aim of my thesis research was more about designing a workflow and communicating these ideas to contribute to achieving societal change that fosters systemic transitions, than about the design output for the region itself.

What would I do differently if I could restart this project, and why?

If I could restart this project, I would try to find more confidence in creating my methodological approach earlier in the process. Between P1 and P2, there is enough time to orient on different methods and take a position within your project. I was very focused on analysing the problems within the study area already, as I had defined those early on, and was eager to discover more issues and solutions to integrate into my approach and design. This focus on analysis, together with an indecisive attitude due to insecurity, led to a very broad research focus, combined with a methodological approach that did not fit with my ambitions. Because of insecurities and self-doubt, I got stuck in a process of overthinking, and focused less on what I enjoy doing: bringing conceptual ideas to life on paper and finding new systemic connections. Therefore, finding confidence in making decisions and creating a workflow that fits with my research aim and ambition are things that I will continue working on in future projects.

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