Cosmogonia of Crete

Critical zones as a continuous altered nature and the transition to the future.

Major and minor Stories of places from the past to the future

Georgia Kokolaki

P5 thesis
June 2024
Key words |
Crete, island, Terraforming, topography, Climate change, water scarcity, flooding, urban design, resilience, design and planning approach

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All the visual material have been produced by the author unless stated otherwise.

The title pages have been adapted from the Admiralty Chart No 2536b Eastern part of Candia or Crete, Greece, Published 1858

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"Earth is incredibly reactive to our actions, and can escape all our hopes of dominating it' compared to Nature which was seemingly indifferent to our actions, and for that reason could be mastered"

Latour, Bruno, 2018a, 223

Ha gorge, Ierapetra active fault zone, Lasithi perfecture, December 2023

Abstract

This thesis investigates the urgent concerns of water scarcity and excess on the island of Crete, identifying their implications for the island's future in the face of climate change. It recognizes the interconnectedness of geological, ecological, and human systems, using water scarcity and excess as a lens to understand these relationships and improve planning and design methods.

The thesis critically examines current planning instruments used by the government and planners and argues that they often fail to capture the dynamic nature of elements like water and soil. It advocates for a more sensitive, climate-resilient approach, encouraging local communities to actively manage their environment with care. The research embraces diverse methodologies, including critical cartography, to analyze the island's complex systems, particularly water and soil processes. Fieldwork, involving observation, photography, and research, supports an understanding of Crete's physical, cultural, and environmental systems.

The research analyzes Crete's past and present through a multi-scalar approach, investigating its geological formation, topography, materiality, and cultural heritage. The project focuses on the eastern part of the island as a case study, highlighting its vulnerabilities, such as flooding, drought, and desertification due to human activities and climate change. Later, it proposes strategic interventions like water retention landscapes, natural water flow restoration, riparian buffer zones, and temporarily flooded agriculture. It also promotes soil restoration through reforestation, agroforestry, and regenerative agricultural practices.

By repositioning the relationship between landscape, water, and humans, the aim is to foster a climate-resilient future for Crete, offering insights that could serve as a paradigm for other islands facing similar challenges globally. Finally, it emphasizes the need for a shift in planning and design approaches, encouraging decision-makers to recognize the interconnectedness of human and natural systems.

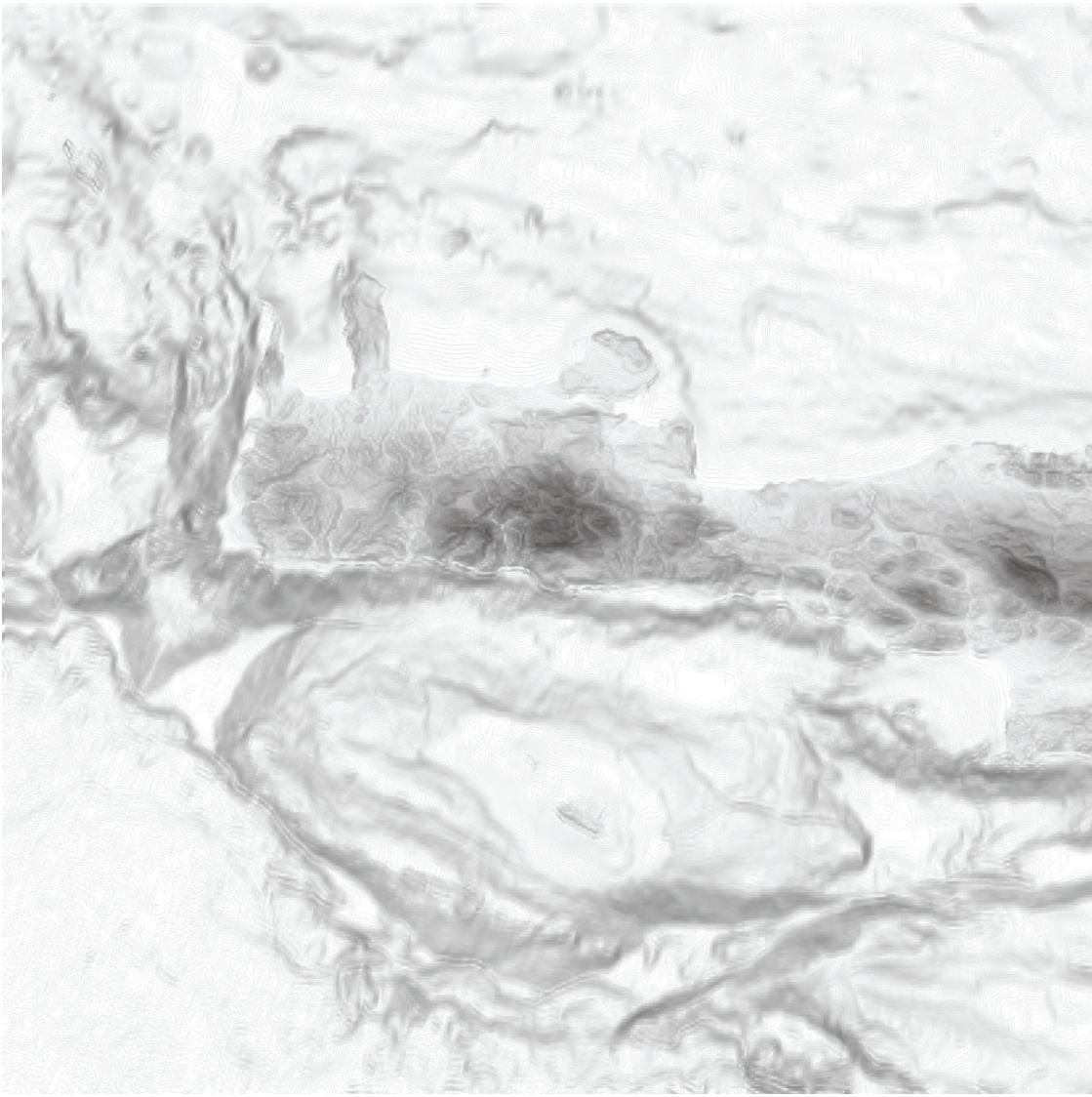
Acknowledgments

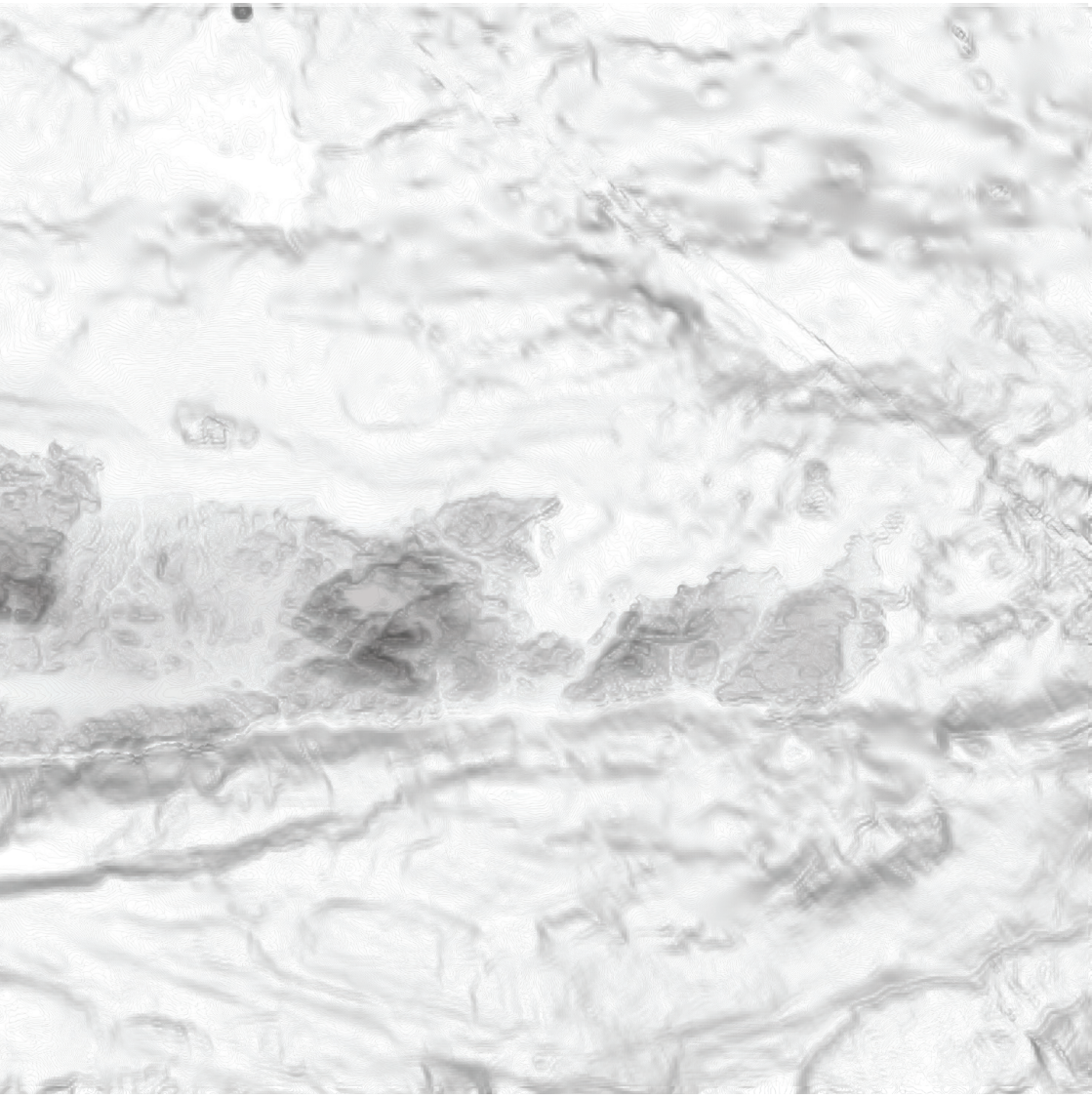
I would like to express my sincere gratitude to all the people who have been vital to the completion of this master's thesis. First and foremost, I extend my deepest appreciation to my thesis mentors, Luisa Maria Calabrese and Elena Longhin, for their invaluable guidance, support, insightful feedback, and relevant comments throughout the research and design process. Their expertise and encouragement have been fundamental in shaping the trajectory of this work. I am extremely thankful for Luisa's mentorship and for her critical conversations that played a critical and transformative role in shaping my work. I am genuinely grateful for her enthusiasm about my thesis, and her guidance concerning narrative and project creation and purpose. I cannot thank Elena enough for her endless encouragement, and assistance in the whole design process and for being there through it all. I extend my sincerest gratitude to Taneha and Francesca for their guidance through this chaos of a thesis project, and for their constructive conversations that helped me navigate the complexities of this thesis.

My most heartfelt appreciation goes to my boyfriend, Nikolas, for his endless support and for pushing me to transcend the bounds of conventional thinking.

It is with the warmest gratitude that I thank my family and friends, whose support I deeply appreciate, for their constant encouragement and understanding during the demanding phases of this academic journey. Their belief in my abilities fueled my determination to bring this project to life. This work would not have been possible without the support, encouragement, and expertise of these people. I am sincerely thankful for their contributions to the successful completion of this master's thesis.

Finally, I extend my appreciation to the Transitional Territories studio. The collective wisdom and contributions of every student and tutor have been instrumental in shaping the depth of understanding, critical thinking and inspiration I have been fortunate enough to gain over the past year.





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Personal Motivation

As an aspiring architect with a background in architecture and urbanism, my fascination with the dynamic relationship between human societies and earth systems has shaped my journey. My motivation to research the extremes of water scarcity and excess on the island of Crete derives from a sense of responsibility towards the island that has been both my home and inspiration but at the same time towards my profession, architecture, and urbanism.

Growing up within the diverse landscapes of Crete, I experienced the complex interplay of its geological formations, historical narratives, and the challenges posed by recent climate changes. This experience has driven my commitment to explore and understand the spatial aspects of those processes and to address the pressing issues of water scarcity and excess that have emerged. Finally, the urgency imposed by climate change and intense human activities demands immediate and thoughtful action, to prepare and strengthen the island against climate impacts and uncertainty.

I envision contributing to shaping a better future for the island where human and natural systems will coexist harmoniously.

Positioning / Introduction

"Not all change is bad, Where a reasonably healthy, reasonably diverse ecosystem is providing at least some kind of service, we might be better off to embrace our altered Earth. . . . We may even learn to find some charm there"

Editorial, Nature, July 23, 2009

Aerial view of the walls of the sunken ancient Minoan city of Olous, Elounda village, Source: *https://www.historyhit.com/photos-of-sunken-cities-in-the-mediterranean/*

Embarking on an exploration of the complex interplay between environmental, cultural, and socioeconomic challenges, this thesis attempts to uncover the interconnections that define the island of Crete and propose an alternative design and planning approach that unlike the current methods will prioritize flexibility, climate resilience and sensitivity about natural dynamic elements such as water and soil. The project is named "Cosmogonia of Crete: Critical Zones as a Continuous Altered Nature and the Transition to the Future," highlighting the urgent need to navigate the island through a web of uncertainties, climate changes, and human activities and regenerate its landscape and resilience.

As a dynamic and semi-closed entity, Crete embraces a narrative that transcends temporal boundaries, from the ancient geological forces that shaped its topography to the contemporary challenges posed by climate change and human actions. With its diverse topography and historical heritage, Crete stands at the forefront of climatic disruptions, urging a holistic approach to preserve its identity and empower its inhabitants to shape a resilient future. The project aims to address the intricate interdependencies of environmental, cultural, and socioeconomic challenges on the island of Crete, driven by uncertainties, climate changes, and human activities. It sets the stage for an in-depth exploration of water-related challenges, with a focus on water scarcity and excess and their impacts on the lives of the inhabitants. Consequently, this research seeks to understand the island's vulnerability and propose critical design interventions that foster resilience, preparedness, and cultural and ecological regeneration.

Why the project is named Cosmogonia of Crete: Critical zones as a continuous altered nature and the transition to the future ?

Cosmogonia of Crete, for the purposes of this thesis, is defined as the origins of the island, and its transformation through time-regeneration with respect to its past and its cultural heritage emphasizing water's significance in mythology and art.

Critical zones for the island of Crete are vital elements and systems both natural and human that interact and depend on each other including water systems, coastline, settlements and human development, relations with soil and earth as well as vulnerable regions.

Alteration processes have been observed on the natural systems of the island, due to various human activities, climatic changes, and long-term geological processes. These alterations have changed the landscape, and the different ecosystems, threatening the water systems, and soil quality.

This thesis presents the island's transition to the future, highlighting the urgent need to navigate the island through a network of uncertainties, climate changes, and human activities, envisioning how it will be transformed, securing resilience against climate change supported by the identification of strategies to prepare the island and embrace alternative planning and design approaches that are more climate resilient and sensitive to water and soil.

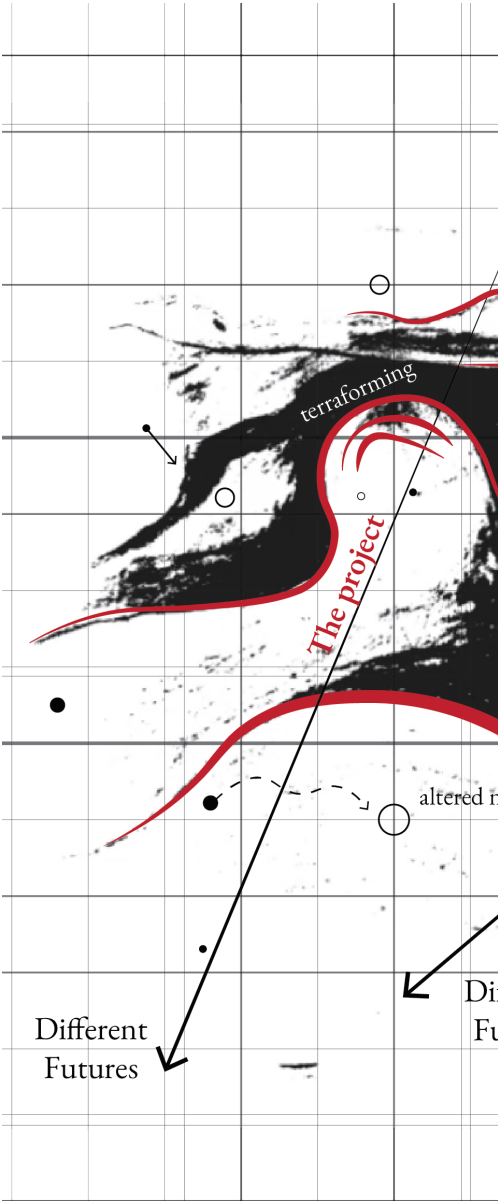
The aim of the thesis is to envision an alternative future for the island by rethinking human activities and their impact on Earth, including agricultural practices and water systems while taking into consideration the worst-case scenario of IPCC (8.5) within a timeframe by 2150.

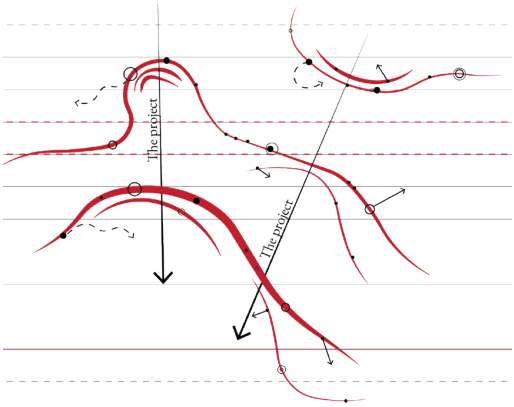
Research Scope

The research scope involves a comprehensive exploration of the altered nature of the Cretan landscape, particularly through the lens of water scarcity and excess influenced by climate changes and human activities. Understanding the island's diverse topography and culture, the project explores the unique formations created by the interplay between the topography and bathymetry of the earthscapes. The study acknowledges the challenges posed by unequal temporal and regional allocation of precipitation, intensified by increased water needs for irrigation and tourism activity, particularly during the summer months.

Later on, the project embraces the case study of the Isthmus of Ierapetra, the narrowest part of the island, delving into its intriguing topography and geological formations, highlighting fault zones that shape the Ierapetra Kavousi alluvial plain to develop a design and thinking method that criticizes the current instruments used by governments that do not reflect the dynamic character of spatio-temporal elements such as water, soil, seasonality etc.

The research investigates the risk of flooding in large alluvial plains like the Ierapetra Plain, emphasizing the region's vulnerability to desertification due to uncontrollable human activities. Furthermore, the project advocates for local water retention landscapes, following a concept of porosity, elasticity and temporality, to change the relationship with soil, earth, nature and water. Through community engagement and education, the project envisions the preservation of the island's cultural identity and its resilience against environmental challenges. Finally, it aims to foster a sustainable and climate-resilient future, that not only addresses the imminent challenges of water scarcity and excess but also becomes a paradigm not only for Crete but for islands facing similar challenges globally.


terraforming
The project
altered
Different
Futures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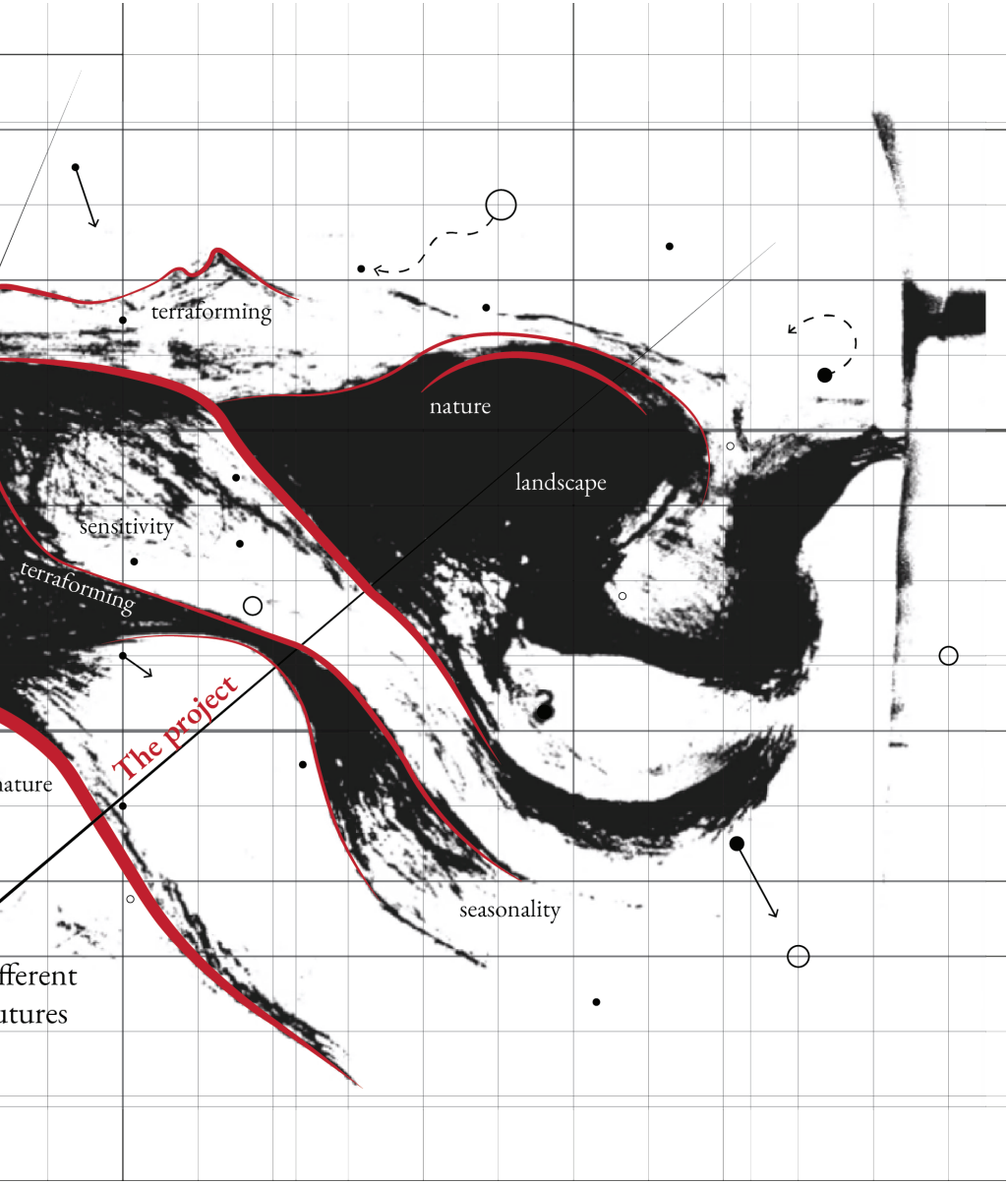
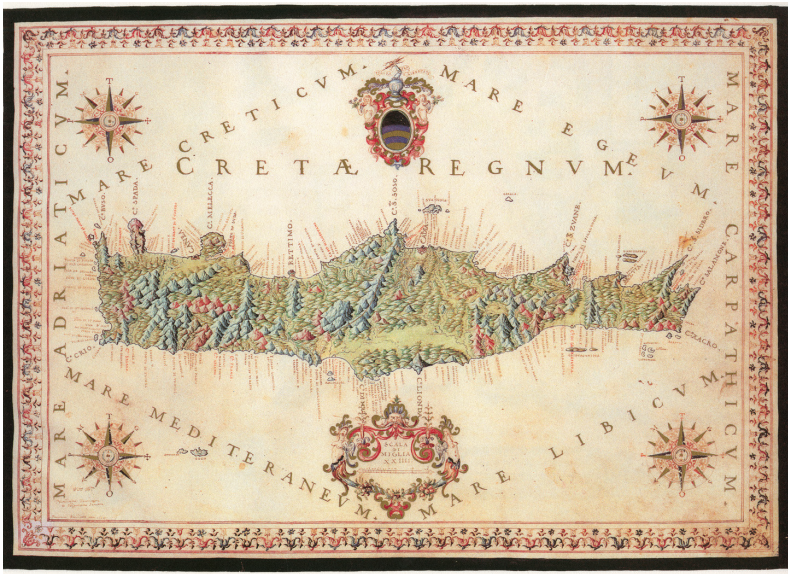


Figure 1: Position of the project, designed by author

Context

"Situated as it is between Europe, Asia and Africa, the island was destined by its geographical position to become the bridge between those three continents. That's why Crete was the first land in Europe to receive the dawn of civilisation which came from the East."

Nikos Kazantzakis, 6th May 1955



Creta Regnum, The kingdom of Crete, Francesco Basilicata, 1618

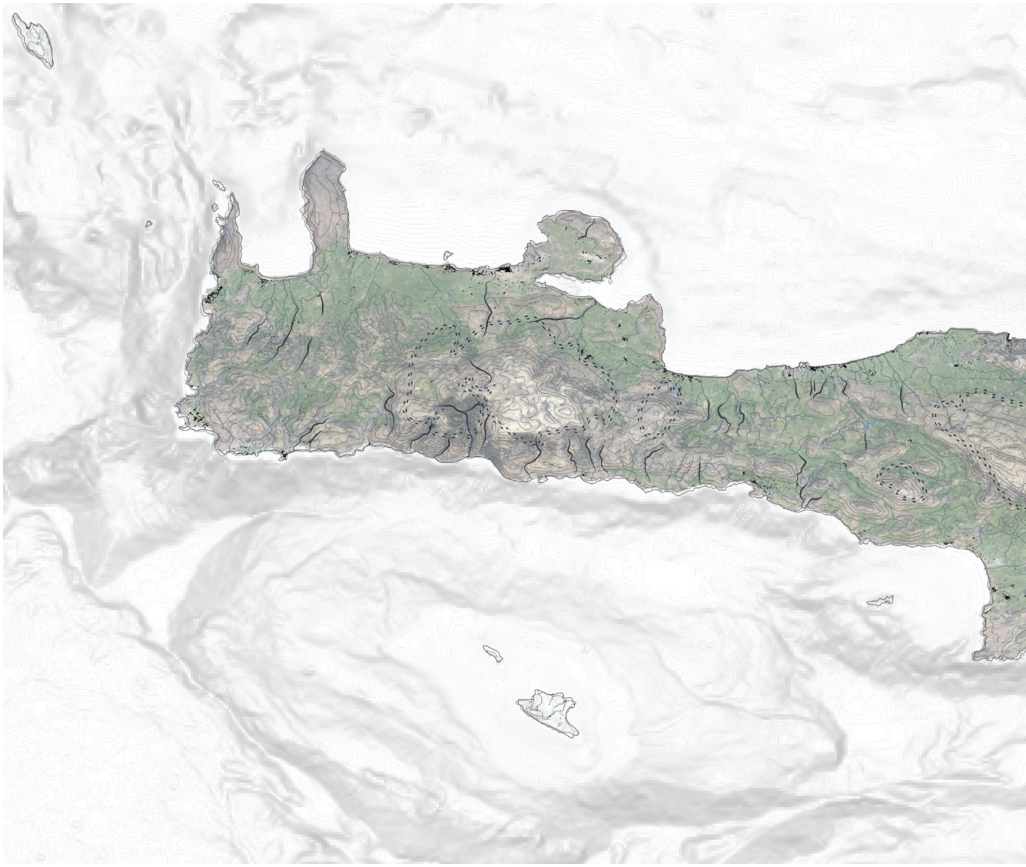
Figure 2: Location of the island of Crete

Crete is the largest island of Greece and one of the largest in the Mediterranean region. The island of Crete is located in the southern part of Greece and administratively is divided into four prefectures: Lassithi (1810 km2), Heraklion (2626 km2), Rethymno (1487 km2) and Chania (2342 km2). The total area of the island is 8260 km2 and it stretches about 250 km in an east-west direction and between 13 and 56 km in a north-south direction. (Kirsten, F., & Heinrich, J., 2022). Its topography is dominated by a series of mountain ranges with a maximum height of 2.456 meters and occupies a strategic location in the eastern part of the Mediterranean, in the southernmost sector of the Hellenic Arc, situated above the active subduction zone of the African and Eurasian plates. The subduction zone is the zone where one tectonic plate is forced beneath another, leading to the gradual uplift of the superimposed plate—in this case, the Eurasian. That is the process that formed the island of Crete (Manoutsoglou, E., Lazos, I., Steiakakis, E., & Vafeidis, A., 2022) classifying it as one of the most seismically active areas in the eastern Mediterranean region, showcasing the effects of intense tectonic movements mainly represented by regional (land) uplift and normal faulting (Crete has plenty of fault zones). (Caputo, R., et al., 2010). These geological configurations have significant impacts on the island's topography, hydrogeomorphology and tectonic activity resulting in phenomena such as the major karstic formations that are created due to limestone mountainous terrain which is dominating Crete's geology, which allows water to penetrate and stored underground, with substantial regional variations in the availability of fresh water. (Chartzoulakis, K., 2001). The abundance of karstic features, such as caves and sinkholes, plays a key role in transporting and redistributing water below ground promoting direct infiltration and recharge, limiting surface water availability. (Houseman, L., 2013) This phenomenon is what gives life to the island because it is the major water supply, however, at the same time, it has implications for its vulnerability to certain climate-related challenges such as sea level rise, salinisation, and desertification. Changes in climate patterns, such as altered precipitation and temperature levels and frequency, can threaten water resources.

Crete's population is approximately 625,000 (Eurostat, 2023), concentrated mostly in in the largest cities along the northern coast, with agriculture and tourism as the main sources of income for the inhabitants. Annually, the island attracts around 5,000,000 tourists, particularly during the summer months, while agriculture covers approximately 71% of the total land cover.

In conclusion, understanding these dynamic systems both natural and human is essential for effectively managing water scarcity and excess on the island of Crete, particularly in the face of climate change.

Figure 3: Location of the island of Crete within Greece, designed by author


0
25
50 km

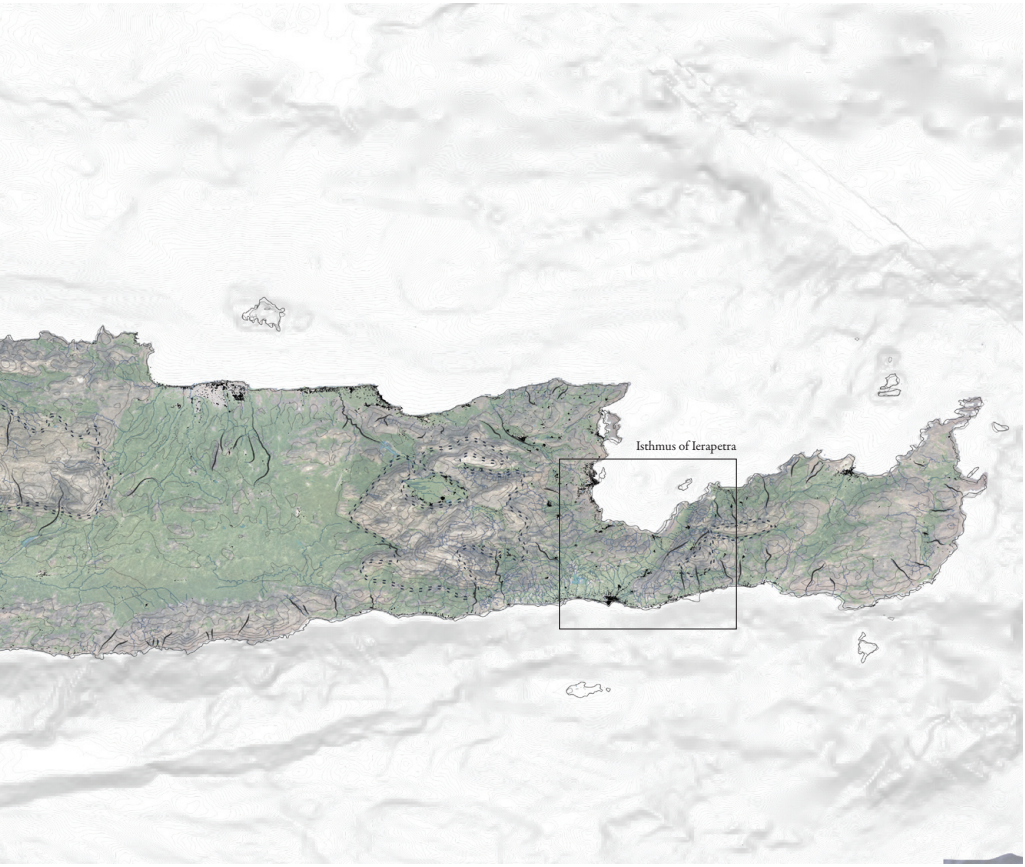
The island of Crete

River system

Contours per 1000m

Gorges

Agricultural land



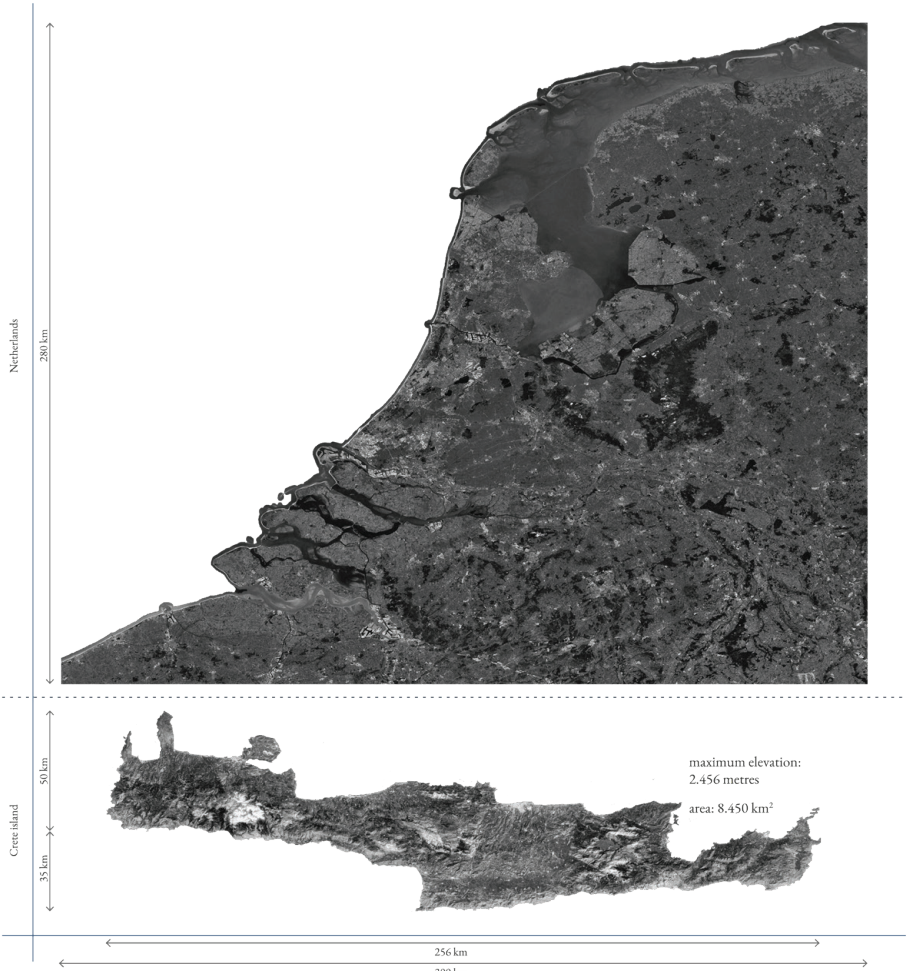


Figure 4: Scale of the island Crete, designed by author

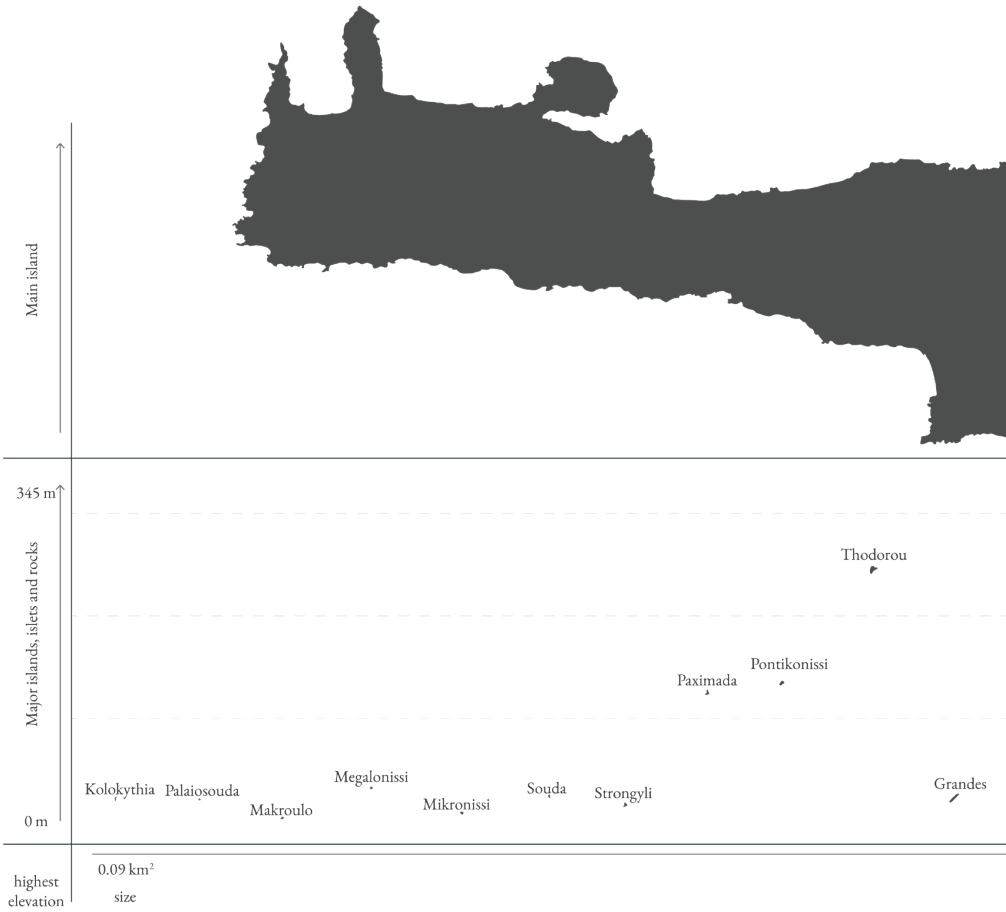

Main island
345 m
Major islands, islets and rocks
0 m
Thodorou
Paximada
Pontikonissi
Kolokythia
Palaiosouda
Makroulo
Megalonissi
Mikronissi
Souda
Strongyli
Grandes
highest elevation
0.09 km²
size
0
25
50 km

Figure 5: Crete and her islands, designed by author

"The island of Crete, is among the regions most threatened with desertification, the transformation of arable or habitable land into desert..."

Tsakona, Maria & Gekas, Vassilis. (2007). Desertification in Crete and the Effect of Global Warming.

Flooding incident, Crete, 20202, source: https://www.naftemporiki.gr/society/1098380/kriti-katagrafi-zimion-se-perioches-pou-chtypithikan-apo-tin-plimmyra/

Climate Crisis

The current climate of Crete is characterized as mild Mediterranean, with distinct seasons. Winters are rainy and typically mild, while summers are warm and dry. However, due to this significant morphological variability, there are considerable climate diversities from region to region. However, in the past, during the Classical and Hellenistic times, it seemed that the climate was colder, and snowfall was more frequent (Rackham et al., 2004).

The rapid development of Crete in the last 30 years has unleashed strong pressures on many natural resources and has altered the landscape significantly. Urbanization, growth and saturation of the agriculture and tourism industry have a strong impact on the water resources of the island by considerably increasing water demand. (Tapoglou, Vozinaki, Tsanis, 2019). Together with the intense human activities, climate change came to alter once and for all the weather patterns, setting in danger both the natural resources that support the societies and the cultural landscape of the island. Climate-induced hazards such as landslides, flooding, droughts and desertification observed during the last decade, have become the new reality. (Koutroulis et al., 2011). Shorter rainy periods and uneven distribution of water resources is seriously affecting water resources by significantly reducing (surface) water availability with severe consequences for local communities and ecosystems. (Tapoglou, Vozinaki, Tsanis, 2019). Increasing water demand from various sectors, including agriculture, tourism, and domestic use, particularly during the summer months has put additional pressure on limited water resources. At the same time, intense rainfall events during the winter months, lead to extensive flooding, due to the fact that the limited (storm)water management mechanism and infrastructure are unable to cope with.

Overall, the island of Crete serves as an analogue for understanding the challenges associated with climate instability in the Mediterranean region where the climate is likely to alter (it has already started) and have less frequent but more intense precipitation on average and more frequent and severe droughts in some regions, especially in the Eastern part of the island. (Koutroulis et al., 2010, 2011; Tsanis et al., 2011).

Problem Statement

" Earth is incredibly reactive to our actions, and can escape all our hopes of dominating it' (Latour 2018a, 223) compared to Nature which was seemingly indifferent to our actions, and for that reason could be mastered. "

Latour 2018a, 223

Disastrous impacts of flooding incident, Sitia, Lasithi perfecture, 2019, source:
https://app.alphanews.live/greece/boyliaxe-i-anatoliki-kriti-apo-tin-kakokairia-binteo

The southern part of Greece, exposed to the Mediterranean Sea, has always been at the core of climatic disruptions. The island of Crete is threatened by challenges posed by the recent and future catastrophic impacts of climate change that can threaten its sensitive ecosystems and environmental diversity, while at the same time stressing the preservation of its historical and cultural heritage and sustaining its socioeconomic systems and resilience. In recent years, the island has been facing a critical challenge with its water resources, intensified by the extremes of water scarcity and excess (flooding and drought), while being exposed to a rapidly changing climate. The island has started facing significant water scarcity, which is becoming even more and more obvious, for example, from the extremely low water level of the existing dams or the case of a particular village that was covered with water when the dam was built, but this year the village reappeared, stressing even more the urgency.

The project focuses on climatic, human, and geological-related problems such as flooding and desertification, but at the same time, it recognizes the causes that are leading in different directions, resulting in major conflicts. In the past 20 years, even more extreme and frequent climate changes have affected the island of Crete, with devastating impacts on both urban and non-urban areas. Flooding and water scarcity have started threatening worryingly human settlements and natural habitats as the existing water infrastructure struggles to meet the escalating demands imposed by settlements and agricultural practices. Simultaneously, the situation along the coast is being exacerbated by the excessive influx of tourists, particularly in the northern part of the island, where tourism has reached saturation levels, and together with the threat of sea level rise, the coast is facing a disastrous challenge. The coastal and inland areas of Crete are increasingly vulnerable to extreme weather events, storm surges, flooding, and desertification. Addressing the risks associated with water excess and scarcity requires a comprehensive strategy that harmonizes with the natural dynamics of the landscape and changes the relationship with soil, earth, nature, and water.

Finally, the current planning and design instruments fail to incorporate these urgencies in their strategies for the island, compromising its preparedness. Often, they are unable to represent spatially the interdependencies between human and natural systems and incorporate this complexity into their plans and policies, resulting in intense, ever-altering human activities that degrade the natural environment, undermining human existence. We have reached the point where it is not enough to change our activities, we need to develop alternative analytical and operational frameworks that rethink the way we perceive elements such as water and soil in space and in our design that are essential for human life and activities.

Research Questions

Extremely low water level - Aposelemis dam, December 2023

Extremely low water level - Aposelemis dam, December 2023

"How might the complex interplay of environmental,
driven by uncertainty, climate changes and human ac
and excess, with a focus on its diverse topography and
ering its citizens to actively engage and act

Devastating flooding at Municipality of Hersonissos, 2020

Devastating flooding at Municipality of Hersonissos, 2020

, cultural, and socioeconomic challenges on the island
tivity, be addressed through the lens of water scarcity
d culture, preserving its cultural identity, and empow-
in shaping a resilient and adaptive future?"

Main research questions:

"How can traditional water management practices and indigenous knowledge from Crete's past be leveraged to address the island's current and future water and climate challenges?

How can strategic design interventions focused on water scarcity and excess enhance adaptive transformation and resilience in Crete's agriculture, water management, and natural ecosystems?"

Sub-research question:

Diagnosis, historical heritage, and interventions

"How do historical and cultural water-use practices shape the hydro-social dynamics in Eastern Crete, and how can this understanding inform contemporary urban design for water resilience?"

"How can indigenous knowledge and local wisdom related to water management be integrated into urban design strategies to enhance adaptive capacity and foster sustainability in the face of climate change?"

"How have historical flood events impacted the region, and what lessons can be learned from them?"

"What are the current and projected climate change impacts on water resources in Eastern Crete, considering factors such as changing precipitation patterns, aquifer depletion, increasing water demand, potential sea-level rise, and temperature increases?" How do these impacts influence the urban fabric and infrastructure of the region?"

"How can urban design interventions address the challenges of water scarcity and excess in the Eastern Crete region, fostering resilience to climate change by integrating sustainable water management practices?"

How do temporal dynamics, such as seasonal variations and long-term climate trends, impact water availability on the island, and how can urban design strategies accommodate these fluctuations for resilient water management?

How do cultural narratives and storytelling shape perceptions of water (in Eastern Crete), and how can incorporating these narratives into urban design projects enhance community engagement and resilience?

Methodology

"We have learned that landscapes cannot be understood as objects when we see them react violently to human activities. We are instead led towards the need for a different understanding of territories and landscapes in order more fully to understand their complexity, to understand all the issues that are entangled with a river, the climate or a forest."

Arenes, A. (2022). Design at the time of the Anthropocene reporting from the Critical Zone

Gaylord Flory, Crete Valley landscape painting

Literature and Research Framework

Methodology and process

While attempting to answer the pressing question of how the island will transition and transform in the future, impacted by climate change and destructive human activities, critical and research cartography methods were introduced that encompass critical thinking and manipulate space and time. Furthermore, the overall philosophy of the studio, together with the literature suggested by the mentors, assisted in developing and expanding the theoretical and conceptual knowledge and thinking and pushing the ambitions and project goals forward. Finally, the project has evolved significantly following unexpected paths, creating a new methodology and critical design and planning approach, aiming to design by setting new priorities and considering a different perspective, where earth and water elements play a vital role in understanding transitions and designing spatial transformations.

Through the Transitional Territories Studio and Geographical Urbanism, and particularly the narrative exercises and inspiring presentations, a coherent narrative was critically synthesized, highlighting the urgencies while reflecting on the past events that influenced the materiality and the complex systems and processes of the island. More particularly on how urbanization forms and patterns and the diverse landscapes (waterscapes, geological formations, materiality) were, are, and will be impacted by climate change. This informed the theoretical understanding to scientifically and logically support the work methodology, providing an evidence-driven project. Over the course of the studio, the importance of research and analysis through critical cartography of complex systems and cycles was highlighted. They proved to be extremely valuable and at the core of the project, including surface and subsurface elements, particularly water and soil, and processes (and the interdependency among them), to, in the end, re-compose a new spatial reality and strategy for the island.

The project takes advantage of the agency of design through critical research by design approach comprised of a literature/data review and the observations from the field trip supporting the cartographical analysis and providing sufficient knowledge and data about the different domains of expertise necessary to understand the island's complex systems and conduct more in-depth research. These acts of cartography, capturing landscapes and systems, and terraforming highlight the agency of research and design for creating possible futures, supported by diverse projects across scales based on decisions informed by the cartographies.

Overall, the most important methods that this thesis project will utilise are:

Analytical mapping and literature review:

Developing an understanding of the island's past and significant geological, hydrological, cultural, and ecological heritage, relating changes in its physical land to significant phenomena through time. Utilizing advanced mapping techniques and manipulating analytical mapping to diagnose, deconstruct, and synthesize a narrative, providing a significant and innovative understanding of hydrogeological and cultural dynamics on Crete could provide the island with the tools to address climate threats. This approach uncovers the island's dynamics and evolution, integrating past events with present challenges and potential.

Extensive Research and Study:

This method involves extensive literature reviews and in-depth studies, delving into the island's past through research and mapping. The main goal is to understand the island's dynamics and diverse and complex systems to be able to design strategic interventions that address the challenges of climate change, water scarcity, and excess that the island is facing.

Critical Cartography:

Creating a narrative as a tool for awareness and initiative by reflecting upon the inland, underwater, and underground topographies Through innovative mapping practices, critical cartography shapes narratives that transcend traditional boundaries.

Experimenting:

In the experimentation phase, I engage in research, scenario-making, and hands-on exploration and prototyping to test design concepts. This iterative process allows for testing ideas and ensures that proposed interventions align with the island's unique features.

Backcasting :

The anticipation of probable realities based on the envisioned change against current trends and the potential tensions in time and in the land.

Scenario Mapping:

This method involves creating hypothetical climates and planning scenarios through the process of terraforming to explore potential futures for the island of Crete. By mapping out various case scenarios, and using the worst-case scenario, the project aims to develop proactive and adaptive strategies and resilience plans for the island's dynamic environment.

Fieldwork:

Fieldwork is an essential method that involves on-site investigation and data collection, allowing for a clear understanding of the island's physical, cultural, and environmental nuances. Through direct observation, photography, and extensive research, fieldwork enriches the research process and ensures a grounded and contextually sensitive approach to the thesis project.

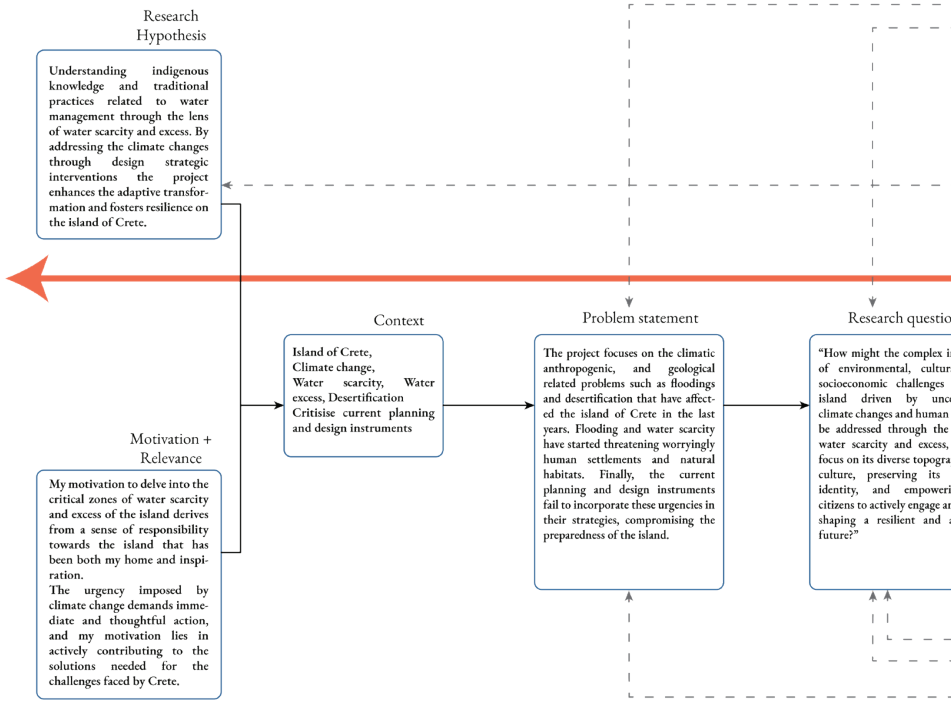
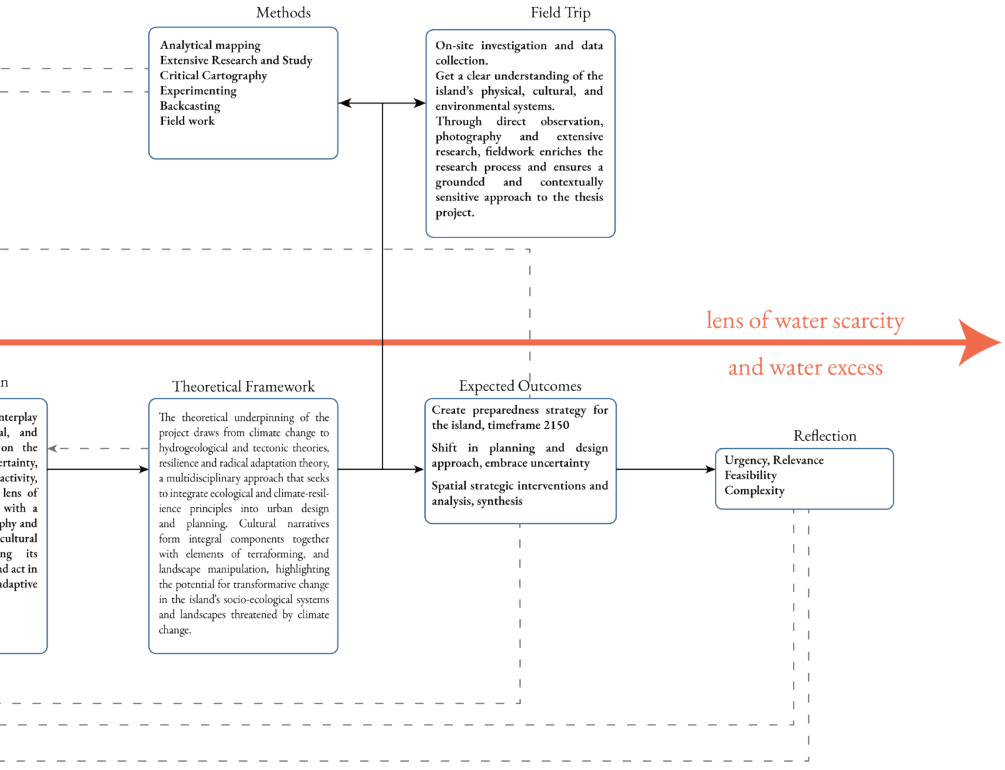


Figure 6: Thesis project diagram, designed by author


Methods
Analytical mapping
Extensive Research and Study
Critical Cartography
Experimenting
Backcasting
Field work
Field Trip
On-site investigation and data collection.
Get a clear understanding of the island's physical, cultural, and environmental systems.
Through direct observation, photography and extensive research, fieldwork enriches the research process and ensures a grounded and contextually sensitive approach to the thesis project.
lens of water scarcity
and water excess
Theoretical Framework
The theoretical underpinning of the project draws from climate change to hydrogeological and tectonic theories, resilience and radical adaptation theory, a multidisciplinary approach that seeks to integrate ecological and climate-resilience principles into urban design and planning. Cultural narratives form integral components together with elements of terraforming, and landscape manipulation, highlighting the potential for transformative change in the island's socio-ecological systems and landscapes threatened by climate change.
Expected Outcomes
Create preparedness strategy for the island, timeframe 2150
Shift in planning and design approach, embrace uncertainty
Spatial strategic interventions and analysis, synthesis
Reflection
Urgency, Relevance
Feasibility
Complexity

Theoretical Framework

The theoretical underpinning of the project draws from climate change, hydrogeological and tectonic theories, resilience, and radical adaptation theory, a multidisciplinary approach that seeks to integrate ecological and climate-resilience principles into urban design and planning.

Within this framework, the project explores the hydrogeological aspects of Crete, considering the island's geological formations, fault zones, and hydrological dynamics. Cultural narratives and indigenous knowledge form integral components, aligning with the project's focus on water scarcity and excess. Additionally, the theoretical framework incorporates elements of terraforming, landscape manipulation, and radical adaptation, highlighting the potential for transformative change in the island's socio-ecological systems and landscapes threatened by climate change.

By synthesizing critical zones theory, hydrogeological theory, resilience, and terraforming, the project aims to contribute to a holistic and comprehensive understanding of Crete's dynamic and complex environmental challenges and manipulate the agency of design to foster resilience and preparedness and sustain life on the island of Crete.

Terraforming

Terraforming narratives are based on the understanding that manipulating a planet's climate is fundamental for establishing and sustaining human settlements. They refer to planetary adaptation to enable their habitation. On Earth, similar speculation is applied to address environmental challenges, such as the use of geoengineering, or terraforming on Earth as a possible emergency response to mitigate climate change impacts, as outlined in the IPCC 2014 report. (Pak., 2019)

Resilience Theory

The origin of the word "resilience" derives from the Latin verb 'resilire', which means "to bounce back," refering to the ability of organisms or systems to recover their original shape after encountering disturbance or interruption. (Oliva, Lazzeretti, 2017).
Resilience theory, particularly in the context of socio-ecological systems, offers insights into how communities and ecosystems navigate disruptions. It can inform strategies for building resilience and flexibility in Crete's communities and systems facing the impacts of climate change and socio-ecological challenges.

Critical Zone Theory

The Critical Zone is a notion invented by Earth scientists to unite diverse disciplines that have not collaborated sufficiently in the past. (Fieldbook Editorial Team, Center for Art and Media Karlsruhe, 2020). It provides a comprehensive perspective on the interconnected layers of the Earth's critical zone, highlighting the porous, dynamic nature shaped by life and geochemical processes. This can be extended to understand Crete's critical zones and their vulnerability to environmental changes, recognizing Earth's surface as a thin porous layer affected by biological and geochemical cycles, a few kilometres thick, when compared to the whole of planet Earth as viewed from outer space (Critical Zones) (Arènes, Latour, and Gaillardet, 2018).

Climate change

Climate change is a long-term process of alteration in the average weather patterns that are defining Earth's local, territorial, and global climates over an extended period and have a variety of impacts on all natural and human systems. (NASA, what is climate change, n.d.) Such shifts can happen due to natural changes in the sun's activity or large tectonic events. However, since the 1800s, human activities have become the primary driver of climate change, particularly due to the burning of fossil fuels. (U.N, what is climate change, n.d.)

Sea level rise scenario 2100, 2150

According to the IPCC report, global mean sea level will continue to increase over the 21st century. Based on the IPCC climate projection-scenarios, relative to 1995-2014, the projected global mean sea level rise by 2100 is 0.28-0.55 m under the very low (SSP1-1.9), 0.44-0.76 m under the intermediate (SSP2-4.5) and 0.63-1.01 m under the very high (SSP5-8.5) greenhouse gas emissions scenario. (Climate Neutral Group, n.d.)

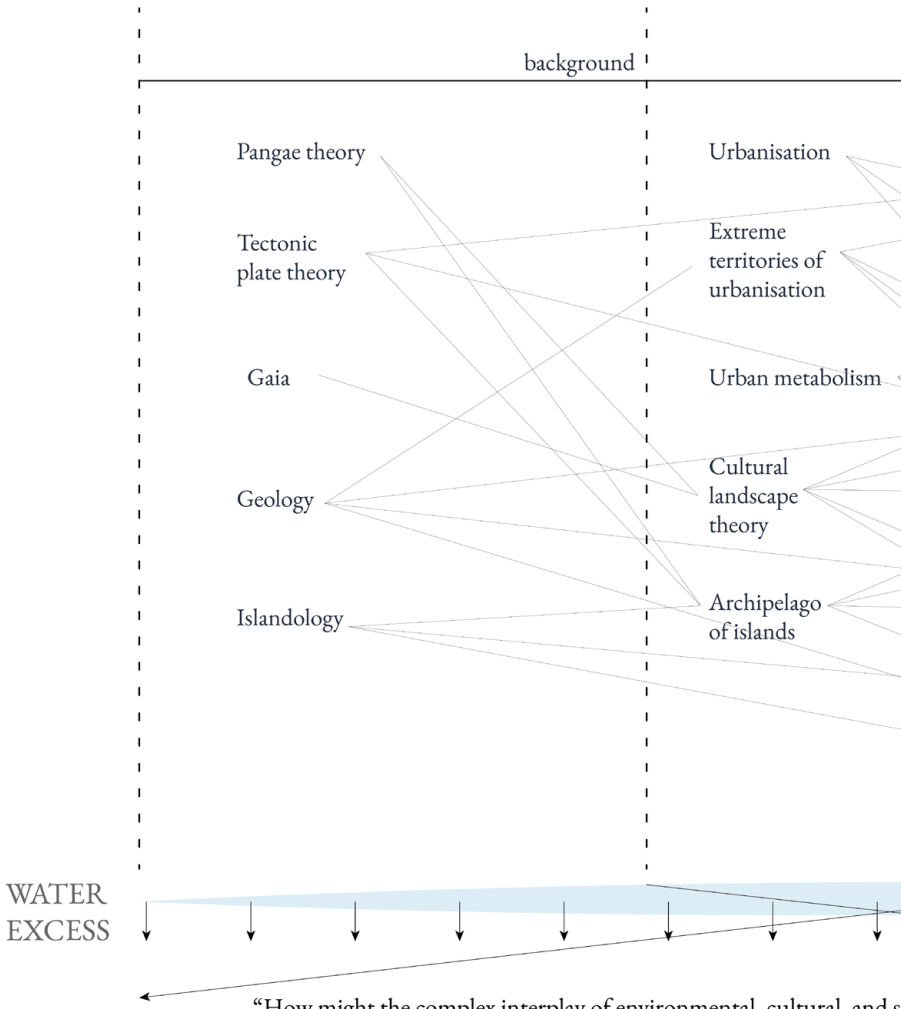
To define the potential impact of uncertain ice sheet processes, a Low Confidence scenario, SSP5-8.5 is also taken into consideration by the IPCC. (Hong Kong Observatory, n.d.). The current global annual temperature is 0.89 °C and the sea level is 101 (± 4.0) mm. (*considering 0 during 1993). For this project we adopt the Low Confidence IPCC scenario under SSP5-8.5 but for the timeframe of 2150. In this scenario with the future projections new, increased annual temperature of 5 °C and sea level change of 1.98 m increase is expected by 2150.

Radical adaptation

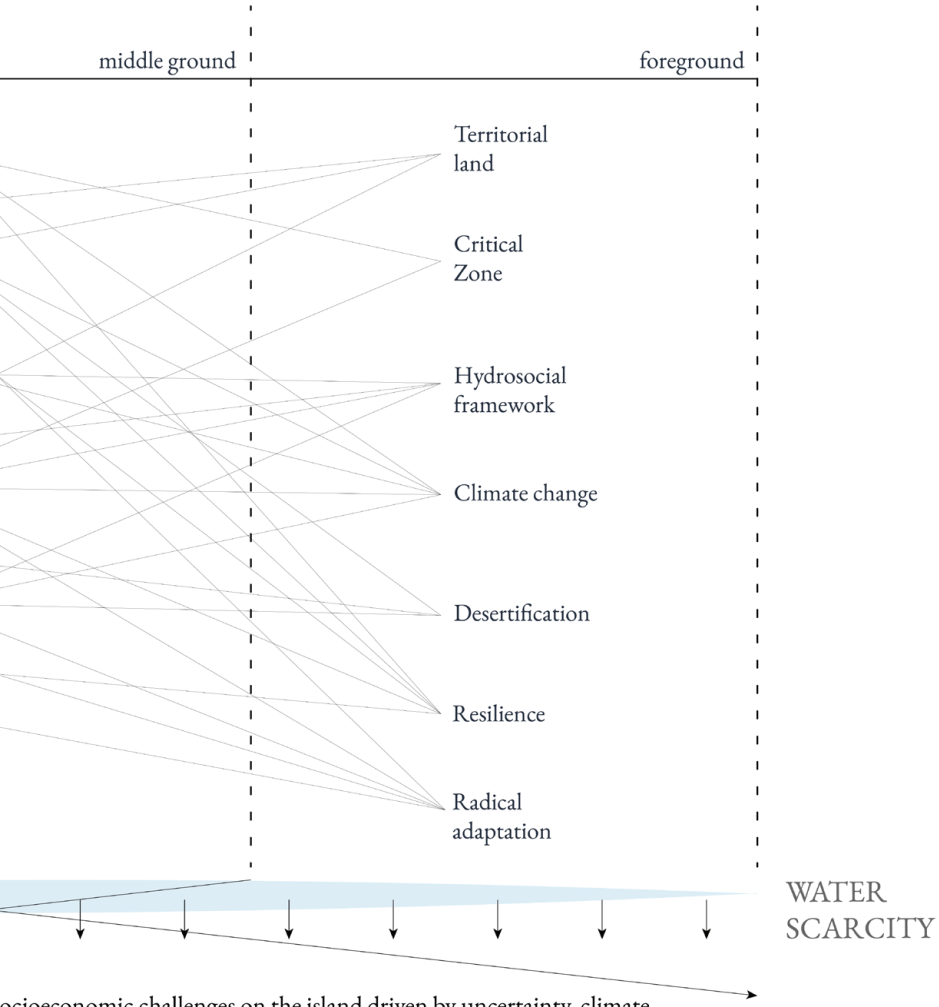
Radical adaptation is an emerging concept that responds to climate challenges and belongs to the category of adaptation, embracing the notion of transformative adaptation and emphasizing proactive and planned interventions. It recognizes the urgency of responding to high climate risks, acknowledging the need to address the root causes of climate change impacts. Therefore, radical adaptation aims to not only build resilience but also actively contribute to mitigating the underlying causes of environmental challenges. (International Institute for Environment and Development, n.d.)

Hydro-Social Framework

The hydro-social theory, which explores the complex interactions between water systems and social dynamics, can enhance the understanding of water-related challenges that the island of Crete is facing. It contributes to unveiling and exploring indigenous knowledge and practices. In the hydrological cycle, human agency shapes the flow of water for different uses, altering the chemical, biological, and morphological cycles of water in favour of human activities. (Rodríguez-Labajos & Martínez-Alier, 2015).



"How might the complex interplay of environmental, cultural, and s
changes and human activity, be addressed through the lens of water s
preserving its cultural identity, and empowering its citizens to ac



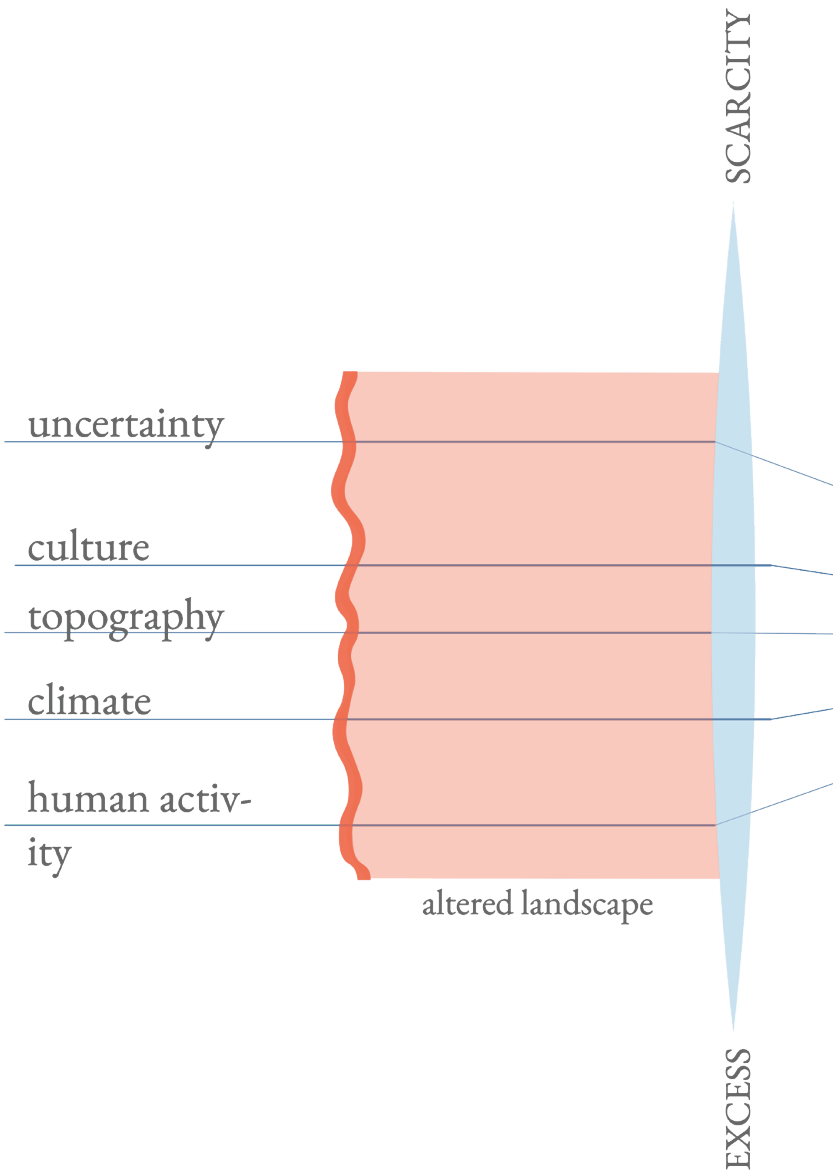
ocioeconomic challenges on the island driven by uncertainty, climate carcity and excess, with a focus on its diverse topography and culture, ctively engage and act in shaping a resilient and adaptive future?"

Figure 7: Theoretical framework, designed by author

Conceptual Framework

The conceptual framework of the project is founded on the theory of resilience and radical adaptation, which emphasizes the interconnectedness of geological, ecological, and human systems. The concept of water scarcity and excess becomes a lens, a framework through which the project examines the system interdependence and dynamics of the island, acknowledging the porosity, elasticity, and seasonality that characterise it.

Elasticity is representative of the adaptive transformation of landscapes and communities, promoting the value of flexible and in-depth design strategies in the face of climate uncertainty. The notion of temporality navigates the understanding of evolving climatic patterns, seasonal variations, and historical changes, along with the island's transformation. Finally, in the context of the altered nature of Crete, the island's topography, culture, and climate uncertainty are going through a lens of water scarcity and excess to strengthen the island's preparedness and adaptive transformation while at the same time fostering water security to sustain its survival. The interdisciplinary methodology aims to provide insights applicable not only to Crete but to regions facing similar challenges globally.


SCARCITY
uncertainty
culture
topography
climate
human activ-
ity
altered landscape
EXCESS

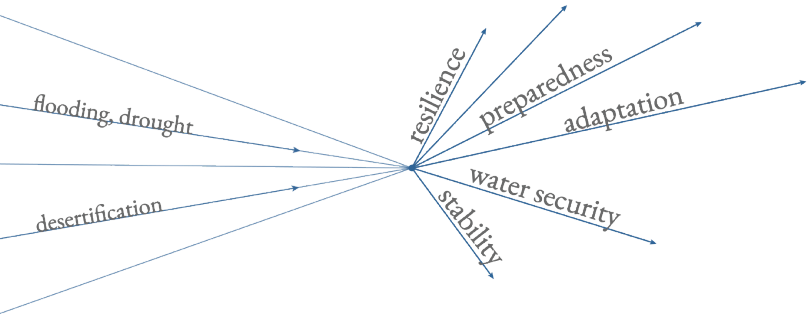


Figure 8: Conceptual frameworks, designed by author

Analytical Framework

Background

The background of the project is setting the stage for an exploration of Crete's past and present through cartographies. Investigating the island's hydrogeomorphological formation involves delving into geological epochs, understanding how tectonic processes and geological shifts shaped the land over millions of years, and how they have influenced water systems. The geological background provides insights into the unique topography of the island, while examining Earth systems offers a holistic understanding of the present environmental dynamics. Analyzing the existing urban fabric allows us to uncover the layers of human settlement, urban evolution, and spatial organization that have contributed to the island's current state. The physiography of Crete is explored, emphasizing its diverse landscapes, topography, and ecological zones. Furthermore, considering materiality, the composition of the island's resources is being analysed. This comprehensive background research forms a solid base, ensuring that subsequent layers are anchored in a deep understanding of Crete's geological, environmental, and human history.

Middle Ground

Transitioning to the middle ground, the focus shifts to the human landscape of Crete. Human systems are embracing societal features, economic activities, and cultural practices. At the same time, climate variations and alterations and their impacts on Cretan ecosystems are being analysed, considering their causes, including human activities, urbanization, and environmental shifts. Lastly, human infrastructure is tested in terms of its capacity to adapt to the increasing needs of the population and the challenges posed by climate change. The middle ground acts as a connecting element, linking the morphological context with human alteration and the pressing issues and opportunities that will be addressed in the foreground.

Foreground

In the foreground, the project takes a proactive position, addressing the imminent challenges of water scarcity, excess, and soil degradation that climate change and human activities are posing. Therefore, water and soil become central elements, necessitating care and shifts in human activities such as agriculture and integrated water management. Water excess requires resilient infrastructure and adaptive urban planning, and land needs soil regeneration and actions of care from humans.

This thesis attempts to influence decision-makers' actions and decisions involving criticizing current static planning methods while translating research findings into actionable spatial interventions. Finally, enhancing the inhabitant's awareness becomes a fundamental component, with emphasis on community engagement and education towards building a sustainable and resilient future for Crete. This approach positions the project as a catalyst for positive change, (pro)actively guiding the island's path through the challenges of the 21st century.

Analytical research and design

This research is being developed across a multi-scalar approach. The expected outcome of this research will be structured first on a territorial scale, showcasing the totality of the closed system of the island, then focusing on a regional scale (meso), identifying the most vulnerable regions, along with design interventions that require a local scale (micro). When going more in-depth on these interventions, design on a smaller scale (nano) becomes relevant to understanding the unique local conditions and relations between communities, natural elements, and processes.

The project will propose a set of interventions that address some of the critical zones of the island, such as the fragmented inland with the agricultural land, the seasonal rivers, water scarcity, excess, soil sensitivity, and degradation.

Scale exploration maps, designed by author

Exploration

"The farther backward you can look, the farther forward you are likely to see."

Winston Churchill

On the Island of Crete, Ivan Aivazovsky, 1867

Spatial Exploration

This project explores the different forms of the Cretan landscape that constitute an altered nature, especially through the lens of water scarcity and excess influenced by climate change and human activities. This thesis is situated within the Anthropocene era, where human activities are having devastating impacts on nature. Therefore, it is extremely relevant to understand the significant changes that took place during this era and to recognize their spatial traces over the past years, when human influence started becoming uncontrollable and the disastrous impacts of human activity started intensively altering the earth and all earth ecosystems. Since their first appearance, humans have not adapted to the previous ecosystems but have attempted to alter them, reshaping the global patterns of biodiversity, habitats, and carbon to better support human populations.

As Curt Stager mentions in his book Deep Future: The Next 100,000 Years of Life on Earth, we are both the products and the producers of this new era, and we have already started facing the significant threats and consequences of our altered world. (Stager, C., n.d.) This project critically acknowledges that humans and the current state of the earth are just one small moment in the evolution of the world, and the epoch will change, shifting the living conditions and creating an altered future where life will thrive again. The project positions the new epoch that could potentially be called "Ecogenecene" and could symbolize an era characterized by a specific set of characteristics that reflect a focus on ecological regeneration and the emergence of a new environmental order. To achieve this fundamental shift, we need to investigate the past, the origins of the world, and previous eras to avoid repeating the same mistakes. For instance, for this project, the Miocene, a previous geological era of the world, is a very relevant analogy, since the climate conditions of the Miocene can provide a clue to where the world is heading, with similar or even more extreme climate changes as today, such as a global average temperature of 2-4 °C and sea levels 20 m higher than today. (Wallace-Wells, D., 2020, Holbourn, A., Kuhnt, W., Kochhann, K. G. D., Matsuzaki, K. M., & Andersen, N., 2022).

Moving on to the project site, in the context of the closed system of the island, the island of Crete is defined as a geographic landmass surrounded by water, isolated from neighboring mainland areas. Islands have distinct boundaries that make them relatively self-contained ecosystems with limited external inputs and outputs. Although Earth's surface is continuous both below and above water, what distinguishes an island is the presence of water around it that defines the island's boundaries – the interface between underwater and dry land. This view highlights the dynamic relationship between geomorphology and water dynamics that has shaped the diverse landscapes of Crete and their interdependence.

Islands such as Crete, frequently face challenges due to their isolated nature and limited resources, and they can depend mainly on the locally available resources and ecosystem services. Water and soil are essential components of the island's ecosystems, and their management and care are fundamental for sustaining life on the island and supporting human activities. The first priority of the island is to sustain life on the island and then expand (export) its activities to benefit other areas.

Origins of the island

In order to gain a comprehensive understanding of the island of Crete, including its geological features and its historical evolution, it is essential to delve into its origin and formation, tracing back to the forces that led to its creation. Starting about 300–200 million years ago, the continent we now know as North America was contiguous with Africa, Europe, and South America, forming a single supercontinent called Pangea. Pangaea began to separate around 175 million years ago following a complex and gradual process of fragmentation of the continents, and it occurred over millions of years, eventually resulting in the current configuration of continents.

The theory of plate tectonics, as an evolution of the Pangaea theory, altered dramatically the earth sciences by explaining how the movement and collision of geologic plates form mountains, volcanoes, and earthquakes. More than 500 million years ago, the area of Crete was submerged in the Tethys Sea (in a different geologic period), and the majority of the island was formed from deformed tectonic plates. Therefore, Crete is located above a subduction zone between the Aegean, African, and Eurasian plates and is formed by the sediments moved by the rivers of the coasts of Pangaea and the wind, forming layers of rocks. Those forces started in Crete around 40 million years ago and are responsible for the present-day seismicity and topographic diversity. (What Was Pangea? | U.S. Geological Survey, 2009; Geggel & Ghose, 2024)

Consequently, although minor earthquakes occur every year in Crete, some extremely intense earthquakes and tsunamis have occurred in the past millennia. According to experts, the most intense earthquake was associated with the explosion of the volcano on Santorini during the 15th century B.C., which caused the disappearance of the Minoan civilization.

Pangaea, designed by author

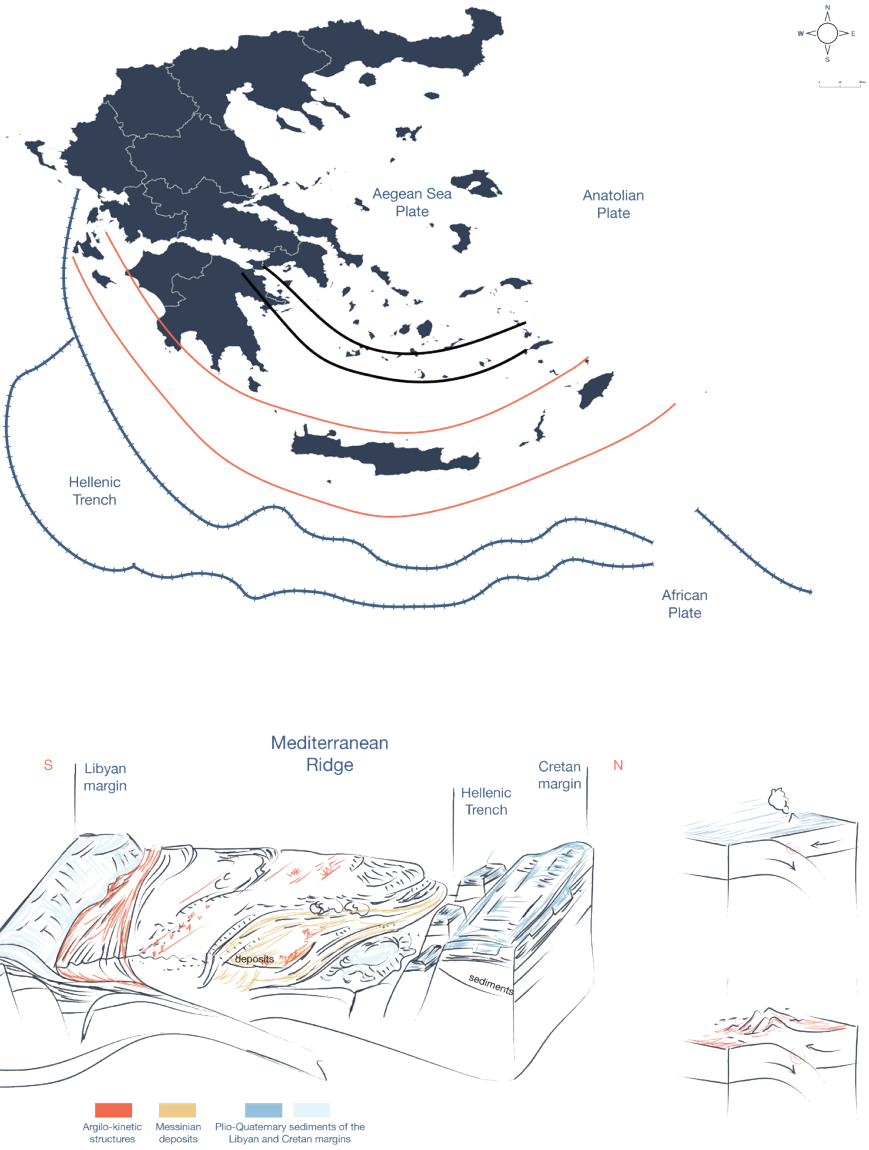
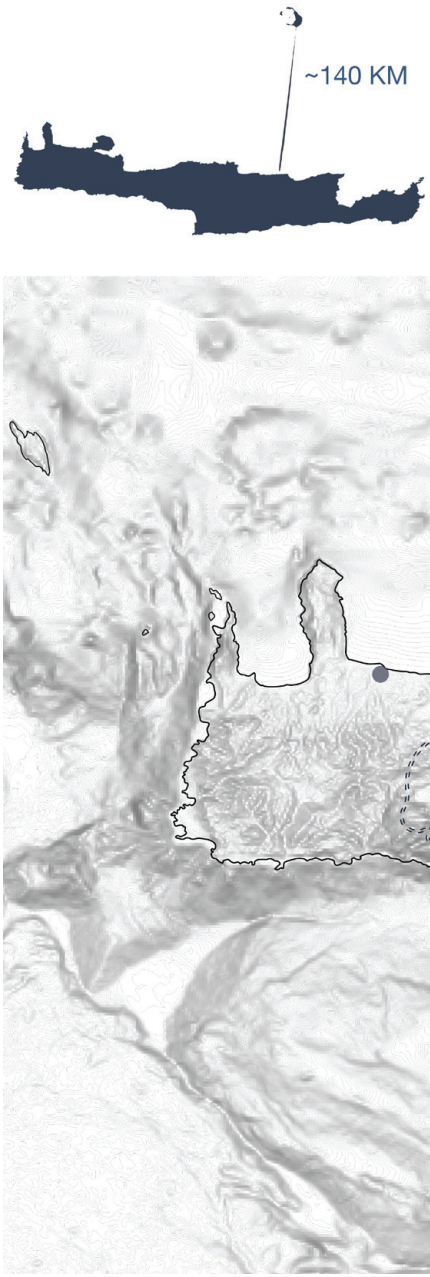


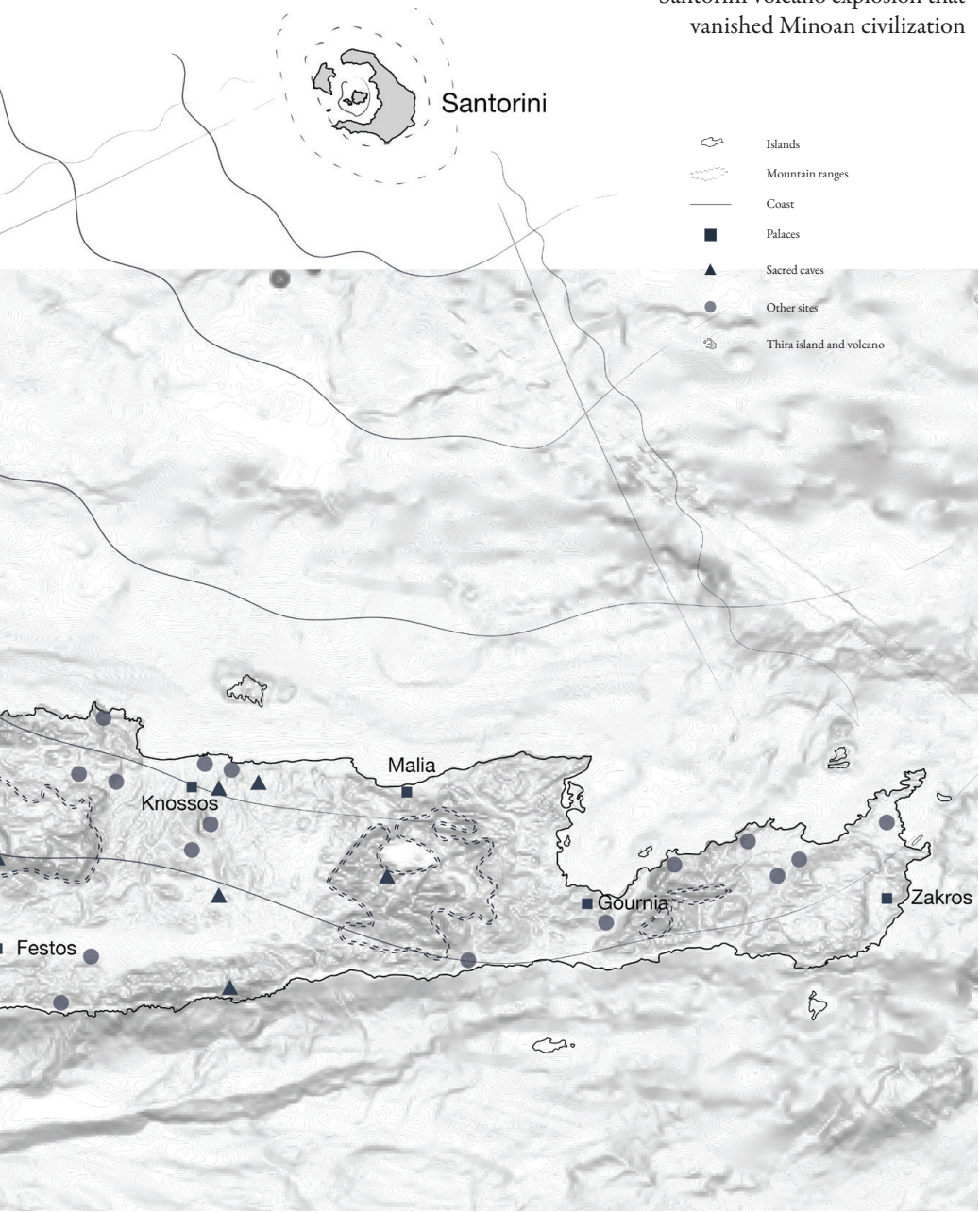
Figure 9: Tectonic processes, adapted from *Huguen, C., Mascle, J., Woodside, J., Zitter, T., & Foucher, J. P. (2005). Mud volcanoes and mud domes of the Central Mediterranean Ridge: Near-bottom and in situ observations. Deep Sea Research Part I: Oceanographic Research Papers, 52(10), 1911–1931. https://doi.org/10.1016/j.dsr.2005.05.006*

North American Plate
Juan de Fuca Plate
Pacific Plate
Cocos Plate
Caribbean Plate
African Pl
Nazca Plate
South American Plate
Scotia Plate
An

American Plate
Eurasian Platę
Arabian Plate
Philippine Sea Plate
Pacific Plate
Indian Plate
Somali Plate
Australian Plate
ntarctic Plate


~140 KM
Agia Triada
0
25
50 km

Santorini volcano explosion that vanished Minoan civilization



Alterations of the island

Over thousands of years, Mediterranean landscapes have been shaped by a combination of diverse forces, from slow, long-term processes such as geomorphological changes, tectonic activities, climatic variations, or climatic processes to anthropogenic activities including urbanisation and agriculture. These forces have left distinct traces on the landscape and cultural identity of the regions.

Consequently, the island of Crete is considered severely altered and degraded due to human actions, habitation patterns, infrastructure development, food production systems, agriculture, industry, and tourism. These activities have significantly transformed the island's landscapes compared to their early-to-mid-Holocene conditions. (Wainwright, 2009; Kirsten, F., & Heinrich, J., 2022) Agriculture, domestic activities, and industry which are the sectors with the largest dependency on resource availability and the greatest impact on natural ecosystems, are expected to be most affected by climate change in Crete. This emphasises the interconnectedness between human activities, land use patterns, and resource management on the island, all of which leave spatial traces on its landscape, earth-water systems, and cultural identity.

Addressing the risks associated with water excess and scarcity requires a comprehensive study that analyzes the natural dynamics of the landscape and water together with their interaction with human activities while identifying the alterations in space. The following section presents an analysis of the main alteration processes affecting the island of Crete, including urbanization, agricultural production, and tourism, exploring their impacts on water availability and quality. The thesis explores how these processes interact with environmental dynamics and human activities, aiming to provide insights into how to incorporate these urgencies and altering forces into the island's strategies to enhance its preparedness and preserve water and soil quality that are essential for human well-being and activities.

Natural slow processes including Tectonic collision, Earthquakes, Geomorphology

Over the years, significant geological shifts have occurred along the coastlines of Crete, influenced by tectonic processes. It is known that the western coasts of the island experienced intense uplift as a result of tectonic activity, during the 5th century BCE (Thommeret et al, 1981; Price et al., 2002). The tectonic system in the region is part of the broader Alpine tectonostratigraphic system, which highlights the complex and dynamic geological nature of the island. This geological configuration has significant impacts on the island's topography, hydrogeomorphology and tectonic activity. The geological features, such as fault lines, influence the island's hydrogeological system and with limestone dominating Crete's geology, which allows water to penetrate, there are multiple major karstic formations. (Chartzoulakis, K., 2001). This phenomenon is what gives life to the island because it is the major water supply, however, at the same time, it has implications for its vulnerability to certain climate-related challenges such as sea level rise, salinisation, and desertification. Changes in climate patterns, such as altered precipitation and temperature levels and frequency, can threaten water resources. Additionally, another geological formation is marine terraces, which are flat surfaces interrupting the continuity of the coastal landscape and are rock terraces created by the interplay of marine erosional and depositional processes. Marine terraces can be preserved for a long time in coastal landscapes, and are therefore among the most widely used sea-level indicators. (Rovere et al., 2023)

Understanding these geological dynamics is essential for effectively managing water scarcity and excess on the island of Crete, particularly in the face of climate change. By comprehensively studying the interactions between tectonic activity, hydrogeomorphology, and climatic shifts, we can develop more resilient water management strategies mitigating the risks associated with sea level rise, salinization, and ensuring the sustainable use of water resources.

Figure 10: Marine terraces in Northeastern coast, Pachia Ammos, Ierapetra fault zone 2023, photograph by author

Figure 11: Marine terraces in Northeastern coast, Pachia Ammos, 2023, photograph by author

Habitation patterns

The island's history and urbanization have evolved over centuries, accommodating important civilizations that left their traces on the island's urban development and landscape transformation. Settlements and the largest cities are predominantly located along the coast, whereas villages are towards the inland within the productive landscapes of Crete, or in the mountains. In addition, over time, few settlements have been abandoned for various reasons, contributing to the dynamic nature of the island's urban and rural environments. One reason is the rural-urban migration of people moving towards cities looking for better economic opportunities. These urbanization processes have led to regional disparities within the island since urbanization in Crete is not consistent across the island causing the concentration of people in cities and abandonment or under-functioning of rural areas that constitute the core of the island leading to fragmentation between the coast and the inland.

Moreover, the rapid development of Crete in the last 30 years has unveiled significant pressures on natural resources such as water and soil. The island's water resources have been severely impacted by urbanization, intensive agriculture, and the expansion of the tourism sector, which has resulted in a significant increase in water consumption, especially during the summer months.

Figure 12: Sitia city development, Northeastern coast, Google Earth image

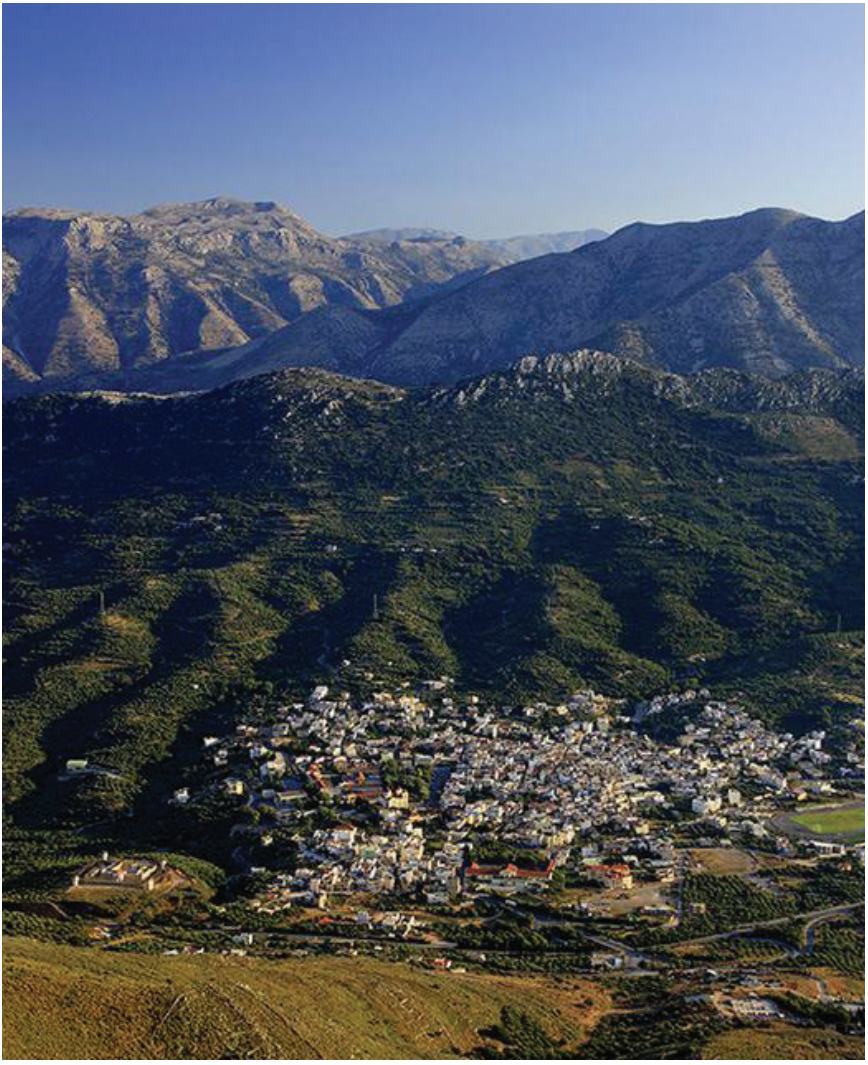


Figure 13: Neapoli village, Lasithi Prefecture, Source: *https://www.madein-greece.news/taksidi/aksiotheata/ta-mikra-mystika-xwria-ths-krhths-pou/*

Figure 14: Kalo Chorio village, Lasithi Prefecture, 2023, photograph by author

Figure 15: Abandoned village due to Aposelemis dam creation, Sfentili, 2023, photograph by author

Figure 16: Abandoned village, Epano Perivolakia, Google Earth image

Infrastructure development

Man-made and natural infrastructure creation is shaping and influencing the island's form. Fundamental to support the increasing population of the island and their needs, is the development of transportation networks, such as roads, harbors and airports to keep the island alive and connected to the rest of the world, facilitating trade and transportation (humans and goods). Human infrastructure development is also contributing to economic development and connectivity shaping both urban and rural landscapes, supporting the island's population and activities while at the same time altering the island's natural environments and systems. Tourism infrastructure, which is concentrated along the (northern) coast, supports Crete's increasing tourism industry, providing accommodation and services for visitors. All the above activities depend on the water resources of the island, emphasising the importance of water infrastructure on the island, such as dams and irrigation systems, which are designed to sustain life and manage one of the island's most valuable resources, supporting agriculture and domestic needs. However, those infrastructures are extremely vulnerable to climate changes, including flooding, droughts and sea level rise.

Figure 17: Road network and water infrastructure (dam), 2023, photograph by author

Figure 18: Largest airport of the island, Heraklion, Google Earth image

Figure 19: Second largest port of the island, Souda, West, Google Earth image

Figure 20: Irrigation system, Eastern Crete, 2023, photograph by author

Figure 21: Water collection infrastructure, Limnes, Lasithi perfecture, 2023, photograph by author

Food production-agriculture

Agriculture, water and soil have always been fundamental to life on the island of Crete, sustaining its inhabitants and supporting their activities. (Koutroulis et al., 2013). However, the spaces of what is considered non-urban on the island have been continuously operationalized to support the human processes throughout the history of capitalist unequal development that have exhausted the land leading to land and soil degradation, pollution, and water depletion. (Koutroulis et al., 2013; Boscov-Ellen, 2016). This has resulted in more and more land, less suitable for large-scale agriculture, being abandoned (Erle C. Ellis., 2014) outside of cities, creating undefined spaces that discontinue the infrastructural and urban system. What causes this exploitation of land, is the need for intensification of agricultural production, in areas next to the cities to support the increasing native and tourist population of the island.

At the same time, due to the rapid pace of urbanization on the island, environmental challenges have emerged, including pressure on water resources, and extreme weather events, posing significant threats to food security, especially concerning water availability and soil quality. Agriculture withdraws approximately 78 per cent of the total water use from rivers, lakes and underground sources through irrigation systems, an amount that nowadays, cannot always be met. Making the required amount of water available on the island is only possible in many cases through the dam creation, diversion of rivers and extensive water resource over-exploitation with consequences such as drop of the groundwater level in some places and salinity intrusion in the aquifers, often destroying the ecosystems that make agriculture possible. As a result, embracing regenerative agricultural practices and efficient water management becomes increasingly critical for ensuring food security and environmental resilience on the island.

Figure 22: Gra Lygia region, Ierapetra, greenhouses and Bramiana dam, Southern coast, Google Earth image

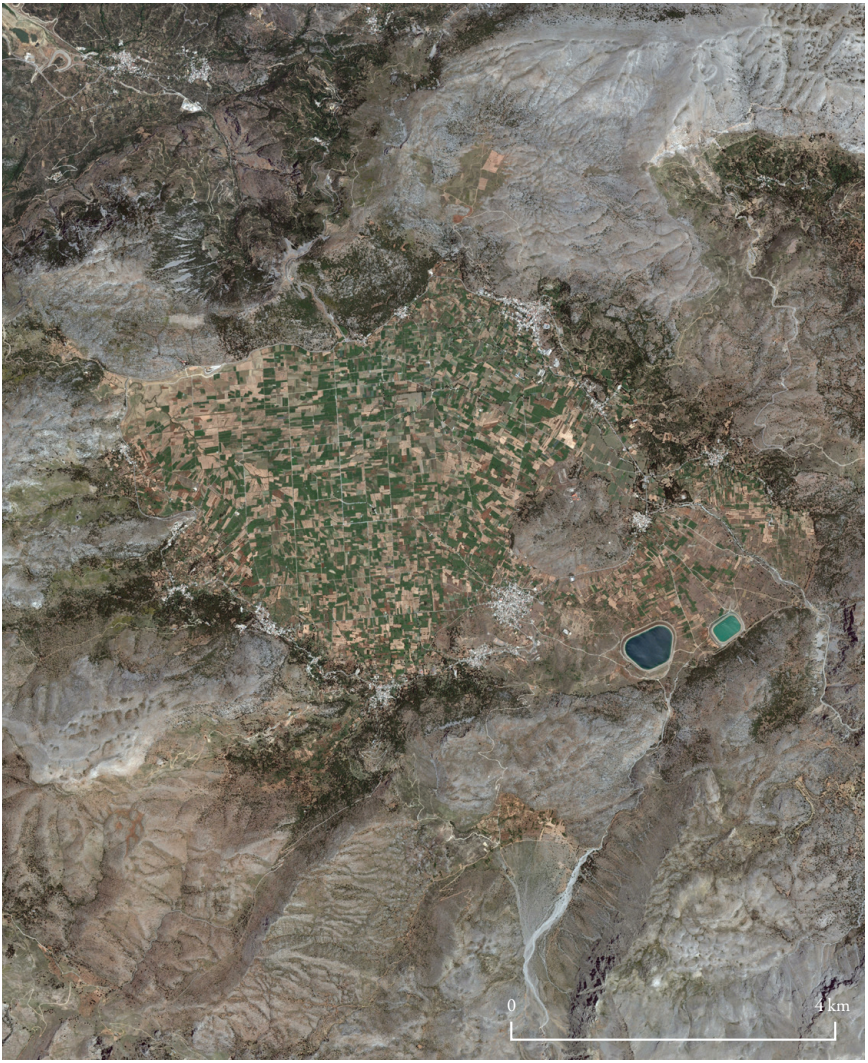


Figure 23: Lasithi plateau, agriculture and water reservoirs, Google Earth image

Figure 24: Lasithi plateau, agriculture and water reservoirs, 2023, photograph by author

Figure 25: Greenhouses and agriculture along Anapodaris river, Southern coast, Google Earth image

Figure 26: West coast, Falasarna, greenhouses, photograph by author

Tourism

Over the years, tourism has become a significant driver of the economy on the island of Crete, influencing urbanization and infrastructure development. According to the Hellenic Statistical Authority, tourism accounts for over 25% of Crete's GDP and employs a substantial portion of the island's workforce. While this economic boom has led to the establishment of critical infrastructure, particularly in the northern coastal areas, it has also created an evident fragmentation in development between the northern and southern parts of the island. Coastal regions, such as Heraklion and Chania, which experience the highest influxes of tourists, tend to urbanize more rapidly compared to the inland or mountainous areas like Sfakia and Anogeia. These inland regions maintain a distinct socioeconomic and relatively self-sustained community identity, often centered around agriculture and traditional crafts. This uneven development has exacerbated environmental degradation, with the overbuilt coastal areas suffering from increased pollution, loss of natural habitats, and strain on local resources. For example, recent studies on the water-tourism nexus in the Mediterranean have shown significant increases in water consumption and waste production in tourist-heavy areas, leading to the depletion of freshwater resources and challenges in waste management. (Ricart Casadevall, S, et al., 2023) Additionally, the construction of large-scale resorts and other tourist facilities often involves the destruction of coastal ecosystems, including sand dunes and wetlands, which are vital for biodiversity and coastal protection. The rapid urbanization driven by tourism threatens to erode the island's cultural and ecological integrity. Traditional farming practices and local customs are often sidelined in favor of tourist-oriented developments, causing a loss of cultural heritage and community cohesion. To address these issues, there is a pressing need for a more balanced approach to development that respects both the northern and southern regions of Crete. Sustainable tourism practices, such as eco-tourism and the promotion of local products, can help mitigate environmental impacts and support the preservation of the island's cultural identity. Implementing comprehensive regional planning and environmental regulations can ensure that tourism contributes to the island's economy without compromising its ecological and cultural heritage.

Figure 27: Vai, palm forest, Eastern Crete, Source: *photography-Κλαίρη Μουσταφέλλου, https://www.kathimerini.gr/k/travel/973523/afieroma-kriti-600-paralies-me-mia-matia/*

Figure 28: Gouves, tourism, Northcentral coast, Google Earth image

Climate changes
Wildfires, Seasonal Variability, Drought, Floodings, Fresh water scarcity, Groundwater Depletion, Extreme weather events, Sea level rise

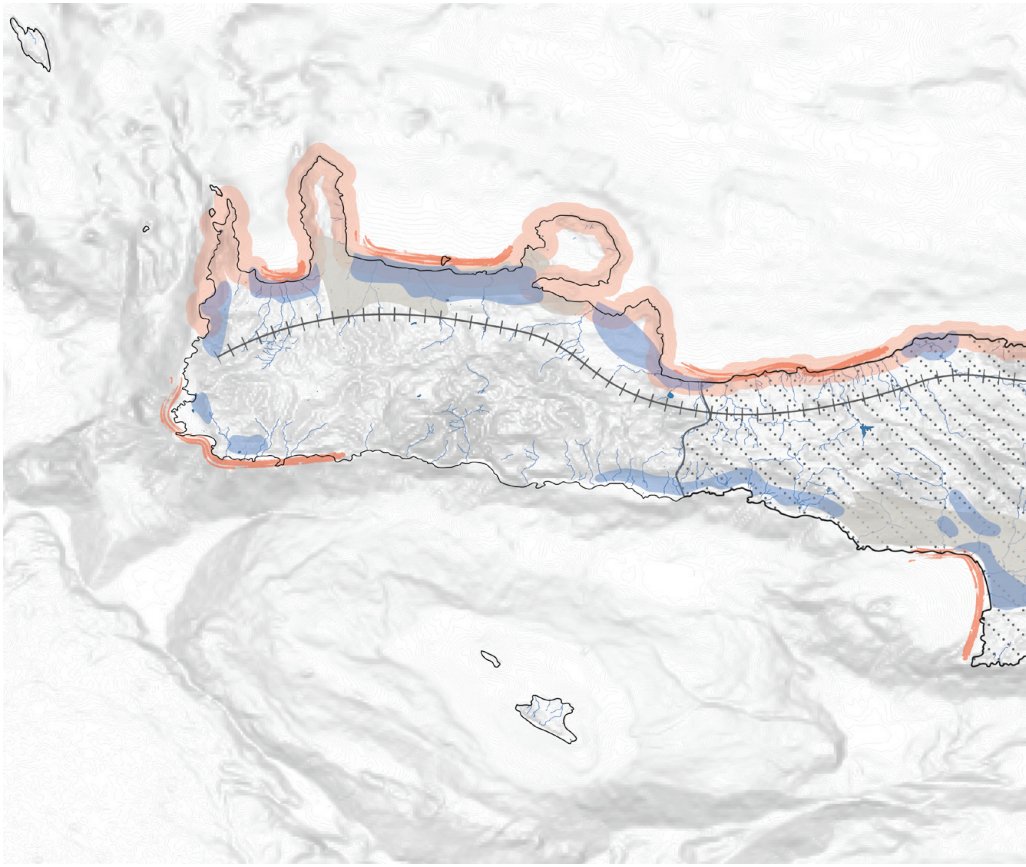
Climate change is challenging the island's resources, including water, soil, and forests with a series of threatening phenomena such as wildfires, freshwater scarcity, flooding, and sea level rise. Wildfires are becoming more frequent and intense due to increased temperatures and extended drought periods, destroying forest ecosystems and biodiversity. Seasonal variability intensifies the risks, leading to unpredictable fire seasons and continuous reduction of forest cover increasing the water runoff and causing soil erosion and landslide. (Εκπαίδευσης, n.d.)

Furthermore, climate change is pressurizing water resources by altering hydrologic cycles and systems, affecting both the intensity and frequency of flooding and drought incidents, water availability and water quality (temperature and nitrate concentration, etc.)(Environment Agency, 2007). Drought events which are intensified by altered precipitation patterns, are decreasing water availability for human activities. More specifically, in the semi-arid areas, the current conditions of intense evaporation and relatively low and less frequent rainfall, combined with the expansion of irrigated areas, limit the possibility of renewing their water capacity, resulting in water scarcity conditions, especially during the dry seasons, and cause damage to infrastructure and agricultural production. Moreover, groundwater over-extraction and salinity intrusion further reduce freshwater resources. However, scarcity not only affects human populations but also has catastrophic impacts on ecosystems, resulting in habitat and biodiversity loss. On the other hand, more frequent and severe floodings, due to the increased water runoff during winter are causing damage to infrastructure, agricultural production, and natural habitats. Another important threat to the island is coming from the sea, with sea level rise, driven by melting ice sheets and thermal expansion, increasing the risk of coastal erosion, flooding, and saltwater intrusion into freshwater resources. Consequently, all these changes can have serious impacts on socio-economic and environmental systems and activities on the island. (Εκπαίδευσης, n.d.)

Figure 29: Wildfire, Apokoronas-Vrises, Crete, 2018 source: *https://radiolasithi.gr/dyo-oi-megales-pyrkagies-stin-kriti-kaikan-ktismata-anthropoi-sto-nosokomeio/*

Figure 30: Flooding, Municipality of Hersonissos, 2020. source: *https://www.dailymail.co.uk/news/article-8933793/Raging-rivers-mud-sweep-towns-villages-Crete-wrecking-hundreds-homes.html*

Figure 31: Navigating the Complex System of Environmental, Cultural, and Socioeconomic Challenges in Crete, designed by author


0
25
50 km

Saturated touristic zone
(Northern coast)

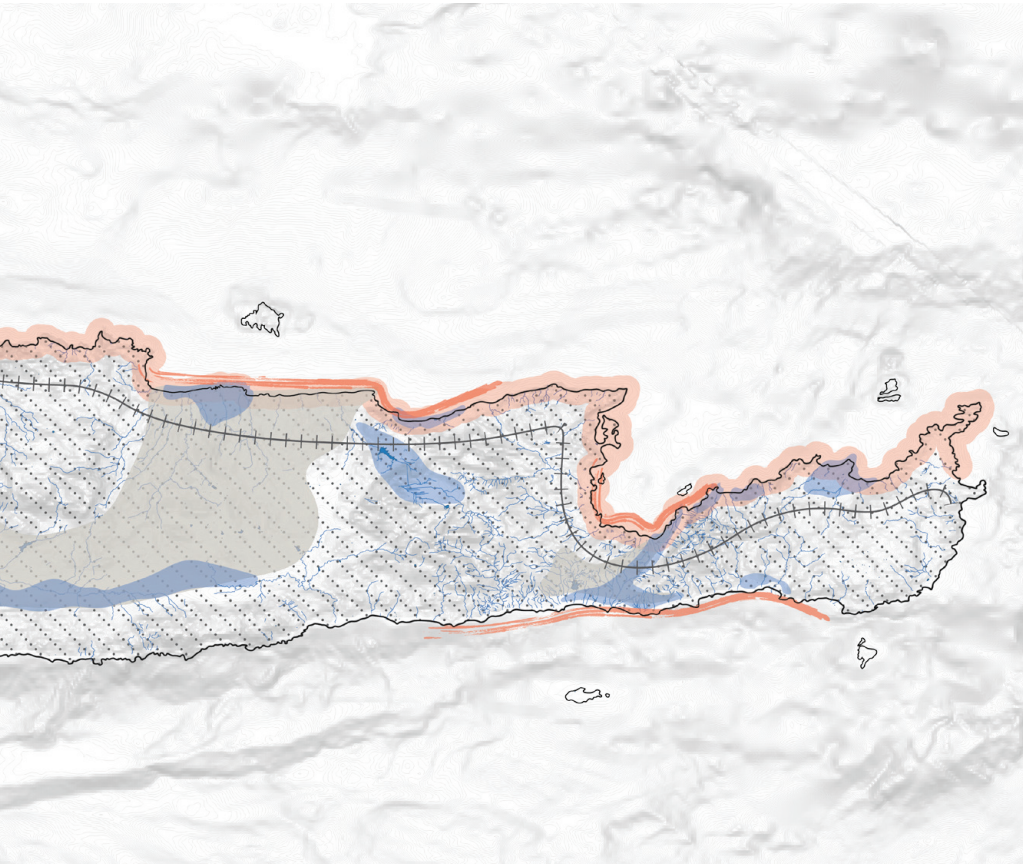
Fragmented areas
(Northern coast - inland)

Flooded areas mapped on
18/11/2020

Agricultural land

High wildfire risk areas
24/07/2023 -emergency state

Flood and desertification
risk zone



Diagnosis

Hypothesis

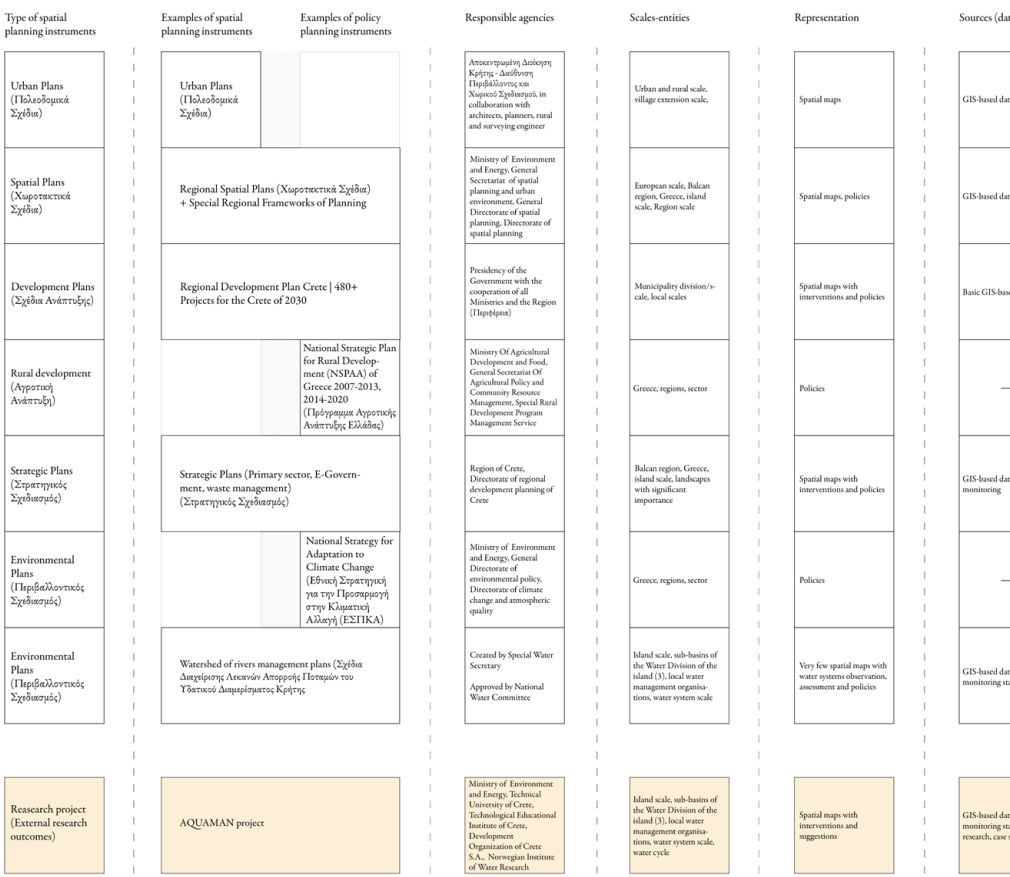
The island of Crete will face increasing water and climate challenges in the coming decades, threatening its systems, resources, inhabitants, and ecosystems. By studying and integrating traditional water management practices, such as ancient irrigation techniques and land terracing used by indigenous communities, spatial planning can restore the balance between habitation and essential systems like agriculture, water management, and natural ecosystems. Through the lens of water scarcity and excess, this approach will address climate challenges and enhance adaptive transformation, fostering resilience and preparedness for Crete.

Diagnosis of the current planning instruments

The thesis aims to criticise the current planning instruments used in Greece, highlighting their limitations in representing the dynamic nature of environmental processes, altered nature and human activities. By emphasizing the linear approach to current design and planning, as well as the static and constraining representation of space, water, and soil, it emphasises the need for a more flexible and radical approach which is essential for ensuring sustainable development and resilience in the face of changing conditions. Furthermore, it repositions the current planning methods and advocates for exploring alternative ways of understanding and addressing spatial and environmental challenges.

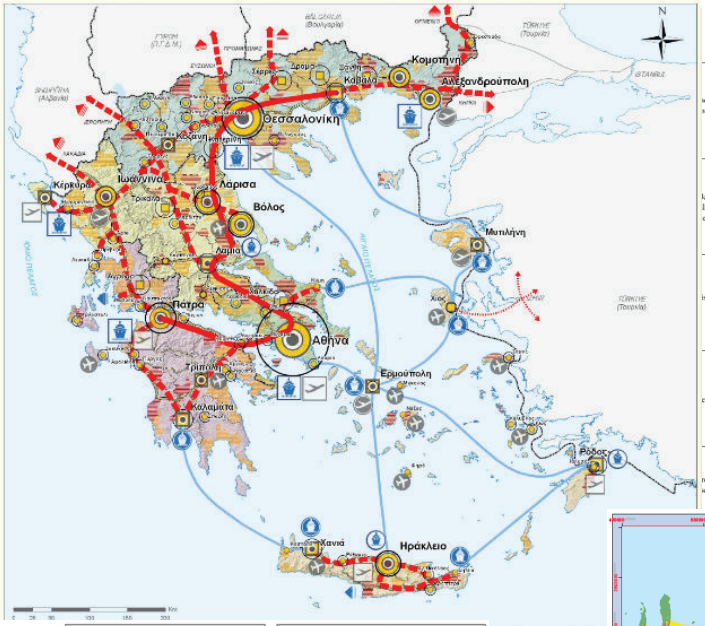
The thesis proposes a particular case study to demonstrate this alternative approach allowing for a concrete exploration of how these principles can be applied in space and time with respect to hydrogeomorphological variations and cultural heritage. Furthermore, the project advocates for a more community-inclusive approach by giving more voice, power, and responsibilities to local communities, recognizing the importance of bottom-up involvement in caring for and shaping their surroundings. It also allows for diverse perspectives and local knowledge to inform decision-making processes.

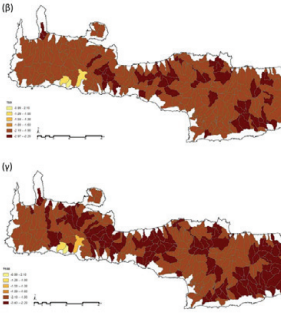
Overall, it presents a clear argument for rethinking planning and design methods in Greece and beyond to restore a balance between natural and human ecosystems.


Type of spatial planning instruments
Examples of spatial planning instruments
Examples of policy planning instruments
Responsible agencies
Scales-entities
Representation
Sources (dat
Urban Plans (Πολεοδομικά Σχέδια)
Urban Plans (Πολεοδομικά Σχέδια)
Αποκεντρωμένη Διοίκηση Κρήτης - Διεύθυνση Περιβάλλοντος και Χωρικού Σχεδιασμού, in collaboration with architects, planners, rural and surveying engineer
Urban and rural scale, village extension scale,
Spatial maps
GIS-based dat
Spatial Plans (Χωροτακτικά Σχέδια)
Regional Spatial Plans (Χωροτακτικά Σχέδια) + Special Regional Frameworks of Planning
Ministry of Environment and Energy, General Secretariat of spatial planning and urban environment, General Directorate of spatial planning, Directorate of spatial planning
European scale, Balcan region, Greece, island scale, Region scale
Spatial maps, policies
GIS-based dat
Development Plans (Σχέδια Ανάπτυξης)
Regional Development Plan Crete | 480+ Projects for the Crete of 2030
Presidency of the Government with the cooperation of all Ministries and the Region (Περιφέρεια)
Municipality division/scale, local scales
Spatial maps with interventions and policies
Basic GIS-bas
Rural development (Αγροτική Ανάπτυξη)
National Strategic Plan for Rural Development (NSPAA) of Greece 2007-2013, 2014-2020 (Πρόγραμμα Αγροτικής Ανάπτυξης Ελλάδας)
Ministry Of Agricultural Development and Food, General Secretariat Of Agricultural Policy and Community Resource Management, Special Rural Development Program Management Service
Greece, regions, sector
Policies
—
Strategic Plans (Στρατηγικός Σχεδιασμός)
Strategic Plans (Primary sector, E-Government, waste management) (Στρατηγικός Σχεδιασμός)
Region of Crete, Directorate of regional development planning of Crete
Balcan region, Greece, island scale, landscapes with significant importance
Spatial maps with interventions and policies
GIS-based dat monitoring
Environmental Plans (Περιβαλλοντικός Σχεδιασμός)
National Strategy for Adaptation to Climate Change (Εθνική Στρατηγική για την Προσαρμογή στην Κλιματική Αλλαγή (ΕΣΠΚΑ)
Ministry of Environment and Energy, General Directorate of environmental policy, Directorate of climate change and atmospheric quality
Greece, regions, sector
Policies
—
Environmental Plans (Περιβαλλοντικός Σχεδιασμός)
Watershed of rivers management plans (Σχέδια Διαχείρισης Λεκανών Απορροής Ποταμών του Υδατικού Διαμερίσματος Κρήτης
Created by Special Water Secretary
Approved by National Water Committee
Island scale, sub-basins of the Water Division of the island (3), local water management organisations, water system scale
Very few spatial maps with water systems observation, assessment and policies
GIS-based dat monitoring st
Reasearch project (External research outcomes)
AQUAMAN project
Ministry of Environment and Energy, Technical University of Crete, Technological Educational Institute of Crete, Development Organization of Crete S.A., Norwegian Institute of Water Research
Island scale, sub-basins of the Water Division of the island (3), local water management organisations, water system scale, water cycle
Spatial maps with interventions and suggestions
GIS-based dat monitoring st research, case

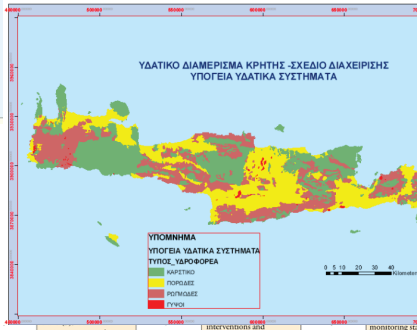
asets)	Legends (subjects)				Outcomes	Date	Link
	• Administrative Boundaries • Physical geographic data – sea – coast – core – beach – spring gorge – significant geological formation • Transportation Infrastructure – main road network – secondary road network – port – small port-marina – airport	• Fishing shelter • Water treatment plant • Landuses – E4 reed – E5 maquis – dams (+under construction) – quarries – forests – natural protected areas (Natura 2000) – archaeological site – villages – village boundaries (+proposed) – excessive proposals	– industrial zone – areas of special natural environmental protection – monasteries – concentrated location of archaeological interest – church-monastery – camping spots – cemetery – proposed educational facilities – sport facilities – green space – general rezoning – redevelopment of a residential area	——	Spatial plans	Ημερομηνία Τροποποίησης: 2021-07-30 Ημερομηνία δημοσίευσης: 2015-03-21	https://data.apdkrits.gov.gr/dl/data-sets/%CE%B3%CF%80%CF%83-%CF%B4%CF%87%CE%BF%CF%80%CE%B9%CF%83%CE%BC%CE%BF%CE%B8%CE%B5%CF%83%CE%B9%CF%82%CE%A3%CF%83%CE%BC%CF%8E%CF%84%CE%BF%CF%8-2-%CE%B9%CE%B5%CF%81%CE%A3%CF%8D%CE%B9%CF%84%CF%8E%CE%BD%CF%82
	• National Boundaries • Regional Boundaries • Maritime border of the EU27 • External borders of the EU • Economic concentration • Distribution traderoutes • Axis of Mediterranean Cooperation • Administration axes of Greece • Capitals • International land-tourist development axes, connexions • Areas of development (urban, etc.) • Urban centers • Population concentration • Island regions	• Regulatory plan boundaries • Municipal boundaries • Regulatory axes for development of activities (tourism, environmental, primary sector) • Physical geographic data – sea – coast – lakes – elevation • Transportation infrastructure – main road network – secondary road network – international port – small port-marina – international airport – train network	• Dams • Significant risk zones (potentially high flood risk) • Important productive activities – Primary agricultural land – industrial zone (+spatial directions) – mining area • Major energy nodes • Natural/Cultural heritage – Natural heritage – Coniferous, broadleaf and mixed forest – Monuments and archaeological sites – Wetlands – natural protected areas (+Natura 2000) – traditional villages	– Landmarks/landscapes of (natural/cultural) touristic cultural interest of National/International importance – Highly visited coastal areas – Areas in need of particularly degraded landscapes • Major power generation/distribution units – existing network stations – wind farms • Concentration of production units from vulnerable sources • Functional dependencies between settlements • Sustainable development models • Zones of urban activity development • Categorization of aquaculture development areas	Spatial plans and policies	Created on 2011	https://ypen.gov.gr/chorikos-schediasmos/choreotaxia/ethniki-politiki/
	• Municipality boundaries • Urban centers • Towns • Villages • Projects (completed, under developmenig, recurring) • Transportation Infrastructure – main road network – secondary road network – international port – small port-marina – international airport – train network	——	——	——	Very few spatial plans and policies, Intervention, infrastructure proposals/actions	Presented on 30/01/2023	https://www.ebrc.gr/anakoinoseis-reader/perifereiakio-schedio-anaptyxis-kritis-480-erga-gia-tin-kriti-toy-2030.html
	——	——	——	——	Policies, funding (support farmers, collaborations)	2007-2013, 2014-2020	https://ypen.gov.gr/perivallon/dasi/programma-agrotikis-anaptyxis-tis-elladas-2007-2013/
	• Main development axes of Crete • International sea connections • Transportation networks – main road network – secondary road network – port – small port-marina – airport • Urban centers • Main function interdependencies • Urban center population • Industry-related functions • Municipality boundaries	• Natural-historical-cultural areas – Natura 2000 network – Unesco areas – wetlands • Monuments with international and national significance (tourism, culture) • E4 reed • Tourism • Agriculture-structure • Mineco-structure • archaeological site • ferries • Extensive vulnerable to threats areas • Spatial units of particularly degraded landscapes+++	• Highly visited coastal areas • Regional unit boundaries • Municipal unit boundaries • Spatial units of particularly degraded landscapes • Significant risk zones (potentially high flood risk) • Coastal zones of urban tourism development and quality / environmental upgrading • Coastal control zones for residential tourism development and quality / environmental upgrading due to the restricted development and promotion of cultural and natural resources	• Areas for agricultural land zone utilization (spatial structure of primary sector) • Important areas of productive activities • Industrial facilities • Relationship between agriculture, settlements, population and elevation • Agricultural land • Ports (existing, proposed) • Precipitation levels • Sea level rise vulnerable areas • Erosion-vulnerable areas • Differentiated zones in terms of socio-economic pressures	Basic spatial plans, charts (numerical data), tables, observations	Created on 2020	https://www.crete.gov.gr/stratigikos-xrisimos/
	——	——	——	——	Policies (for different sectors), framework, tables (+numerical data)	Created on April 2016	https://ypen.gov.gr/perivallon/klimatiki-allagi/prosarmogi-stin-klimatiki-allagi/
	• Water divisions of Greece • River water systems • River water system types • Coastal water systems • Lentic water bodies of the island • Regional Units of the island • Municipalities of the island • Hydrobiological map of the island • Agricultural areas • Forest and semi-natural land • Water bodies • Water management • Island's topography • Groundwater systems of the island • Lygaro dam's inflowmation (zero tables)	• Vulnerable zones from nitrate pollution of agricultural origin of the island • Natura 2000 network • Water treatment facilities • UM pres-facilities • Landfills • Quarries-quarries • Hydrol water withdrawals stations • Lagoro gulf-fields • Withdrawal volume at sub-basin level (coral, for oil press, for fresh water, for irrigation, for industrial use) • Pressures on the underground water system of the island	• Main brakish springs of the island • Inundation zones of the island • Ecological status and potential in the surface water systems • Ecological status and potential in the coastal water systems • Assessment of the quality status of the underground water systems • Existing surface water monitoring stations • Existing groundwater monitoring stations • Irrigation and fresh water network for the regions of Chania and Rethymno	——	Very few spatial plans, charts (numerical data), tables, policies	Approved on 2015	https://wfdverype-ka.gr/el/management-plans-gr/approved-management-plans-gr/gr13-approved-gr/
	• Water Exploitation Index values for the basins of Crete (+difference scenarios) • Rivers • Drought indexes, per sub-basin (as part of climatic simulations) (SPI12, SRI12, SPEI12) • Extreme precipitation frequency analysis under climate change for study basins using GEV distribution for different climate periods per sub-basin (past and future) • Mean annual change of hydrological drought per sub-basin • Relative percentage change of flooding per sub-basin (future projection) • Extreme precipitation frequency under climate change for study basins using GEV distribution for different climate periods per sub-basin (past and future)	• Extreme precipitation frequency analysis under climate change for study basins using GEV distribution for different climate periods per sub-basin (past and future) • Precipitation and temperature measurement stations • Distribution of average annual rainfall in Crete, as obtained from corrected and completed measurements data • Division of Crete into 1562 basins using ArcHYD • Land use distribution map of Crete for the OSOZ model • Coastline of Crete • Land use • Agriculture • Big Basins	• Inland Water • Water • Residential-High density • Apple tree • Inland Flow • Olives • Olive • Potato • Vine • Corn • Pasture • Soil distribution map for the SWAT model and Layer areas from the geological map of Crete • Lithological units from the 1:50.000 geological map • Resource supply-measuring stations • River supply-measuring stations (surface)	• Water extraction by sub-basin (coral irrigation from shallow, deep aquifers and springs) • Spatial distribution of SPI3, SPI12, SPI6, SPI24, SPI12, SPEI12 index values for September 2007 • Spatial distribution of SRI3, SRI6, and SRI12 index values for September 2007 • Hydrological drought frequency analysis (SRI index) for study basins using GEV distribution for (4.50, 100 years • Meteorological drought frequency analysis (SPI index) for study basins using GEV distribution for (4.50, 100 years • Historical flood events and zones prone to flood risk • Flood frequency analysis for study basins using GEV distribution for (4.50, 100 years	Spatial plans, charts (numerical data), tables, observations, simulations	Completed in February 2017	https://oakae.gr/anaptyxiaka-ergasies/crevnitika-programmata/aquaman-crevnitiko-programma-gia-tis-ydatikes-dynamikes-kritis/
	• Precipitation frequency analysis for study basins using GEV distribution for (4, 50, 100 years • Dams • Lakes • Irrigation and fresh water network for the eastern part of Crete • Fresh water network for the eastern part of Crete • Average annual hydrological balance • Climate change scenarios for (2020-2050) (2070-2100) • Water deficit to cover irrigation requirements for agriculture • Groundwater systems (karstic, porous, cracks, gypsum)	• River basins of the island Regional Units of the island •	——	——			

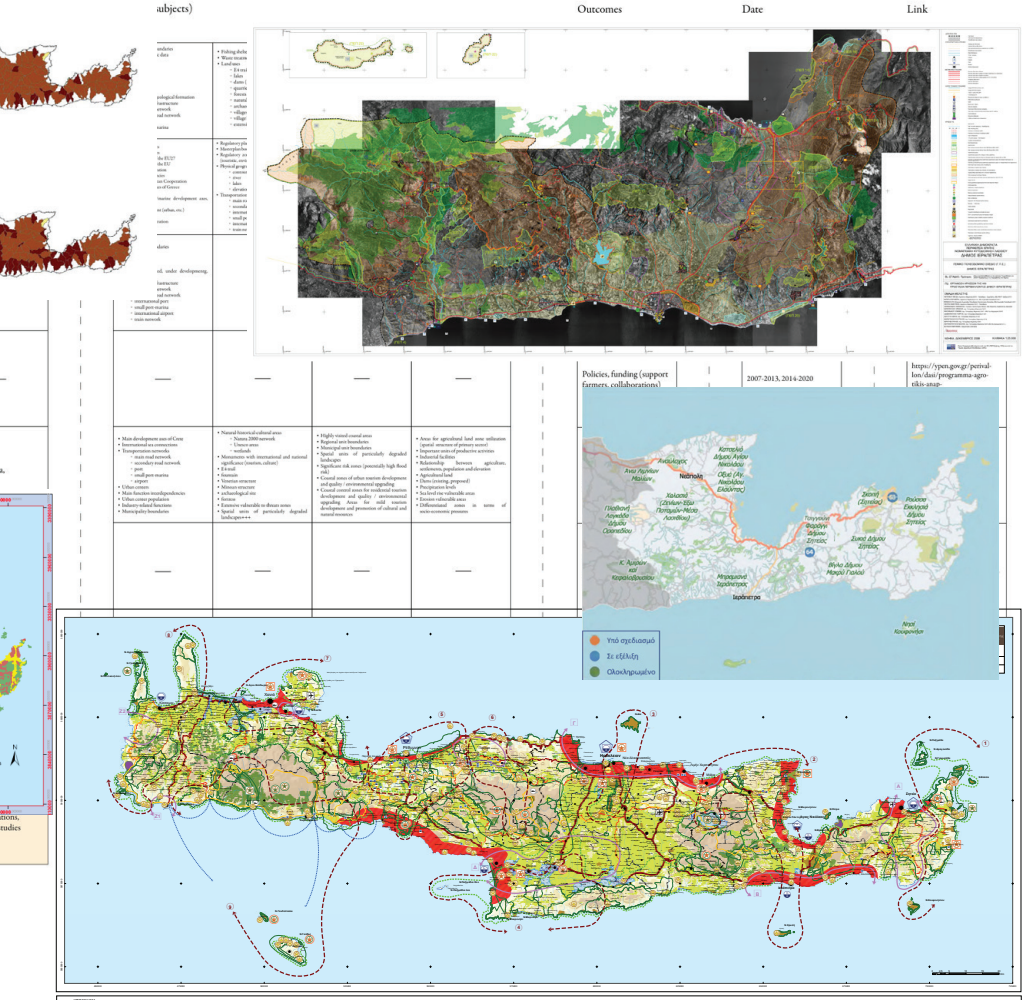
Figure 32: Selection of planning instruments in Greece / Crete, designed by author





	2020-2059	2060-2098
Ευνοϊκό	P=6570Mm³ ET=2590Mm³ I=340Mm³ Q_{apt}=895Mm³ Q_{tot}=2100Mm³ Έλλειμμα=16.9Mm³	P=6895Mm³ ET=2640Mm³ I=340Mm³ Q_{apt}=950Mm³ Q_{tot}=2270 Mm³ Έλλειμμα=16.5Mm³
Ενδιάμεσο	P=5663Mm³ ET=2500Mm³ I=350Mm³ Q_{apt}=700Mm³ Q_{tot}=1620 Mm³ Έλλειμμα=21.6Mm³	P=5518Mm³ ET=2490Mm³ I=360Mm³ Q_{apt}=695Mm³ Q_{tot}=1560 Mm³ Έλλειμμα=27.4Mm³
Δυσμενές	P=6090Mm³ ET=2540Mm³ I=350Mm³ Q_{apt}=800Mm³ Q_{tot}=1870 Mm³ Έλλειμμα=19Mm³	P=4580Mm³ ET=2390Mm³ I=370Mm³ Q_{apt}=545Mm³ Q_{tot}=1195 Mm³ Έλλειμμα=48.1Mm³



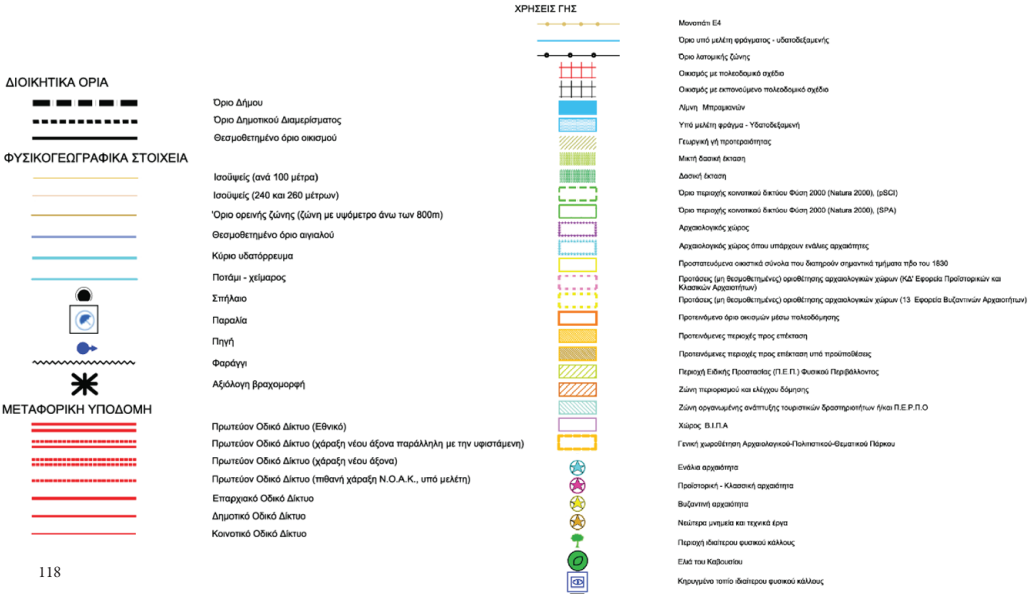


Selection of planning instruments in Greece / Crete, designed by author

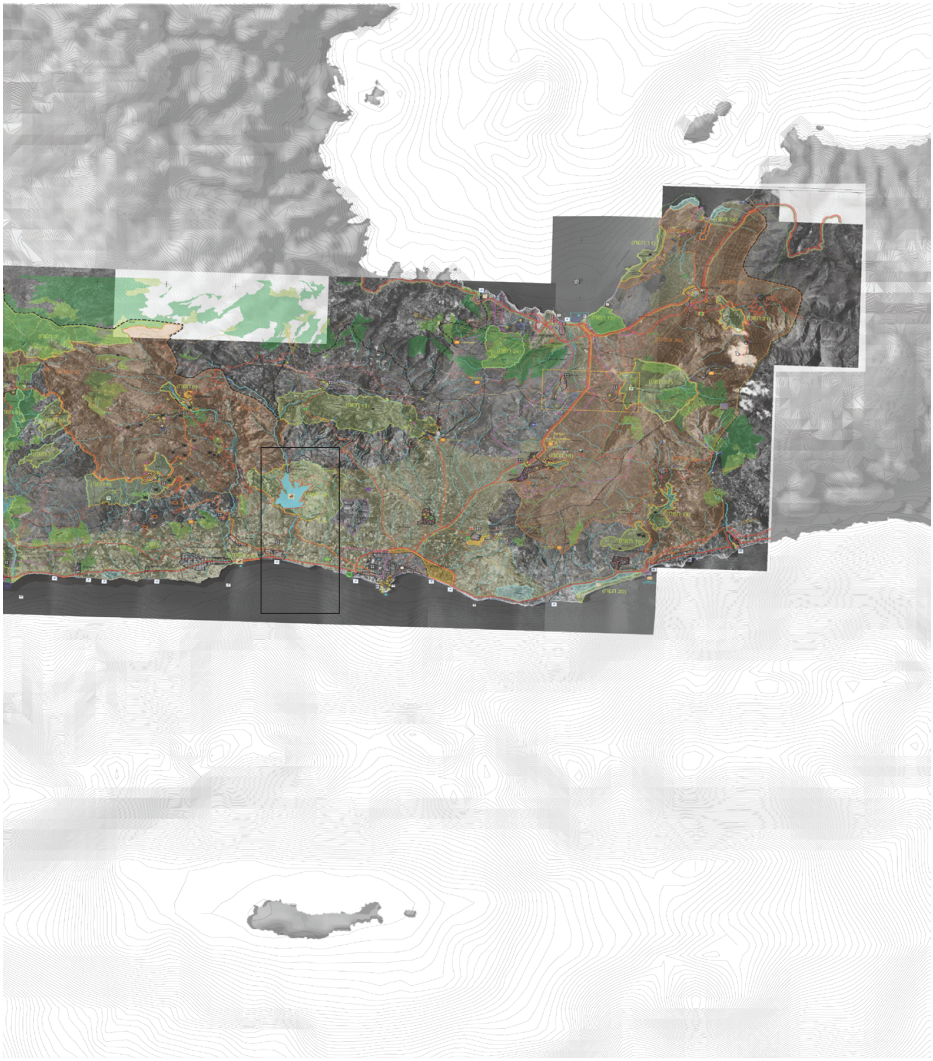
Representation of Dynamic Environmental Processes such as Space, Water, and Soil

The existing planning mechanisms in Greece tend to adopt a linear and non-flexible approach, which fails to represent the dynamic and interconnected nature of environmental processes and elements such as water and soil that are necessary for human activities and ecosystems. Specifically, these plans often impose strict boundaries and non-flexible, superficial land use categories that do not reflect the dynamic character of these spaces, undermining the ability of the island to adapt human activities to changing environmental conditions.

Furthermore, current plans do not sufficiently integrate the latest climate simulations and projections, leading to insufficient preparedness for long-term climate changes and extreme weather events. This results in the absence of adaptation to altering hydrological patterns and geomorphological transformations, compromising water management and increasing vulnerability to flooding and freshwater scarcity. Moreover, the static representation of water systems does not showcase the temporality, seasonal variations, and long-term changes in water availability and quality, resulting in ineffective water management strategies.



Existing urban plan for the
Isthmus of Ierapetra



0 5 10 km

Diagnosis through the lens of water scarcity - excess

The process of the Diagnosis and understanding of the closed system that is called the island of Crete is analysed from two perspectives: that of the complete island as a system and the elements that it is comprised of, and then the diverse and important cultures and heritage that have inhabited and inhabit the island.

The island view explores and analyses the topography, biophysical processes, and water as an element and their interdependencies and connections through a series of cartographies, whereas the culture's view studies the indigenous knowledge and practices related to water use, water scarcity and excess, the societal component, the agricultural practices, and the life of the inhabitants of Crete through time.

The project, through the diagnosis chapter, develops a comprehensive analysis of the island's territorial features, including natural landscapes, water resources, soil types, and existing human settlement patterns and agricultural practices. The main goal of this chapter is to illustrate the spatial distribution of these elements and identify areas of vulnerability and opportunity on the island.

Island

Crete, as an island, receives water only from precipitation (rain, hail, and snow), and its location and geomorphology do not favour large surface water volumes (Water Resources Management Plan, 2015; Ioannidou, n.d.). Thus, there are regions, mainly the coastal and eastern ones, that suffer from a significant water imbalance due to the uneven temporal and regional distribution of precipitation. This situation is intensified by the particularly high water needs for irrigation and water consumption due to tourism, especially during the summer months, and the difficulty of transporting water due to the mountainous terrain. Most of the annual precipitation occurs in the western mountains of Crete. (Wageningen University & Research Designing Systems for Informed Resilience Engineering, n.d.) It is estimated that water consumption in Crete has increased significantly in the last few years, and most of the total water consumption is used in agriculture for irrigation.

The first contribution of this thesis is the creation of a comprehensive and detailed cartography of the fundamental systems of the island of Crete, highlighting their interdependencies and identifying areas for improvement.

Karst formations

Crete has extensive karst topography, which is characterized by limestone formations, sinkholes that occur when rainwater dissolves the crystalline limestone common to most of the island's mountains, caves, and large networks of underground rivers and streams. Karstic landscapes perform two important functions: they store significant amounts of water from precipitation and also redistribute rainwater and direct the flow of groundwater throughout the island, creating springs and oases. (Houseman, L., 2013)

One highly visible effect of this karstic landscape is the abundance of caves and cavities on the island. (Speleologists have estimated that there are at least 2,000 caves and cavities in the Cretan terrain.)

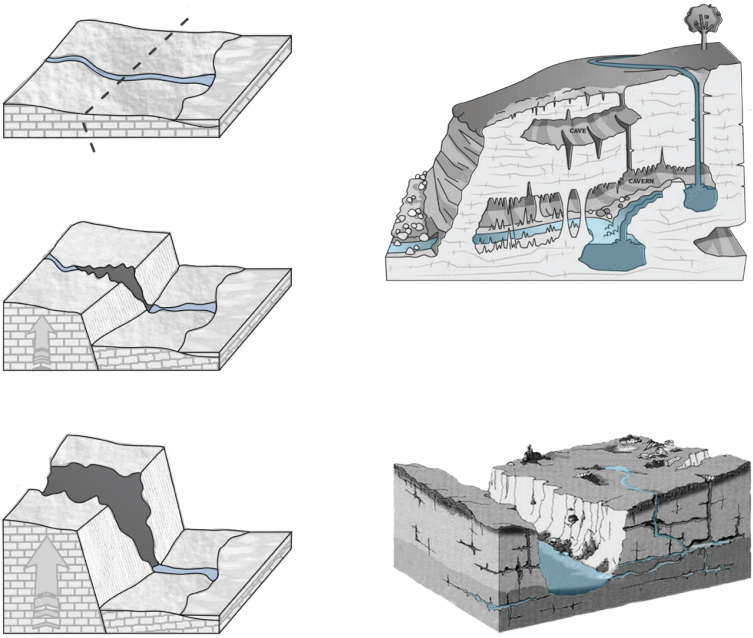


Figure 33: Cretan karstic landscape, adapted from *https://www.istockphoto.com/*, *https://www.sfakia-crete.com/*

Alluvial formations

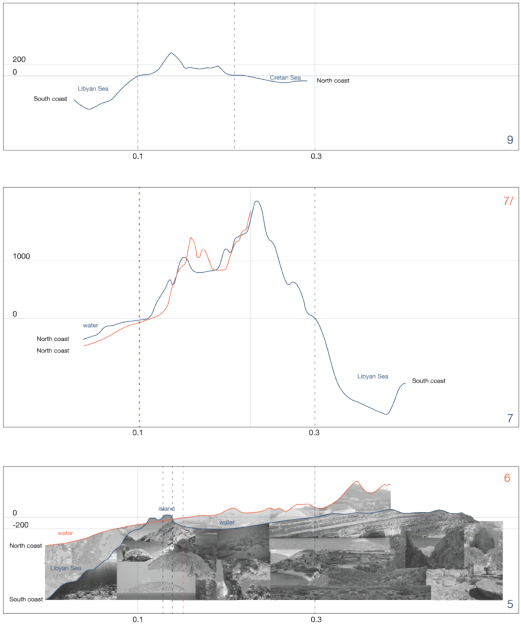
Previous studies on the island and in generall in the Mediterranean region, show that the construction of Quaternary alluvial terraces and fans is linked with climate fluctuations. Also, human land use and vegetation cover have been influencing sediment dynamics and alluviation patterns, and the eastern Mediterranean has been central to the investigation of the interplay between climate fluctuations, long-term tectonic processes, and anthropogenic activities. Most Cretan alluvial deposits share common features in fields such as stratigraphy and sedimentology. Alluvial fan and terrace formation is traditionally reflecting a fluvial system response to Quaternary climate variations influenced by slow and long tectonic processes. (Bruni, E. T., Ott, R. F., Picotti, V., Haghipour, N., Wegmann, K. W., & Gallen, S. F., 2021)

Coastal landform diversity

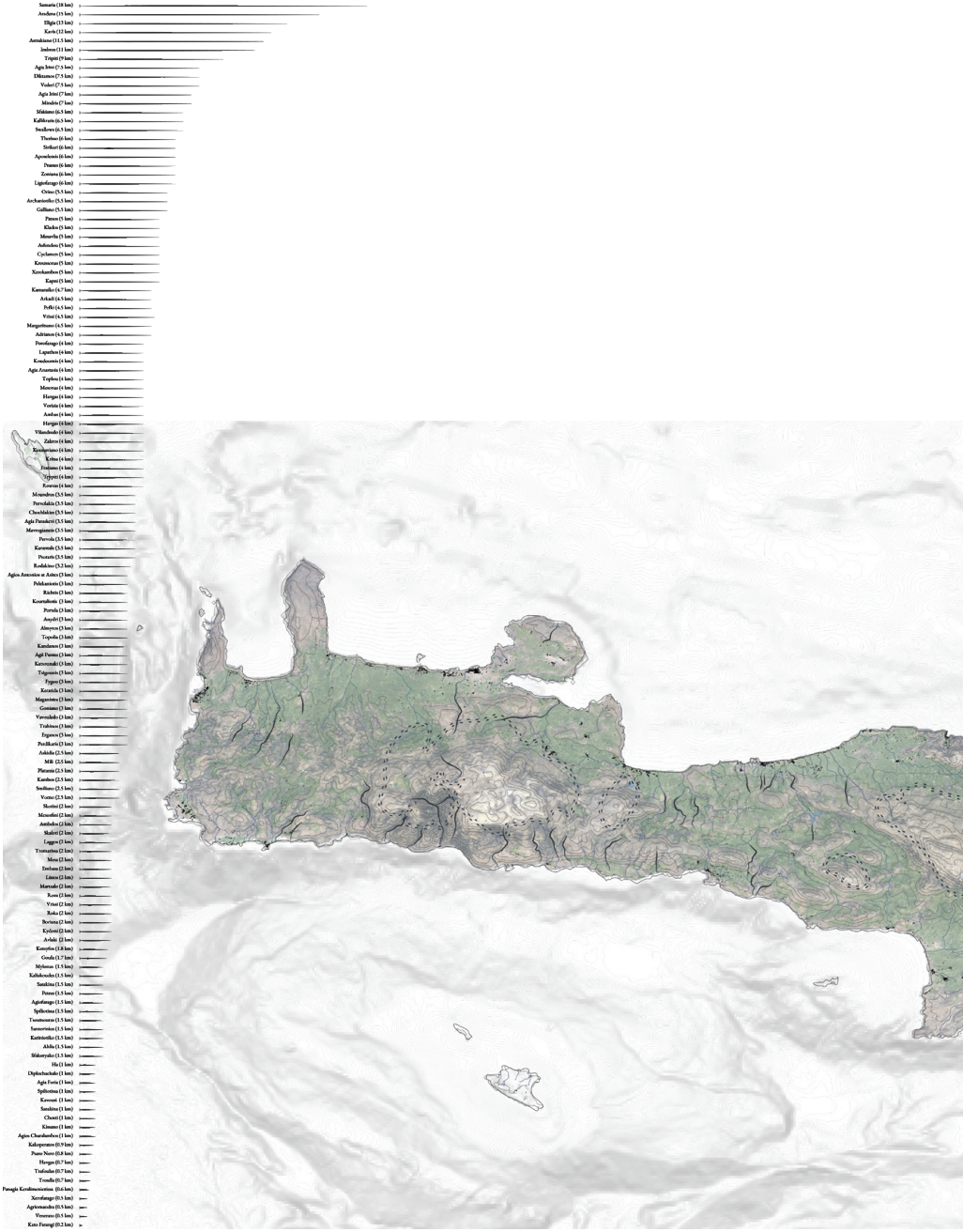
Crete's coastal zones display a unique diversity in terms of geography, climate, tourism, environmental sensitivity, and cultural features. They are characterized by a diverse range of landforms, including sandy beaches, rocky cliffs, and coastal caves formed by coastal erosion. The total length of the coastline is 1.046 km.

The northern coast, characterized by sandy beaches and milder Mediterranean climate, is heavily developed, concentrating the largest cities and facing greater vulnerability to the impacts of mass tourism, such as erosion and pollution. In contrast, the southern coast features numerous sandy beaches, dramatic cliffs and arid landscapes exposed to African climate influences, characterized by unique flora and fauna adapted to harsh conditions offering a more undisturbed environment.

At the same time, we can identify contradictions between western and eastern part of the island. Eastern coast is characterized by gentle slopes, sandy beaches, and a Mediterranean climate compared to the western coast that is designated by rocky, dramatic terrain, and deep gorges.



Cretan coastline diversity, design by author

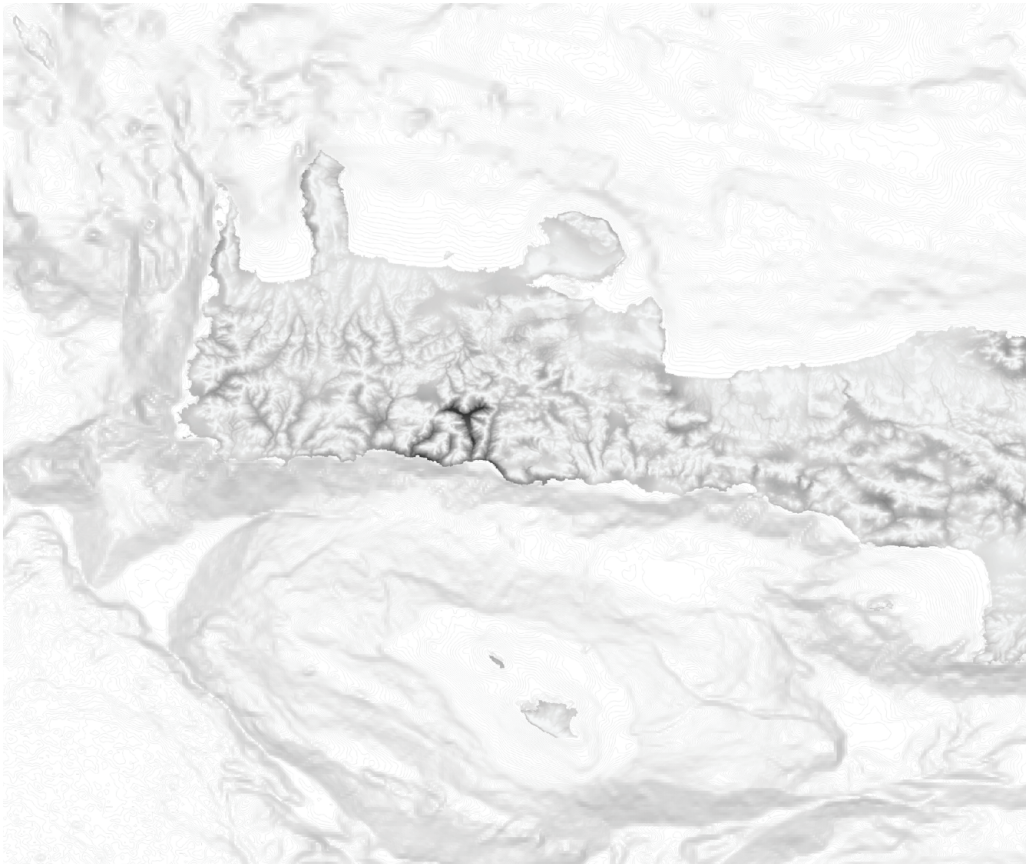

Samaria (18 km)
Aradena (15 km)
Tilgia (13 km)
Kavki (12 km)
Asteksinne (11.5 km)
Imbros (11 km)
Tripiti (9 km)
Agia Irini (7.5 km)
Diktaynna (7.5 km)
Vedari (7.5 km)
Agia Irini (7 km)
Miraleta (7 km)
Sfakiano (6.5 km)
Kallikratis (6.5 km)
Swedroni (6.5 km)
Thetsso (6 km)
Stelkari (6 km)
Ayeoeleusis (6 km)
Pranes (6 km)
Zoxiana (6 km)
Ligofaryga (6 km)
Orino (5.5 km)
Archanioniko (5.5 km)
Gallinos (5.5 km)
Panos (5 km)
Klados (5 km)
Monerfia (5 km)
Ardendos (5 km)
Cyclamos (5 km)
Kouneonas (5 km)
Xerokambos (5 km)
Kapni (5 km)
Kamaraiko (4.7 km)
Arkadi (4.5 km)
Perki (4.5 km)
Vrisi (4.5 km)
Margaritimos (4.5 km)
Adrianos (4.5 km)
Potofango (4 km)
Lapathos (4 km)
Kouskouvis (4 km)
Agia Anastasia (4 km)
Tsyliva (4 km)
Meneraa (4 km)
Horiges (4 km)
Vortsia (4 km)
Ambas (4 km)
Horiges (4 km)
Vilanchodo (4 km)
Zakros (4 km)
Kyrsiporiano (4 km)
Xylos (4 km)
Elatiano (4 km)
Vrysses (4 km)
Kavros (4 km)
Meandros (3.5 km)
Perivolakia (3.5 km)
Choulakian (3.5 km)
Agia Paraskevi (3.5 km)
Mavrogiannis (3.5 km)
Perivola (3.5 km)
Kastrosk (3.5 km)
Prestetis (3.5 km)
Rodakino (3.2 km)
Agios Antonios se Astro (3 km)
Pelekanionis (3 km)
Richtris (3 km)
Kourtaliotis (3 km)
Portelo (3 km)
Anydri (3 km)
Ateriros (3 km)
Topolio (3 km)
Kandanos (3 km)
Agii Pantes (3 km)
Karoxostado (3 km)
Tsigounis (3 km)
Pygros (3 km)
Keratitis (3 km)
Magassitra (3 km)
Gonitano (3 km)
Vavvelado (3 km)
Trahtsos (3 km)
Ergaroi (3 km)
Pseftkaris (3 km)
Askidia (2.5 km)
Mili (2.5 km)
Platanis (2.5 km)
Kambos (2.5 km)
Sivilianu (2.5 km)
Votto (2.5 km)
Skotini (2 km)
Messoliri (2 km)
Ambelos (2 km)
Skalotí (2 km)
Laggos (2 km)
Tzoumatias (2 km)
Mesa (2 km)
Embasa (2 km)
Limni (2 km)
Martsalo (2 km)
Xoxo (2 km)
Ymos (2 km)
Roka (2 km)
Bortsna (2 km)
Kolotsi (2 km)
Avlaki (2 km)
Kanyelio (1.8 km)
Gouda (1.7 km)
Mylonas (1.5 km)
Kalkalocudes (1.5 km)
Sanidina (1.5 km)
Petres (1.5 km)
Agiofanago (1.5 km)
Spiliotrina (1.5 km)
Tsoutsouras (1.5 km)
Saxoroviza (1.5 km)
Kastrinello (1.5 km)
Akiba (1.5 km)
Stalomylos (1.5 km)
Ha (1 km)
Diplochachaki (1 km)
Agia Foria (1 km)
Spiliotrina (1 km)
Kavrosi (1 km)
Sanidina (1 km)
Chomi (1 km)
Kinano (1 km)
Agios Charalambos (1 km)
Kalopetaton (0.9 km)
Psano Nero (0.8 km)
Horgas (0.7 km)
Trafoulas (0.7 km)
Troulli (0.7 km)
Panagia Kerakimenotissa (0.6 km)
Xerofango (0.5 km)
Agrioxarados (0.5 km)
Vrysseno (0.5 km)
Kato Fasagi (0.2 km)
0
25
50 km

Topography and gorges

River system

Contours per 1000m (island)
per 10m (sea)

Gorges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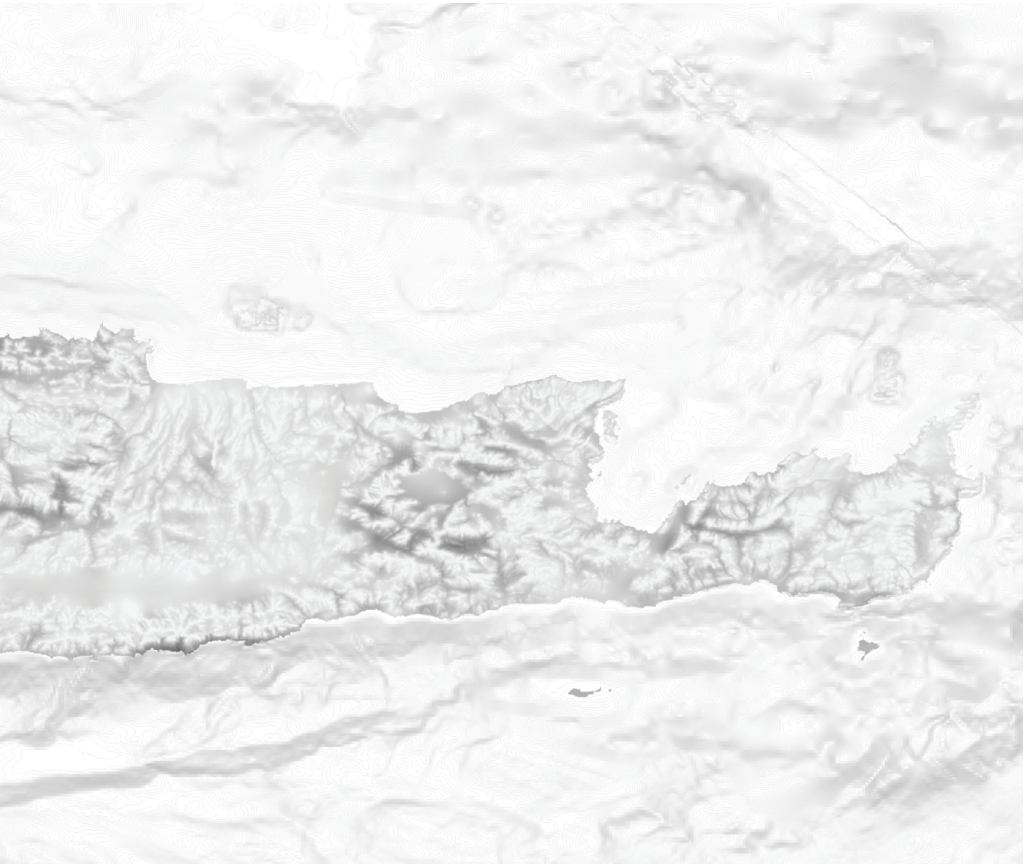
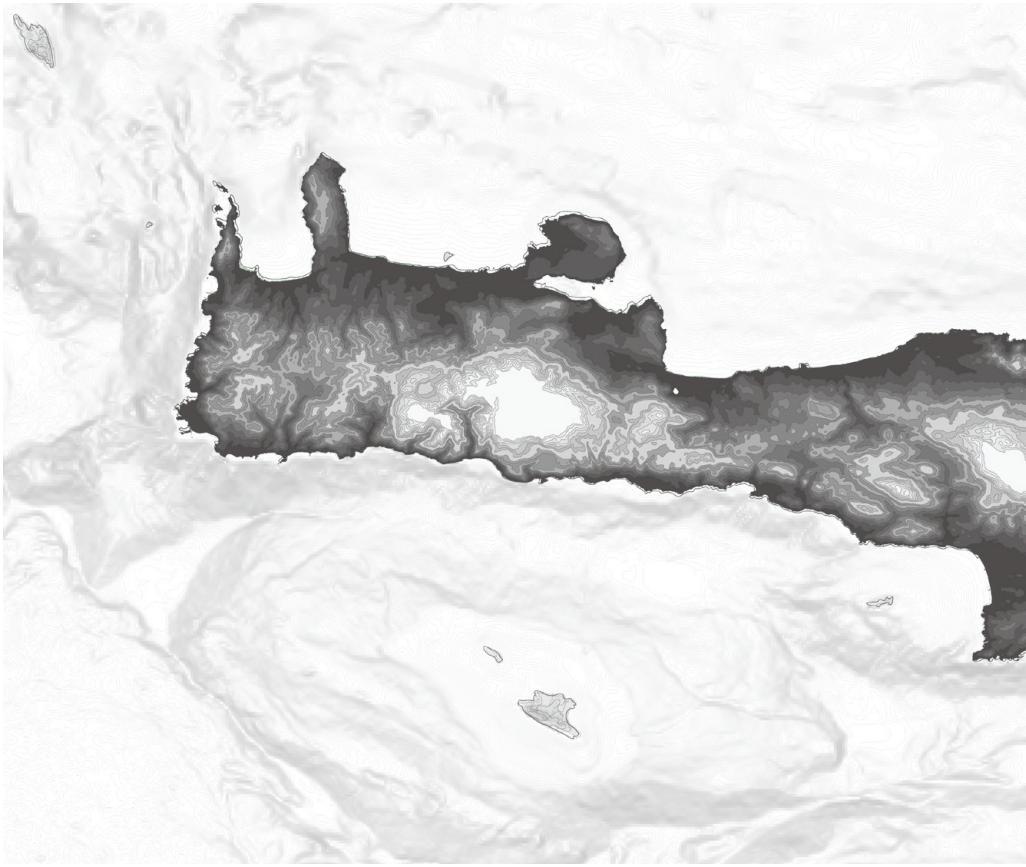
Valley depth

Deep to shallow

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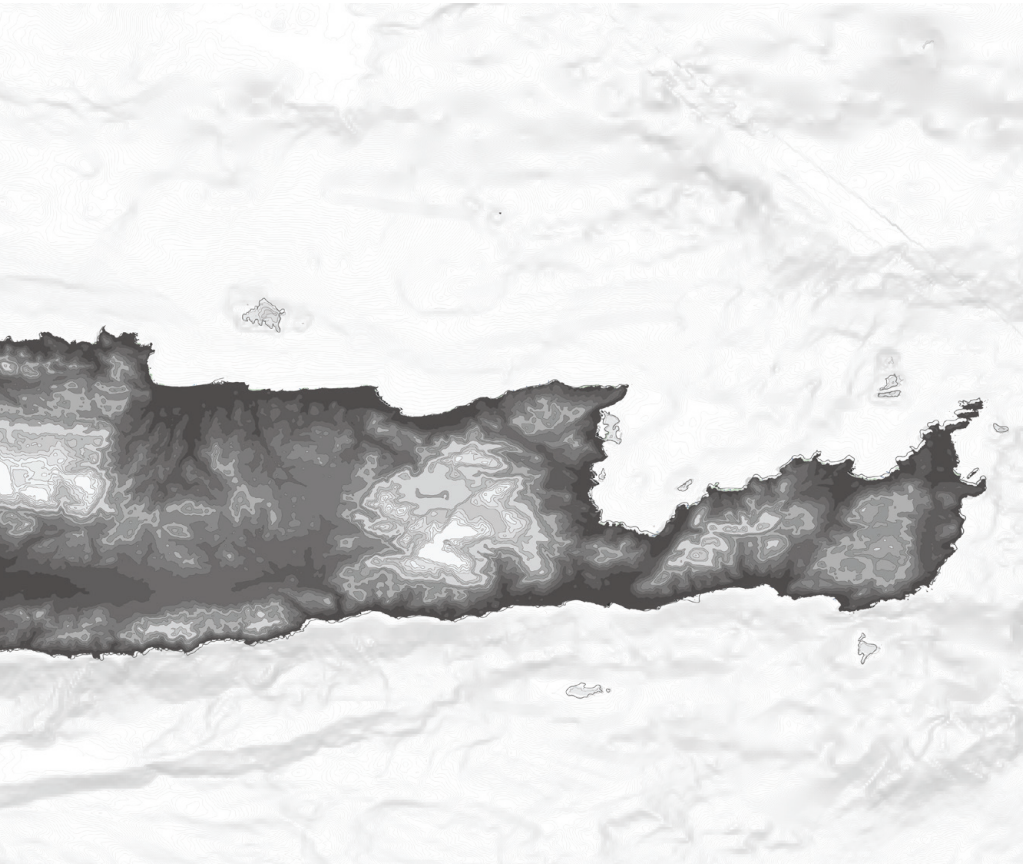
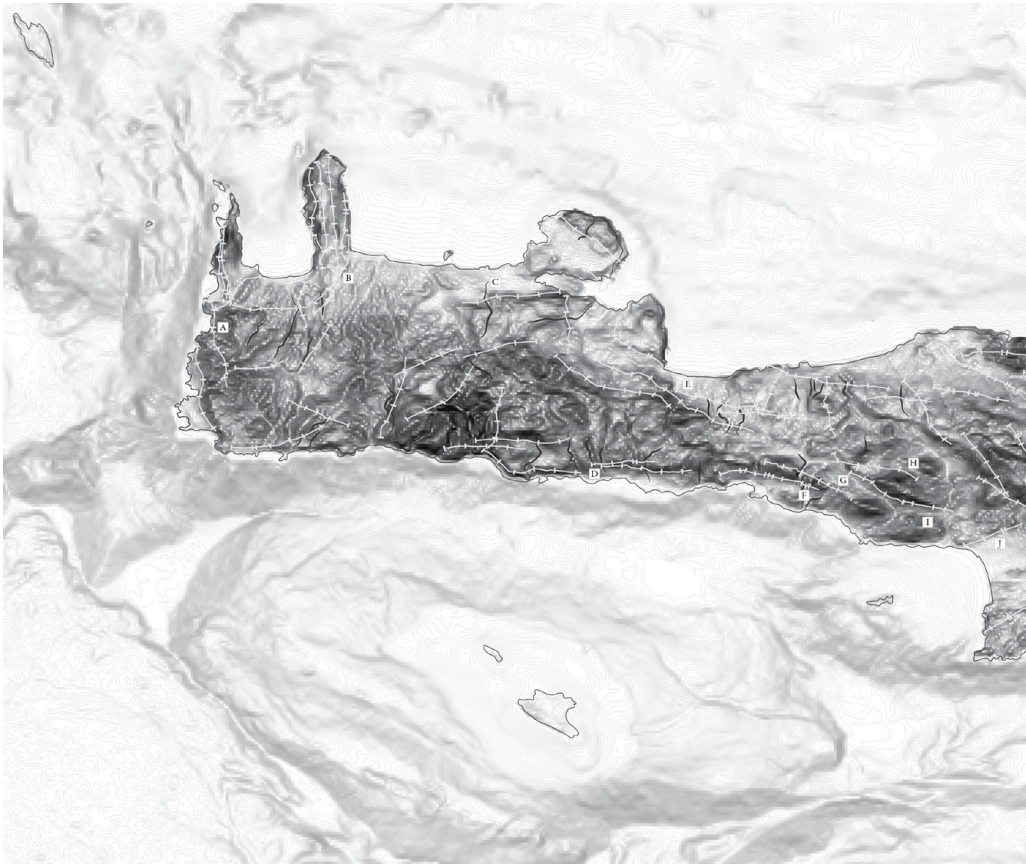
Elevation

Low to high elevation
(0-2456 m)

Contours per 1000m (island)
per 10m (sea)

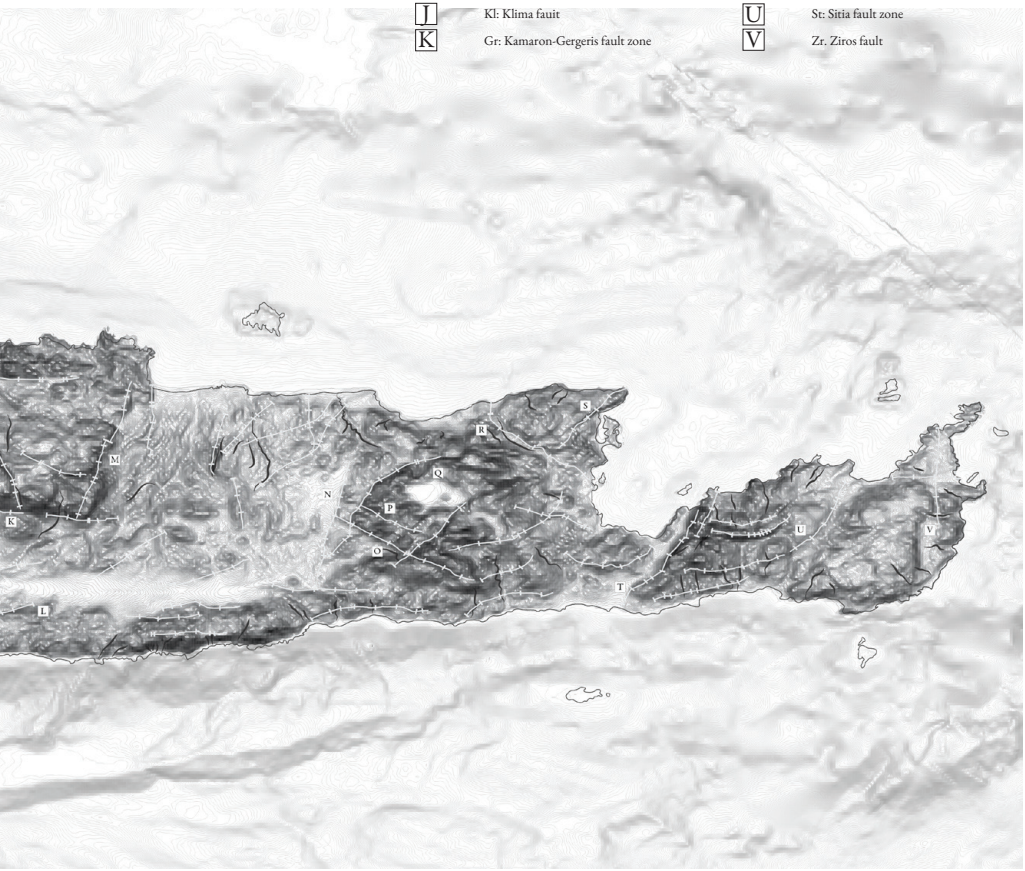


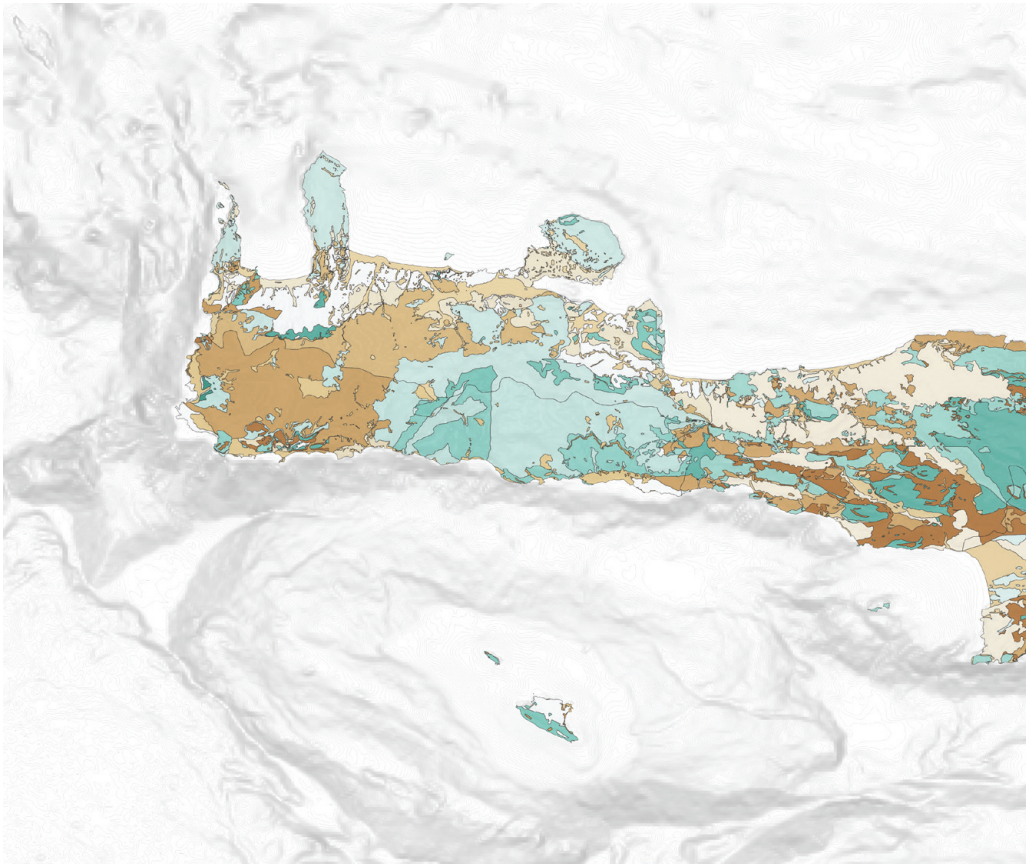


0 25 50 km

Contours per 10m

A	Cr: Western Crete fault zone	L	Ml: Malevisi fault zone
B	Ker: Kera fault	M	At: Asterousia fault zone
C	Sd: Souda fault	N	Ch: Kastelli-Chersonisos fault zone
D	Kr: Kourna-Kare fault zone	O	Xn: Xenaki fault
E	Sf Sfakia fault zone	P	Dk: Diktea fault
F	As: Asomatos fault	Q	Kth: Afenti Christou-Katharou fault
G	Sp: Spili fault	R	Np: Neapolis fault
H	Am: Amari fault zone	S	In: Agios Ioannis fault zone
I	Gl: Agia Galini fault	T	Ir: Ierapetra fault zone
J	Kl: Klima fauit	U	St: Sitia fault zone
K	Gr: Kamaron-Gergeris fault zone	V	Zr. Ziros fault

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Lithology

A1- Practically impermeable formations, low permeability

A2 - Practically impermeable formations, low to very low permeability

Π1 - Granular alluvium, varying permeability

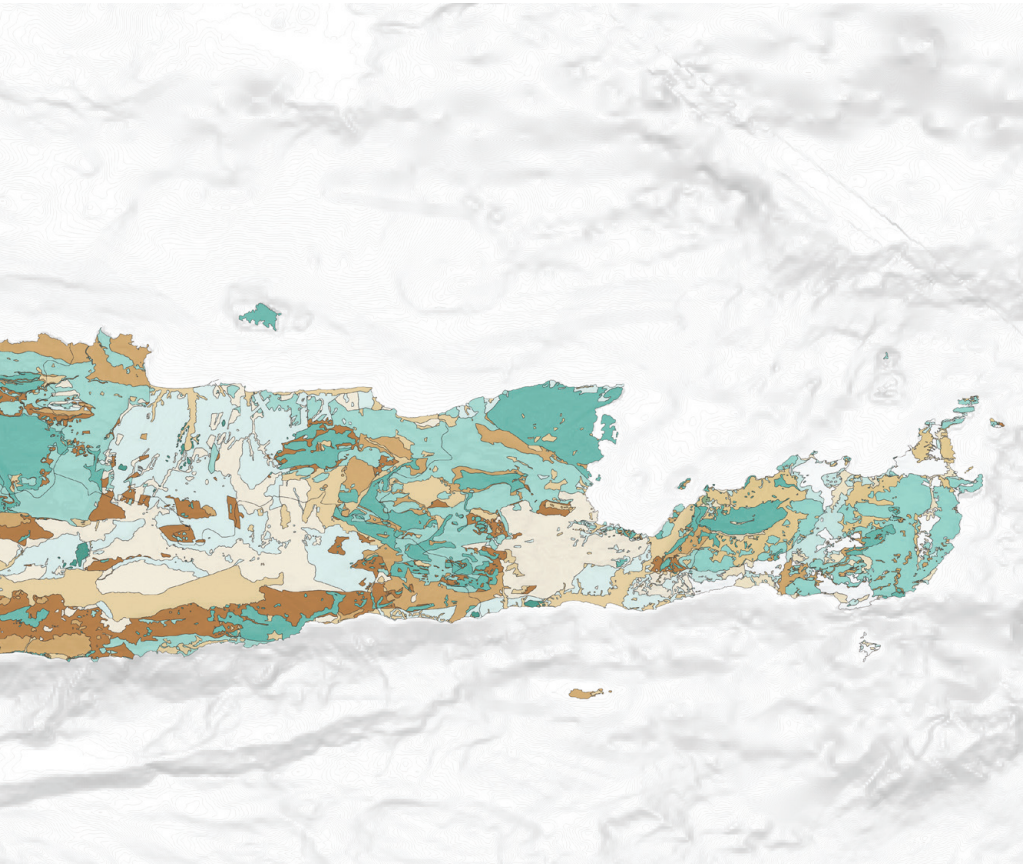
Π2 - Miocene and Pliocene deposits of moderate to low permeability

Π3 - Granular non-alluvial deposits of low to very low permeability

K1 - Karstic formations of high to moderate water permeability

K2 - Karstic formations of moderate to low water permeability

Gypsums

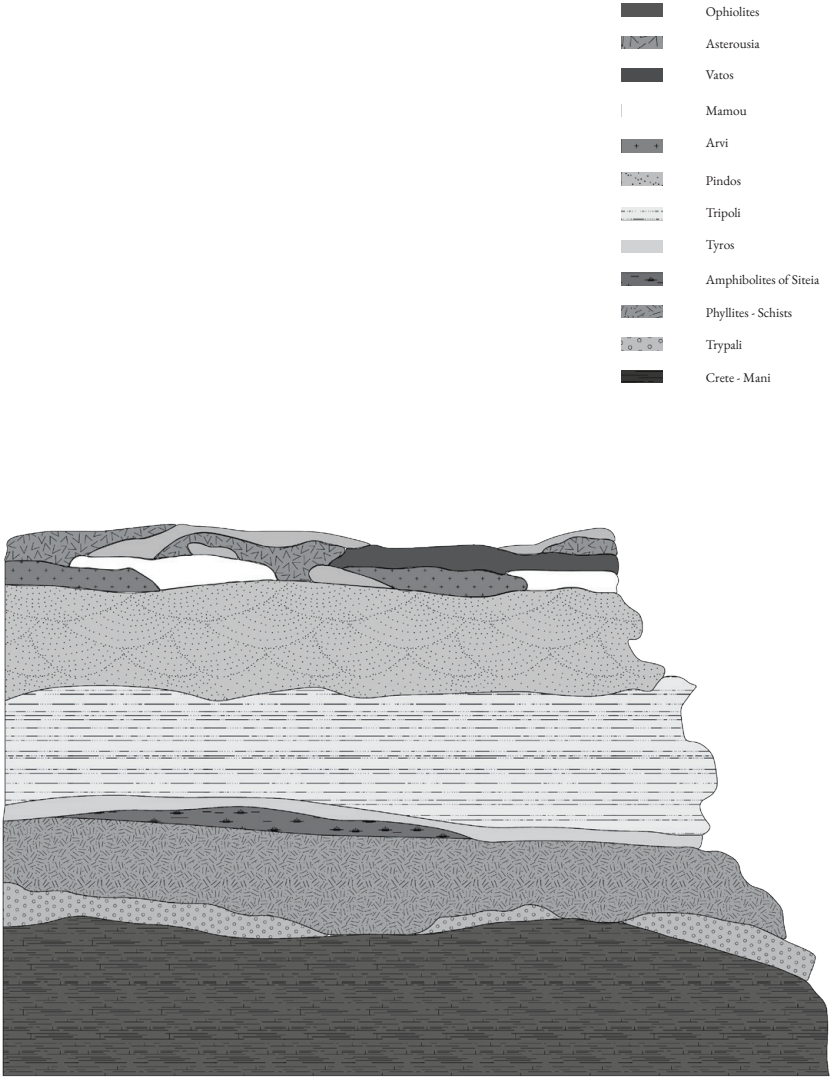


Geology

The island is located over a forearc in the Hellenic subduction zone, resulting in a thick mass of marine sediments. A complex history of extension, juxtaposition and uplift, belonging to specific stratigraphic position is responsible for the fact that the different layers, can be found in different elevations in the Holocene landscape. (Kirsten, F., & Heinrich, J., 2022) Younger basins (Miocene to present) consist of marine and terrestrial deposits of mostly marly composition while limestones belonging to the Tripolitza, Trypali and Pindos units generally form a karstic geology, the limestones and dolomites of the Plattenkalk unit are only lightly karstified due to their platy structure. (Kirsten, F., & Heinrich, J., 2022)

Geomorphology

Soil formation in the Mediterranean is driven by geological and climatic processes. (Kirsten, F., & Heinrich, J., 2022) The island's relief is dominated by three carbonate massifs (Lefka Ori, Psiloritis, Dikti from west to east) reaching elevations between 2150 and 2500 m a.s.l. and the Sitia mountains in the eastern part of the island with altitudes up to 1500 m. The relief on Crete is considered very steep, especially along the southern coast, and characterized by gorges and karstic features. Due to the geological setting described above, karstification is the dominating geomorphological process in all limestone areas of Crete. There are no large flat areas on Crete, except for the Messara plain (sediment-filled tectonic trench) in the south of central Crete that is used for intense agriculture. (Kirsten, F., & Heinrich, J., 2022)



Geomorphological earth layers, design by author

Groundwater

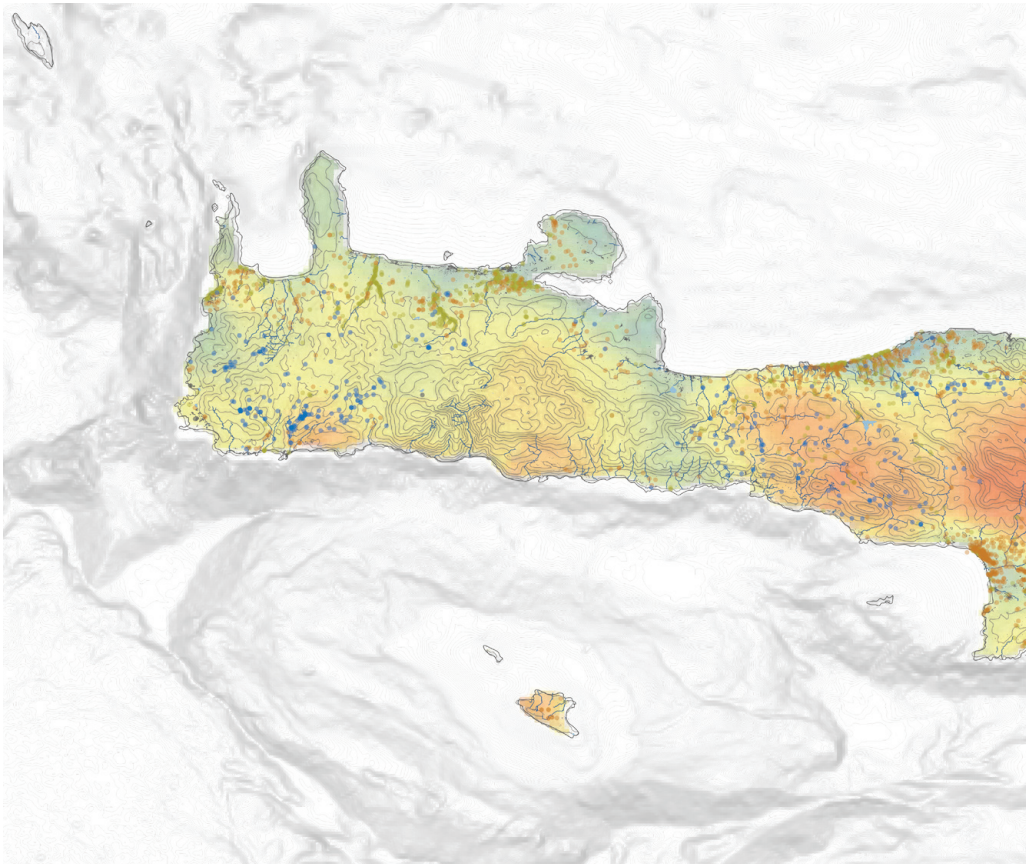
Groundwater is one of the main sources of drinking water in many regions and therefore investing in its protection is essential. (Staboultzidisa, Dokoua, Karatzas, n.d.) There are two most common ways that the groundwater for drinking and irrigation is being extracted, first through man-made wells drilled into the aquifer to pump water to the surface or collecting water that naturally emerges from springs or is discharged into lakes and streams. (National Geographic, n.d.)

In Western Crete, the vast water resources come from the Lefka Ori (White Mountains) which have limestone and dolomites geological formations surrounded by karst geomorphology. The complex system of underground water below the mountains is creating a number of natural springs on the north of the mountains. However, even though these springs have large capacities (yearly capacity at 350 million m^3), only a small portion is used yearly due to the lack of appropriate infrastructure to capture and store the water. (Wageningen University & Research Designing Systems for Informed Resilience Engineering, n.d.)

However, to meet the increasing water needs of agriculture an overexploitation of the groundwater is observed. Especially during the high season (driest months with the biggest water demand), ranging from mid-May until September, and more specifically July-August and September. In many places of the island, groundwater is being extracted faster than it can be naturally recharged resulting in steadily drain the aquifer and allowing saltwater to seep in and contaminate the whole supply. (National Geographic, n.d.) The common observation is that all the boreholes have started to run dry and the water has moved to great depths. In Tzermiado, for example, in a borehole where the water used to be at 8-10 meters, it has now moved to 70 meters below the ground and even more. (newspaper, n.d.) Another example of groundwater overexploitation on the island is in the Messara aquifer in North Irakleion where it is estimated that the water quantity that is being extracted each year is five times more than the safe aquifer yield. (Baltas, Tzoraki, 2013).

Small catchment areas, low rainfall and special geology in some places make it impossible to store sufficient amounts of water, causing severe shortages during the summer months when demand peaks with increased irrigation and a large influx of tourists. (National Geographic, n.d.) Nowadays water needs across the island are covered by a dense network of pipes that transfer water from springs, reservoirs and groundwater bodies to settlements along with local water management projects such as dams and artificial lakes to supply fresh water or to support agricultural activities. (Baltas, Tzoraki, 2013). These water transfers are usually expensive and unstable, especially in the context of the island of Crete, leading some Greek islands to explore desalination. Desalination is now being proposed as the best long-term water solution for the islands, after many failed attempts. (National Geographic, n.d.) However, Crete has only one desalination facility which is considered a very expensive solution and will be chosen only in case of emergencies.

Another significant threat to the water resources is pollution of surface and groundwater. According to a study (Frazier, 1999), pollution, agriculture and urbanization impacts are among the most frequently recorded threatening water and wetlands all over the world. (De Stefano, 2004). The main water contamination drivers on the island are olive oil industries, urban waste from the towns located near or within the basin (Staboultzidisa, Dokoua, Karatzas, n.d.) and hotels located along the coast that are sometimes not connected to any sewage system. (De Stefano, 2004).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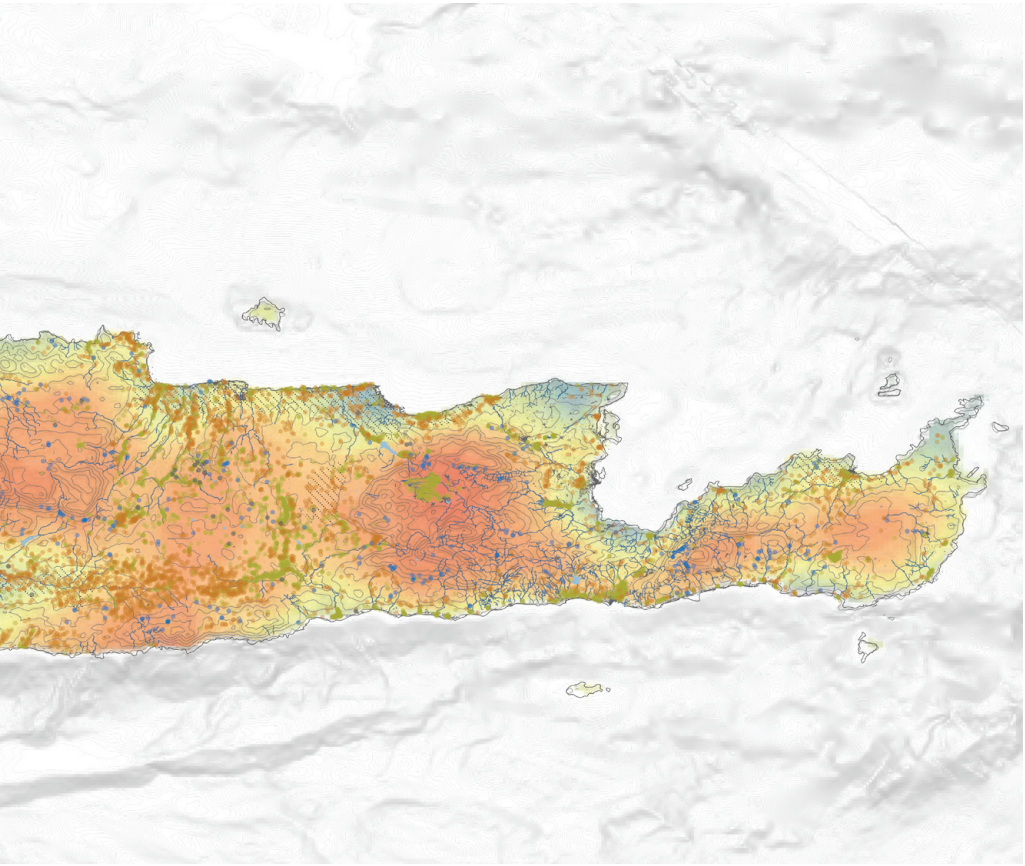
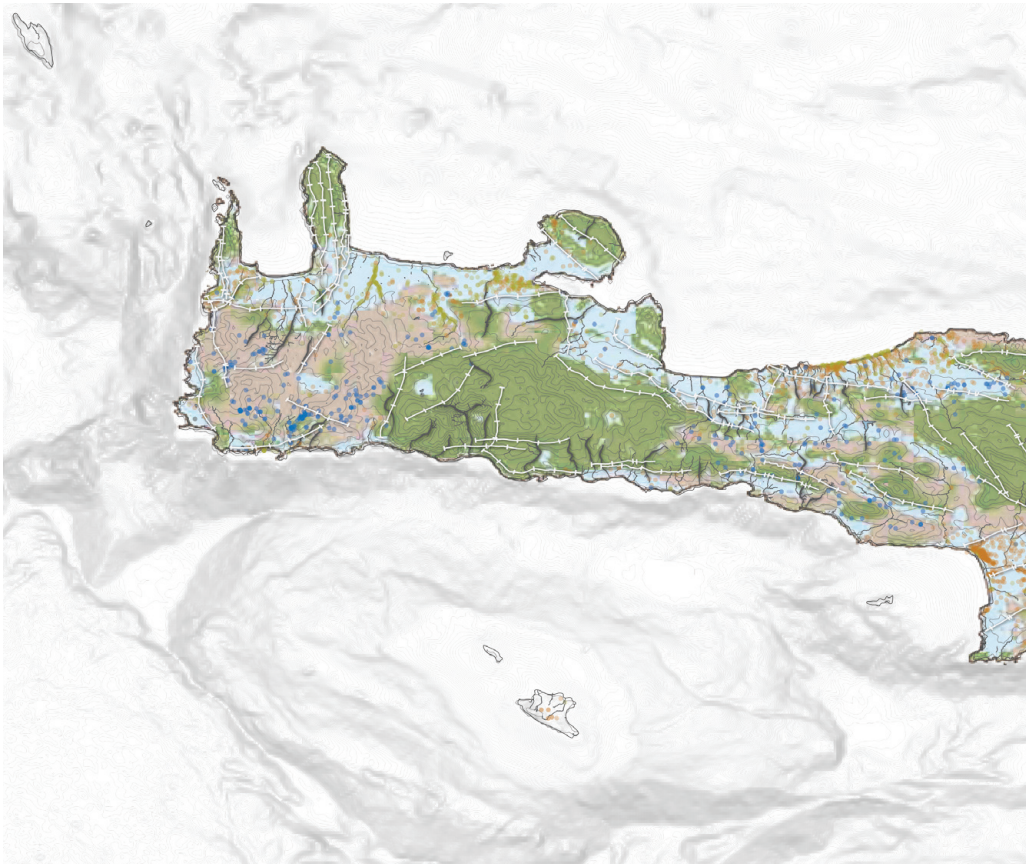
Groundwater system

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Hydrogeology

Cretan soils

The soil is a major component of the island's ecosystem, sustaining its inhabitants and supporting their activities. (Koutroulis et al., 2013). Because of their limited resources, the inhabitants of the island need to take care of them, particularly water and soil which are the main elements that give life to them and support their activities.

According to Panagos et al. (2014) and the European Soil Database, soils in Crete are generally poorly developed and shallow. (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018). In general, they conclude that soil formation on Crete is decisively influenced by relief and denudation processes in most cases (Nevros and Zvorykin, 1939). Limestone and dolomites dominate the mountain terrain, whereas Neogene sediments, including limestones and sandstones cover large areas of the lowlands. According to the Institute of Geology & Mineral Exploration (Greece), there are also phyllites (fine-grained metamorphic rocks), flyschs (sequences of sedimentary rock layers), pyroclastic rocks and alluvial deposits on the island. (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018).

The most important threat of the soil on the island is intense agricultural activities which causes soil degradation particularly in areas of long-term intensive agriculture or greenhouse cultivation. The degradation is a result of the high concentration of salts, the high microbial load and the nitrate pollution of the soil and water. Also long periods of drought can amplify soil salinization.

Most domminant soil types on the island are the following.

Luvisols that cover the largest part of the island have clay-enriched subsoil and are widely used for agriculture. Additionally, they are fertile and suitable for a wide range of agricultural uses. **Regosol** is a very weakly developed mineral soil. Limiting factors for soil development range from low soil temperatures, prolonged dryness, characteristics of the parent material or erosion. Regosols can be found in eroding lands, in particular, in semi-arid areas and in mountainous regions. Land use and management of Regosols can vary from capital-intensive irrigated farming but the most common land use is low volume grazing. Regosols in mountain areas are beneficial for forest cover. **Fluvisols** are relatively young mineral soils common in periodically flooded areas such as alluvial plains, river fans, valleys, tidal marshes, and marine deposits. Their characteristics and fertility depend on the nature and sequence of the sediments. Alluvial soil is in generall the most fertile soil because it has a loamy texture (containing sand, clay and slit) and is rich in organic nutrients that help to increase soil fertility. (Iowa Geological Survey n.d.). **Cambisols**, relatively young soils, are formed mostly from colluvia or alluvial deposits and can be found in mountainous terrain in all climates covered by a wide range of vegetation types and are used for a wide variety of agricultural uses (in steep lands mainly used for grazing and/or forestry). Finally, **Leptosols** are shallow and extremely gravelly soils and can be found mainly in mountainous regions and in areas where the soil has been eroded. The suitability of Leptosols in most areas is limited to forestry.

As you can see in the following table most of the soil types on the island are suitable and very fertile for crop production according to the European Soil Atlas.

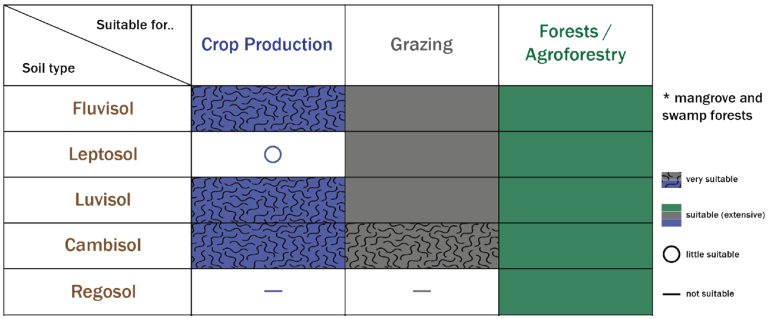
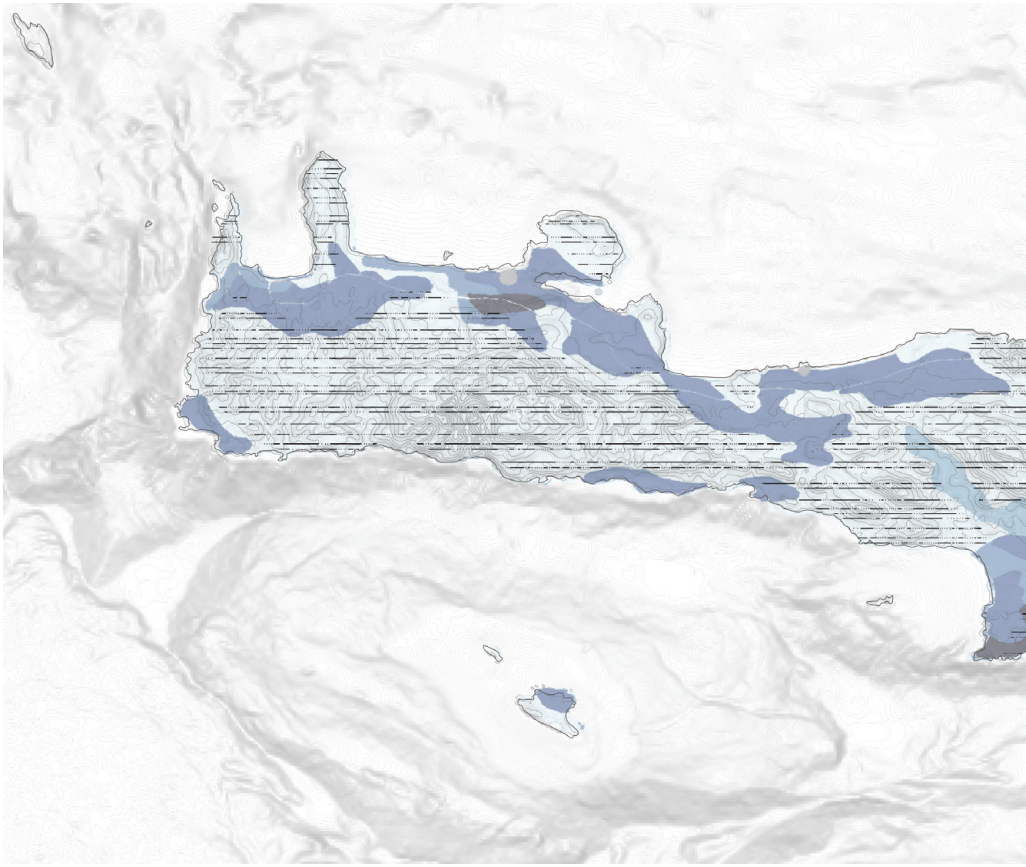


Figure 34: Soil suitability for agriculture and forestry, designed by author. Sources: *European Soil Bureau Network European Commission. (2005), Soil Atlas of Europe, Office for Official Publications of the European Communities, Luxembourg, ISRIC – World Soil Information. (n.d.). https://www.isric.org/about*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Soil types and sensitivity

Rivers, Springs, Lakes and Wetlands

Finally, the discussion turns to the above-ground fresh water on Crete, such as rivers, springs, lakes and wetlands. The island of Crete does not have large rivers due to its geological and geological characteristics (small width). Most of the river water systems on the island are characterized by seasonal streams, experiencing significant fluctuations in water flow throughout the year, while a few, mainly in the west, are considered small Mediterranean streams with a catchment area of less than 100 square kilometres and a strongly seasonal flow regime. (Φυσικό τοπίο και κλίμα, n.d.)

Only ten of the rivers on the island have water throughout the entire year, and these usually come from springs. In the past, the rivers may have contained more water than today (Rackham et al, 2004). The limited availability of surface water can also be attributed to the porous nature of the island's limestone bedrock, which allows more water to infiltrate underground rather than forming larger river systems, creating major karstic formations. Despite the lack of large rivers on the island, smaller rivers and streams play a crucial role in supporting the local ecosystems, and agriculture and for sustaining its diverse flora and fauna.

The island has only one significant lake, the Kournas in the Apokoronas region since the other lakes are more seasonal acting as water reservoirs that retain water seasonally. There are also a variety of swampy areas that are usually located near streams, springs, or the coast (saltwater lagoons) at the alluvial plains. However, a large number of them, have disappeared because of drainage projects. (Folklore - Dance Club "Krites" n.d.)

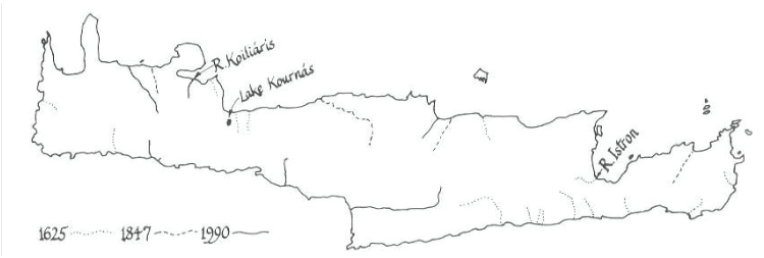


Figure 35: Map of Crete's perennial rivers from 1625, 1847 and 1990. Source: *Houseman, L. (2013). Fluid Metaphors: Exploring the Management, meaning and perception of Fresh water in Minoan Crete.*

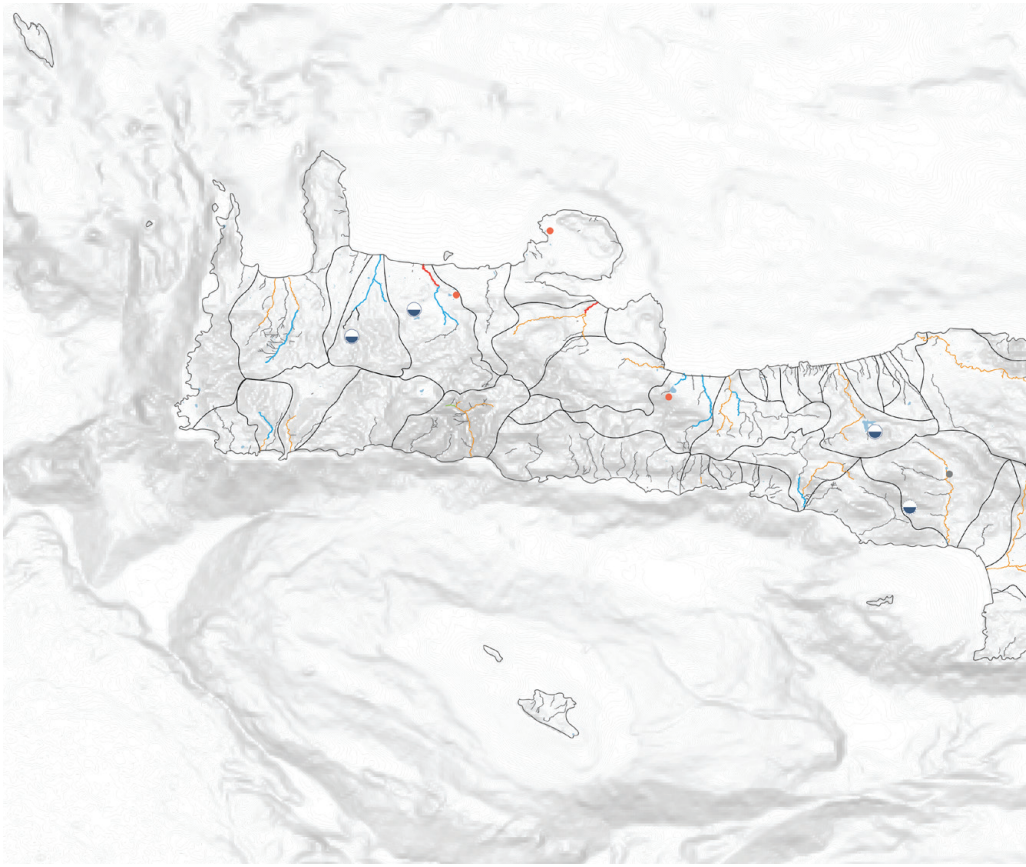
Characteristics of Mediterranean type rivers according to European decision 2013/480/EE

Type	Characterization of rivers	Catchment area (km²)	Geology	Flow
R-M1	Small Mediterranean streams	< 100	Mixed (except silicates)	Strongly seasonal
R-M2	Medium Mediterranean streams		Mixed (except silicates)	Strongly seasonal
R-M4	MountainMediterranean streams	100 - 1000	Non - except silicate background	Strongly seasonal
R-M5	Seasonal streams		-	Periodic

Subcategories later added to European decision 2013/480/EE for the Water Districts of Crete

Type	Characterization of rivers	Catchment area (km²)	Geology	Flow
R-M1a	Small Mediterranean streams	< 10	Mixed (except silicates)	Strongly seasonal
R-M5a	Seasonal streams	< 10	-	Periodic

Figure 36: Management plan of River Basin of Water Division of Crete (GR13). Source: *Special Secretariat of Water (2015)*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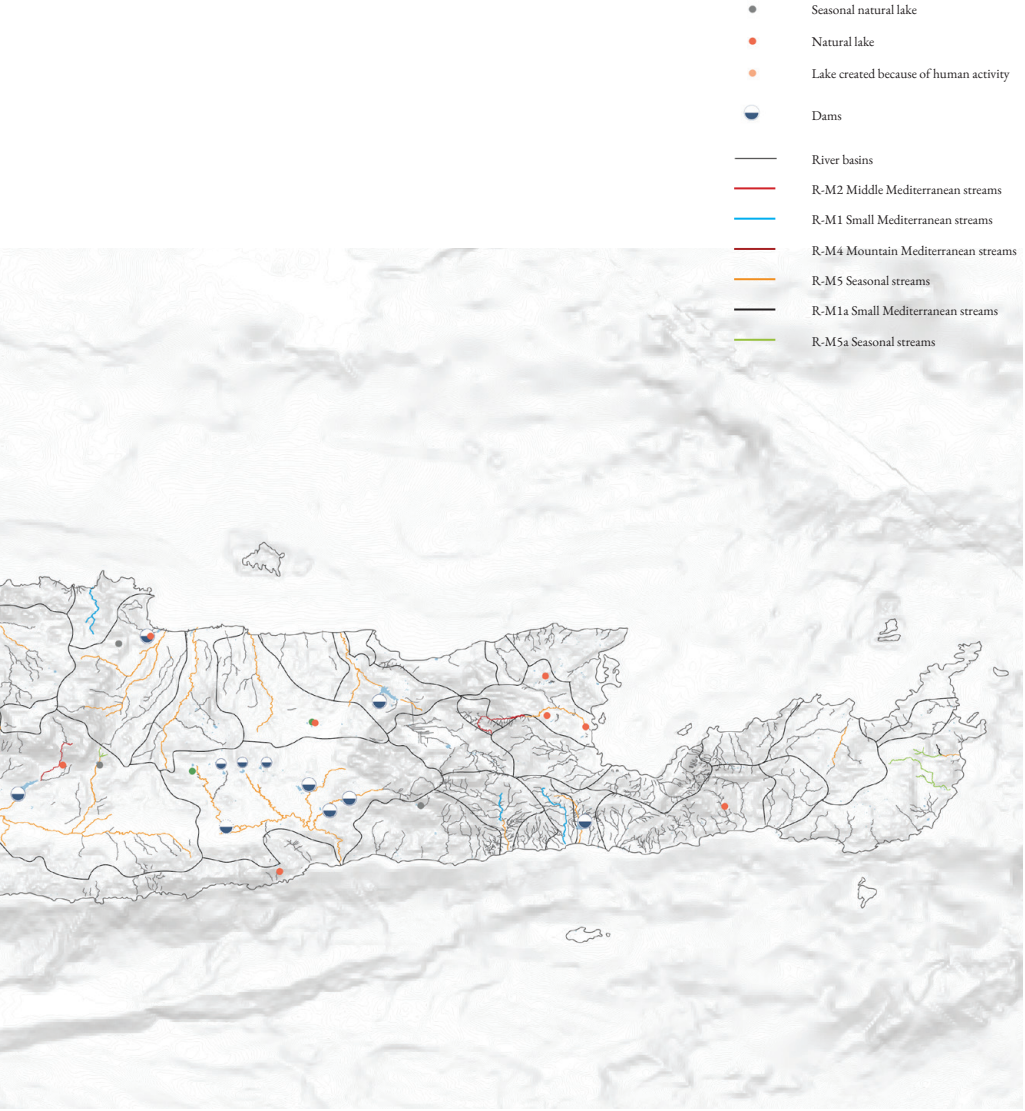
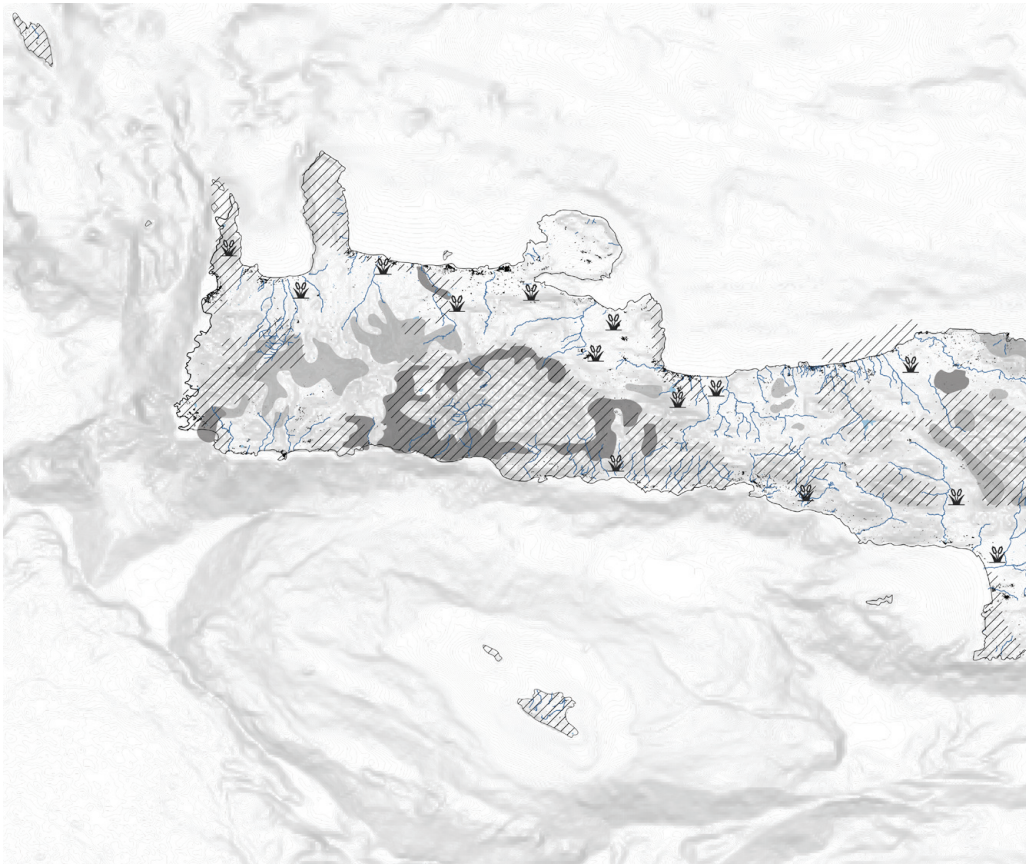
Seasonality - River system types

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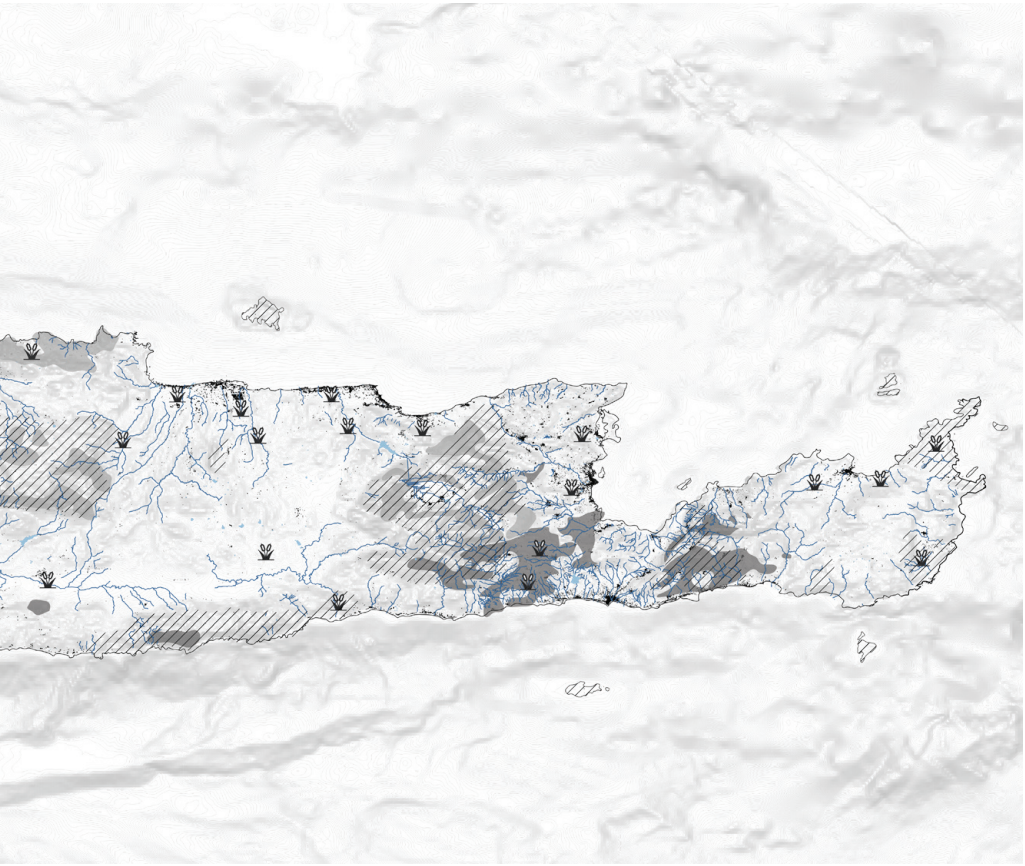
Maquis and oak forests
Pine and cypress forests
Natura 2000
River system
Wetlands



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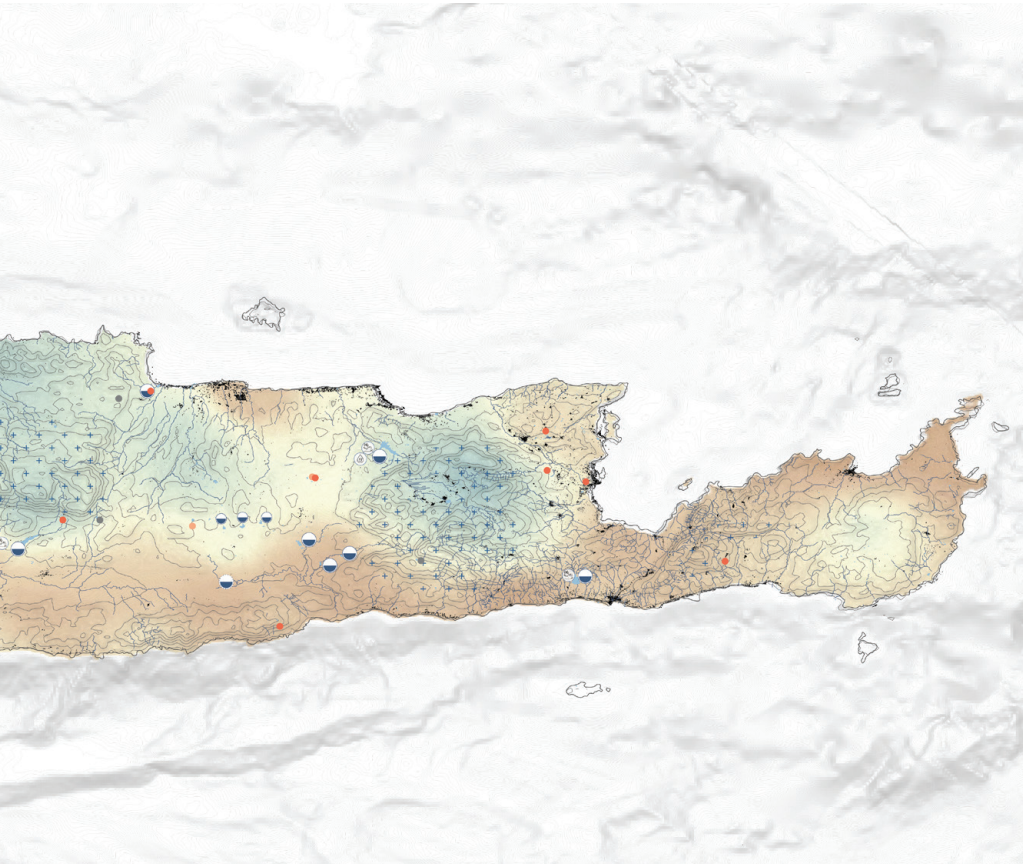
Precipitation



Climate and Vulnerabilities

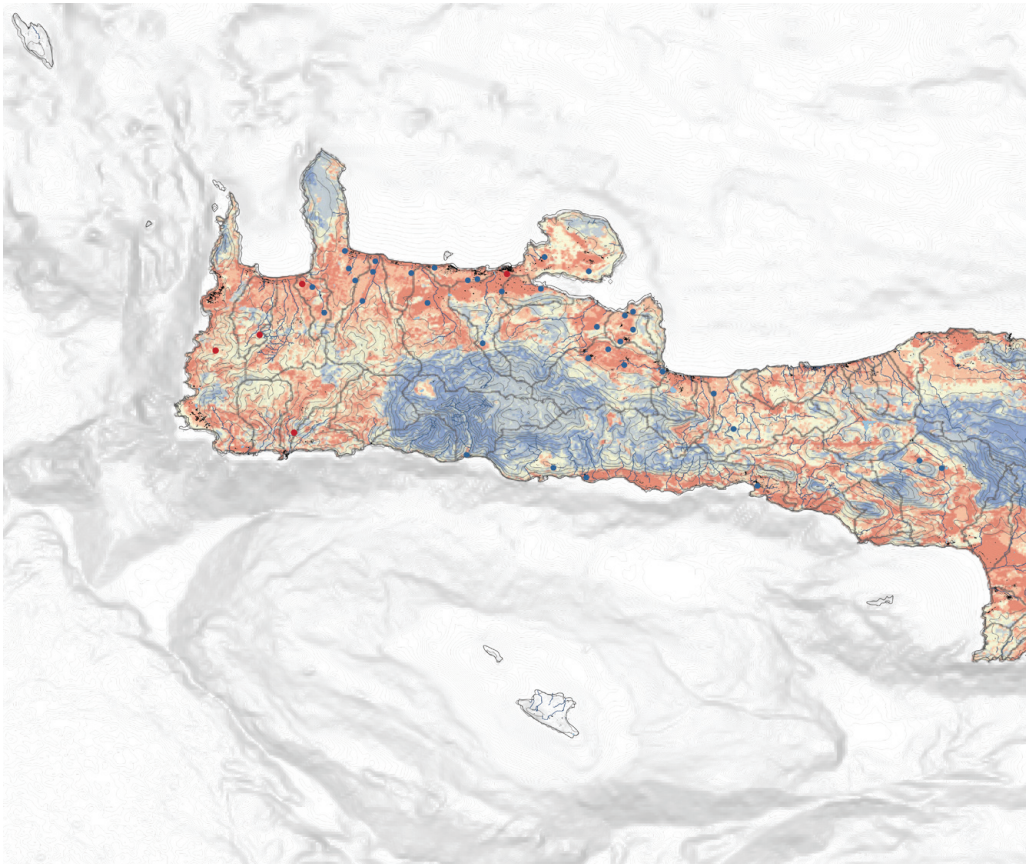
The island's climate is typical of the Mediterranean region, with humid and relatively cold winters and dry and warm summers. The average annual precipitation is about 665 mm, of which over 95% occurs between October and May (Kourgialas & Karatzas, 2016). Significant rainfall differences are recorded between the western and eastern areas of the island during the wet seasons.

Cretan winters provide a plentiful supply of water, even to the point of deluges and floods, destroying infrastructure and agricultural land; however, hot, dry, and windy conditions during the summer months, combined with a landscape that retains little surface water, cause the amount of fresh water to decline drastically, threatening the regions with drought incidents. The island is extremely vulnerable against flooding, drought, and desertification, which affect mainly the areas where human activities have altered the landscape and disrupted the balance between the natural systems. Within the same year, a single region may experience both catastrophic floods and droughts. Crete's Mediterranean climate, coupled with its unique geographical and topographical features, makes the island highly susceptible to both flooding and drought incidents, which are expected to become more frequent and severe due to climate change. Effective water management strategies and adaptation measures are crucial to mitigating the impacts of these extreme events and ensuring the island's long-term water security and sustainability. (Tsanis, I. K., Koutroulis, A. G., Daliakopoulos, I. N., & Jacob, D., 2011).

One of the most vulnerable areas to climate change is the eastern part of the island, which receives the least amount of precipitation and is characterized by intense human activities such as agriculture and tourism. According to research, 37% of the island's area is characterized as critically sensitive to desertification. This percentage varies significantly across the island, with the western part having the least critically sensitive areas and the eastern part the most critically sensitive. The results of this study also indicate that critically sensitive areas are found on the eastern side of the island, mainly due to human-related and climatic factors. (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018).

Desertification is one of the major hazards threatening arid and semi-arid regions, such as the eastern part of the island. The risk of desertification, in combination with the expected climate changes, is a significant threat in several regions of the Mediterranean area.

The most widely known definition has been given by the United Nations Convention to Combat Desertification (UNCCD). According to this, desertification is 'land degradation that occurs mainly in arid, semi-arid, and dry sub-humid areas' where land degradation is the 'reduction or loss in the biological or economic productive capacity of the land caused by human activities and often intensified by the impacts of climate change' (UNCCD, 1994). Thus, desertification is a process that can affect the ecosystem of an area and the quantity and quality of water resources, resulting in reducing agricultural productivity. (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018). Overgrazing, intensive agricultural practices, and deforestation are the main causes of desertification. Especially in arid regions, trees and vegetation are necessary to prevent soil erosion and nutrient loss. In addition, improper agricultural practices such as long-term conventional tillage may also make land more vulnerable to desertification. (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018).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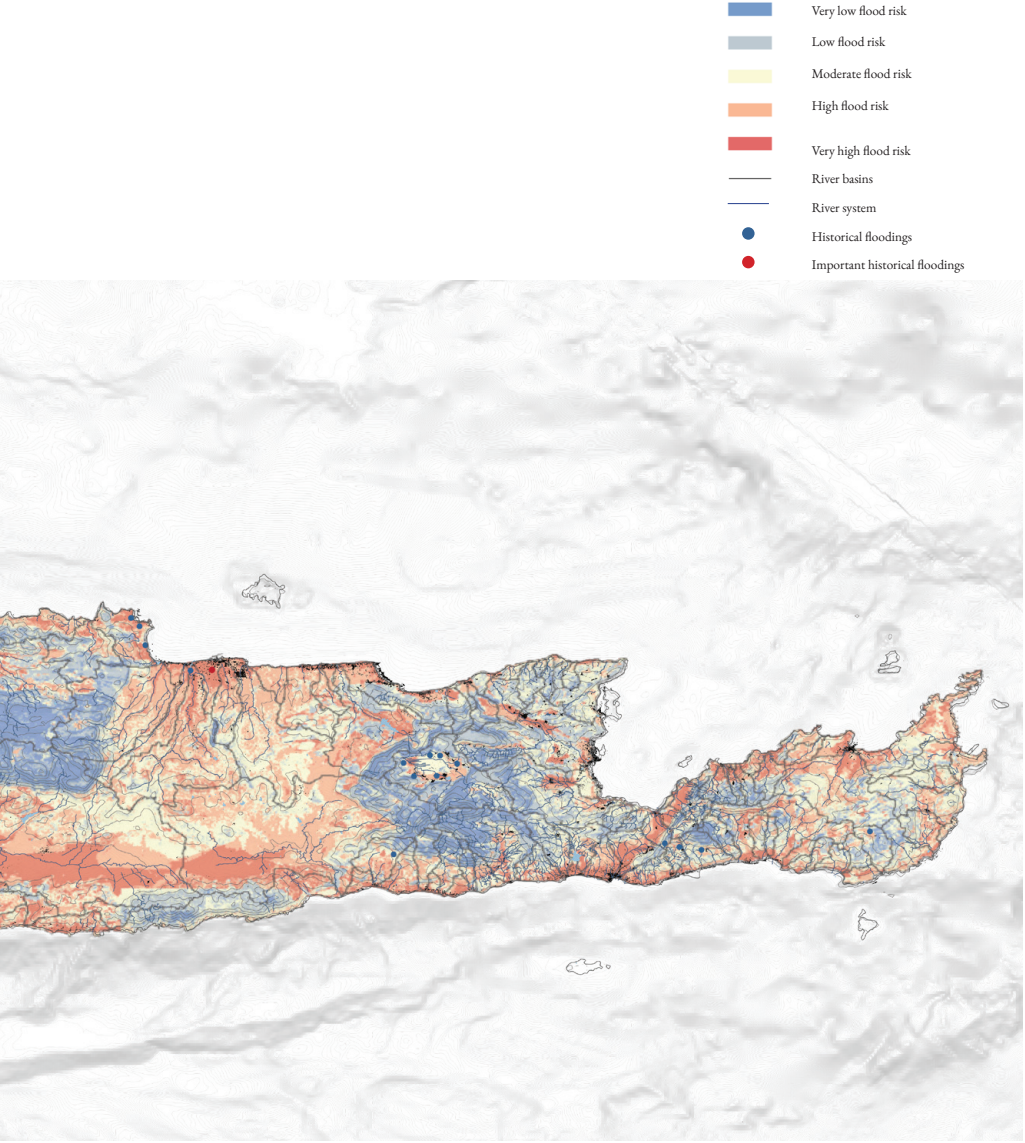
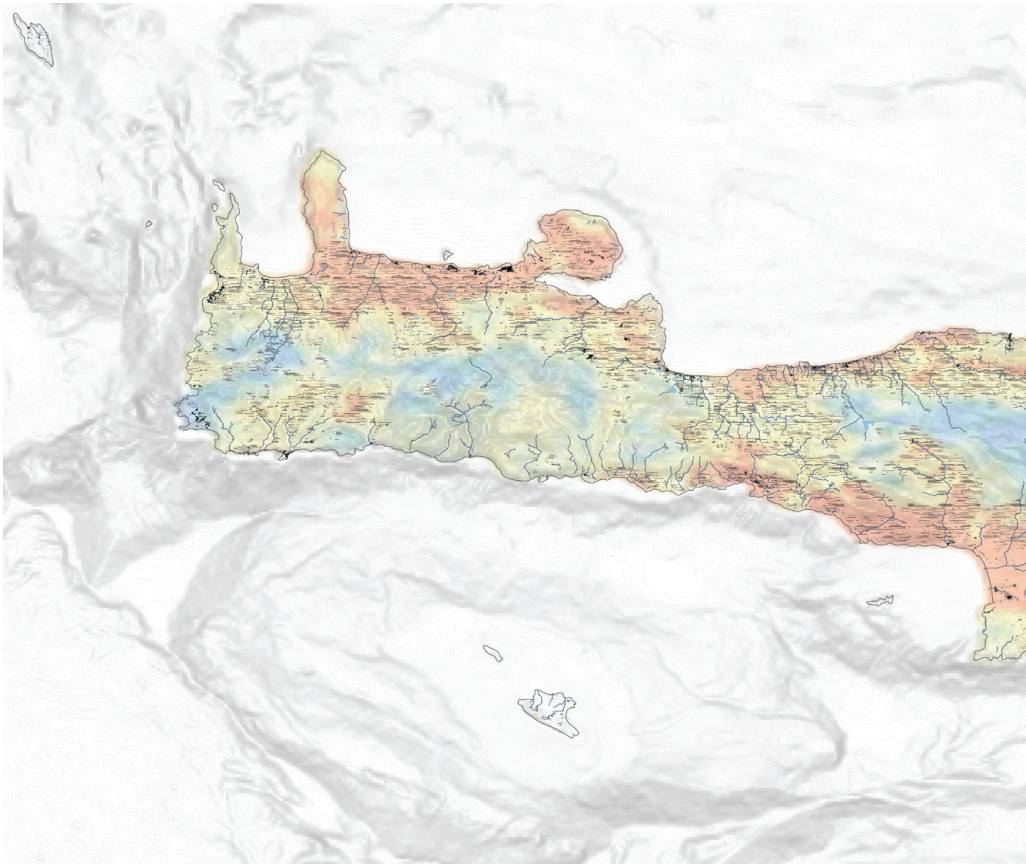
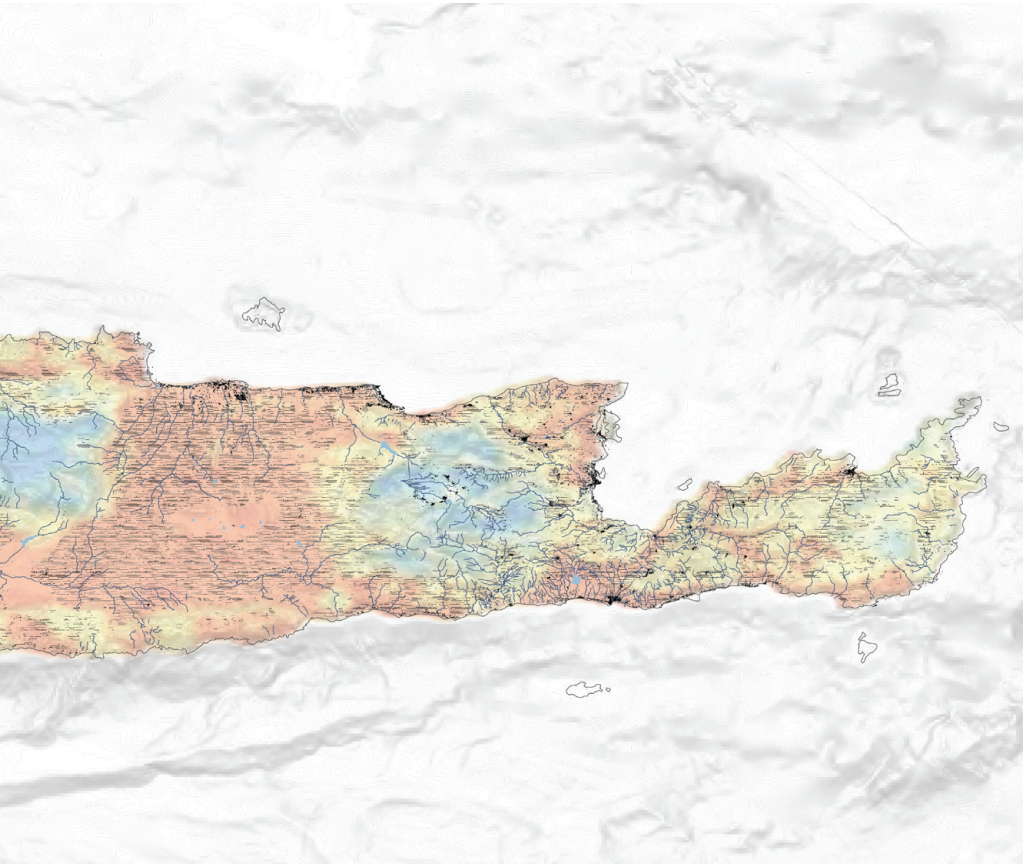
50 km

Flood risk


Very low flood risk
Low flood risk
Moderate flood risk
High flood risk
Very high flood risk
River basins
River system
Historical floodings
Important historical floodings


0
25
50 km

Desertification risk



Island's water culture

Now, we continue with the study of the cultures that inhabited the island from the past until today. The culture's view explores the indigenous knowledge and practices related to water use, water scarcity and excess, the societal component, the agricultural practices and the life of the inhabitants of Crete.

As the uses and meanings of water are inseparably integrated into human activity, understanding historical dynamics provides insights into how Cretan communities have navigated the challenges of varying water conditions. (Houseman, L., 2013) The exploration of the different societal and human systems on the island that will follow, with a focus on the communities that inhabit it and their agricultural activities, reveals their inherent dependencies on water and soil resources.

Meaning of Water

Water symbolizes life and vitality, serving as a fundamental source for the existence of all living organisms. It represents purity, and regeneration, with rituals and traditions across cultures centered around water sources such as rivers, lakes, and springs. Water is essential for human consumption and a significant driver for agricultural, industrial, and economic activities and societal development.

Water Dynamics and Transformation

Water exists in various states and cycles, including liquid (rivers, lakes, oceans), solid (ice, glaciers), and vapor (clouds, humidity) and it changes shapes and transforms itself. (Houseman, L., 2013) The hydrological system, includes processes such as evaporation, precipitation, infiltration, and runoff, defining the movement of water on Earth's different layers and in the atmosphere. Water with its dynamic behavior is often responsible for terraforming landscapes through erosion, deposition, and sediment transport. Water existence facilitates transformations in ecosystems by supporting biological processes such as photosynthesis, nutrient cycling, and habitat creation while its absence can destroy those systems. Human activities can lead to transformative changes in water cycles, altering natural hydrological processes through activities such as dam construction, groundwater extraction, and pollution.

Regeneration and Fertility

Across many cultures, including that of Crete, successful food production is interdependent on seasonal rains and streams. (Houseman, L., 2013) Therefore, water is often closely associated with fertility and regeneration, a relationship that is often expressed in myths and religious beliefs, as water embodies fundamental forces beyond human control. Water influences fertility and productivity in agricultural landscapes, providing irrigation for crops, sustaining livestock, and enhancing biodiversity. However, it is also capable of causing floods and other forms of damage.

Water in Greek mythology and art plays a significant role, reflecting the profound connection between humanity and this life-sustaining element. The ubiquity of water art in Greek culture underscores its vital role in shaping the human experience, serving as a continuous reminder of our inextricable link to the natural world and the need to respect and preserve this essential resource. As we continue to confront modern water challenges, revisiting these ancient narratives and artistic expressions can inspire an appreciation for water's life-giving properties and our responsibility to safeguard it for future generations.

Importance of (fresh) water in Greek Mythology

According to a myth, Cecrops, a strange creature with the characteristics of both a man and a snake, was the founder of a city (Athens). Cecrops had named his city after him, Cecropia. However, the gods of Olympus saw this beautiful place and wanted to name it after them and become its patron. The most persistent rivals between the gods, were Poseidon, god of the sea, and Athena, the goddess of wisdom. The symbol of Poseidon's power was the fisherman's trident, through which could form earthquakes and raise islands from the bottom of the sea. (Ancient Greece., n.d.) To solve their argument, Zeus decided that each of them would make a gift to the city and King Cecrops would then decide on the most exceptional gift and then the god whose gift would be selected, would be designated as the city's patron. (Greekacom, n.d.) One day, Cecrops and the residents of the city went up to a high hill to watch the god's gift exchange. Poseidon, struck a rock with his trident and caused a spring of water to emerge from the ground.

Figure 37: Conflict between Athena and Poseidon for the City of Athens. Source: *Blondel Merry Joseph (1781-1853), Oil on canvas, Paris, Louvre Museum, RF1939-15*

This signified that he was assuring the citizens with water and therefore they wouldn't face any drought incident. However, the people were not pleased with his gift because the water from the spring was salty, just like the water of the sea. Next, there was the goddess Athena who planted a seed in the ground, which grew up to become an olive tree. The inhabitants liked this gift better because it would give them food, oil and firewood. In the end, they loudly praised Athena as their patron. (Greekacom, n.d.)

This myth highlights the importance of fresh water in sustaining human life and civilization. The emphasis on fresh water remains relevant today, as modern societies continue to face issues of water scarcity, quality, and distribution.

Figure 38: Conflict between Athena and Poseidon for the City of Athens, Etruscan cupped krater from Campania. Source: *attributed to Naples Group 3227, 360-320 BC. Museo Arqueológico Nacional, Spain*

Figure 39: Conflict between Athena and Poseidon for the City of Athens. Source: *Copper engraving, Camassei, Andrea, around 1620-1700 London, British Museum, 1951,0407.40 The Trustees of the British Museum*

The symbols, characters and elements depicted in art have been used to explore attitudes, religious beliefs, and cultural practices of the Cretan civilization. Through the analysis of those symbols, researchers aim to understand the perspectives on various aspects of life of people on the island, including their relationship with fresh water. By examining how water is portrayed in Minoan art, such as through ceramic decoration and other artefacts, scholars explore techniques and motifs used to overcome the problems of representing water, water environments and, more generally, 'wetness'.

Ancient Greek Art and references in Greek Mythology

A design pattern commonly represented in ancient Greek art and especially in pottery is "meander" the wave pattern, which recalls the twisting and turning path of the Maeander River in Asia Minor (present-day Turkey), commonly observed in rivers. Meander or Maiandros (Ancient Greek: Μαίανδρος) was a river god in Greek mythology, the patron deity of the Meander river (modern Büyük Menderes River) in southern Asia Minor (modern Turkey). Those patterns highlight that water symbolizes life and vitality, as it is an essential element for the existence of living organisms. (Invaluable, n.d.)

Figure 40: (left) Red figure bell krater, attributed to Python Paestum, c. 340-330 B.C., (right) Red-figured bell-krater, Scene from a comedy: youthful Dionysos and Ephebos. Source: (left) *http://www.wondergreece.gr/v1/el/Perioxes/N_Irakleioy/Politismos/Arxaiologikoi_Xwroi/4168-Minwiko_Anaktoro_Knwsoy*, (right) © *The Trustees of the British Museum*

Pottery (Hydrophoria)

In pottery, a typical Greek water jar is known as a 'hydria', with which women used to go to the fountain or fountain house to collect water and are often depicted carrying the vessels on the tops of their heads. (Hydrophoria, see representation on the right).

Fountain houses like those shown in the vase-paintings have been found in Athens. (Brouwers, J., 2019).

Another common representation was the flow of water that the craftsmen depicted in their designs, representing the movement, life-giving and purifying qualities of water. The depiction of flowing water or streams on ceramics serves as a visual metaphor for the continuous flow and vitality associated with water resources. (see representation on the right)

Figure 41: Women at fountain house, Terracotta black-figure hydria (water jar), ca. 510–500 BCE. Source: *The Met Museum collection*

Minoan Frescoes

Central position in the Minoan civillisation and art had the Minoan Frescoes which frequently represented marine themes in their art and wall paintings, showcasing the strong relation of Minoans with water and natural world. Some of the most well known Minoan Frescoes were found in the Minoan palace of Knossos in Crete. Minoans were also relying in water and nature for their food and fresh water. Last but not least, water was considered sacred and was used in sacred ceremonies as a gift to the gods. That is why it was placed in carefully decorated vessels (aggeia). Water also symbolizes life and represents purity, cleansing, and renewal, with rituals and traditions across cultures centered around water sources such as rivers, lakes, and springs.

Figure 42: (left)The dolphin fresco, the Minoan palace of Knossos, Crete, (1700-1450 BCE), (right) Fresco of a fisherman with Coryphaena hippurus, Akrotiri, Santorini, Greece, (between 1600 to 1500 B.C.). Height: 1.10 m. Source: (left) *https://www.tiqets.com/el/knossos-attractions-c263091/tickets-for-knossos-palace-archaeological-site-p990644,* (right) *Le musée absolu, Phaidon, 10-2012*

Figure 43: Water carrier fresco, symbol of Minoan culture, Knossos palace, Crete. Source: *http://www.wondergreece.gr/v1/el/Perioxes/N_Irakleioy/Politismos/Arxaiologikoi_Xwroi/4168-Minwiko_Anaktoro_Knwsoy*

This chapter presents a research and exploration of the most significant water management systems of Crete. In order to adapt to the often extreme climatic conditions and water scarcity during the summer months, a series of traditional water management infrastructure and techniques were developed to collect rainwater and ensure a reliable water supply. The systems and main devices presented include among others underground cisterns for rainwater collection and storage, wells for water extraction, spring chambers capturing natural spring water, aqueducts transporting water, dams and reservoirs for water regulation and flood prevention and terraced agriculture. The aim was to address the island's arid climate and seasonal water scarcity.

Cisterns

Cisterns can be found even from the Minoan era (circa 2600–1100 BCE) and there are found in Classical and Hellenistic (circa circa 500–31 BCE) as well as Roman (circa 67 BCE to 4th century CE) water management systems.

Cisterns are structures constructed to store liquids, particularly but not exclusively to harvest and store rainwater. Minoan cisterns have a cylindrical shape and the capacity to collect and store rain or fresh water for household, agricultural and industrial uses. The cisterns are generally constructed from local stones. (Houseman, L., 2013) They collect water from two main sources, rain and spring water with rainwater either falling directly into the cistern or being channelled into the cistern via drainage channels from a courtyard or roof-top. The location of some settlements was such that there were no nearby springs or wells and therefore the rain-water collected by the cistern, would have been extremely important. (Houseman, L., 2013)

Figure 44: Central Minoan cistern in House C at Tylissos, Heraklion. Source:
https://www.slideshare.net/pergeo/brief-history-of-minoan-technologies-a-angelakis

Figure 45: Hellinistic water cistern in the ansient city Eleftherna, Rethymno. Source:
https://www.slideshare.net/pergeo/brief-history-of-minoan-technologies-a-angelakis

Wells

Wells are defined as vertical holes dug into the ground to access and extract groundwater, penetrating down through soil and rock layers until they reach water tables or permeable zones containing groundwater. Wells have been used for centuries as a reliable means of obtaining groundwater for drinking, irrigation, and other domestic or industrial uses, showcasing their significance as a fundamental component of water management systems.

Although the evidence for Minoan wells is relatively sparse, the number of wells in the more extensively excavated sites such as Knossos and Palaikastro seems to indicate that the Minoans favoured this water management method. In total, 21 Minoan wells are known with depths varying from 2m to 19.4m. The shaft of the well is dug directly into the bedrock, with the upper sections of the well shaft finished with stone blocks or slabs. Usually, a stone well head is constructed around the opening to prevent the well from eroding at the surface and to provide a platform from which the water can be drawn. (Houseman, L., 2013)

Figure 46: Minoan well at the eastern section of the Palace of Zakros, eastern Crete.
Source: *https://www.slideshare.net/pergeo/brief-history-of-minoan-technologies-a-angelakis*

Figure 47: Lygenia Pigadia, Palailoni village. Source: *https://hania.news/2021/01/31/%CE%A7%CE%B1%CE%B-D%CE%B9%CE%AC-%CE%A0%CE%B7%CE%B3%CE%AC%CE%B4%CE%B9%CE%B1-%CE%BA%CE%B1%CE%B9-%CF%83%CF%84%CE%AD%CF%81%CE%B-D%CE%B5%CF%82-%CE%BC%CE%B1%CF%81%CF%84%CF%85%CF%81%CE%BF%CF%8D%CE%BD/*

Figure 48: Lygenia Pigadia, Palailoni village. Source: *https://hania.news/2021/01/31/%CE%A7%CE%B1%CE%B-D%CE%B9%CE%AC-%CE%A0%CE%B7%CE%B3%CE%AC%CE%B4%CE%B9%CE%B1-%CE%BA%CE%B1%CE%B9-%CF%83%CF%84%CE%AD%CF%81%CE%B-D%CE%B5%CF%82-%CE%BC%CE%B1%CF%81%CF%84%CF%85%CF%81%CE%BF%CF%8D%CE%BD/*

Fountains

Fountains have been an important element in the design of public spaces since ancient times. Originally, they served the practical purpose of collecting water from natural springs and supplying it to the population. Over certain periods, fountains were considered sacred and symbols of purification, often dedicated to the gods of water, such as Poseidon and Artemis. (T. Editors of Encyclopaedia, 2013)

A distinctive feature of Minoan water collection systems is the Spring Chamber. The Spring Chambers, however, have considerably smaller potential capacities, indicating that their primary function was not to collect large quantities of water but rather to provide a space where spring water could be accessed. (Houseman, L., 2013). An example of a spring chamber is at the Caravanserai, in Knossos and features a sunken gypsum basin that is accessed via three steps. (Houseman, L., 2013)

Figure 49: Kato Zakros Spring Chamber viewed from North East. Source: *Houseman, L. (2013). Fluid Metaphors: Exploring the Management, meaning and perception of Fresh water in Minoan Crete.*

During Venetian rule (**13th–17th centuries**), ornate fountains were constructed in Crete, showcasing water as a central element in public spaces. Public fountains became focal points in urban planning, providing access to clean water for residents and emphasizing the communal nature of water usage. These fountains often featured sculptural elements and reliefs representing aquatic themes. An example, symbol of the city of Heraklion, Crete, is the Morosini Fountain which was built during the Venetian period. At that time there was a water shortage problem in the city which had no water resources and its inhabitants used wells that stored rainwater. To address the water shortage problem, the Venetians provided water to the city from the Yuchtas mountain that reached Heraklion through a 15-kilometer aqueduct. This water ended up in the Morosini Fountain from which then the inhabitants of the city of Heraklion could easily access it. ("Lions Square and Morosini Fountain in Heraklion", n.d). The Fountain has an octagonal shape to allow for more people to fill their containers with water. The Fountain is decorated with reliefs inspired by ancient mythology while the water flows from the mouths of the four lions. At the top of the fountain was placed a large marble statue of trident-bearing Poseidon, made by a local artist. ("Κρήνη Μοροζίνι ή αλλιώς Λιοντάρια: Η ιστορία της", 2019). It is worth noting that during the Turkish occupation, alterations were made to the Fountain, including the addition of taps and modifications to its shape. In 1900, however, the monument was restored to its original form. In the past, the authorities have decided to stop the supply of water from the Fountain due to water scarcity. In 2016, after a decade-long drought, the municipality of Heraklion revived the Fountain by supplying it with water from the Aposelemis Dam.

Figure 50: Morosini Fountain, present. Source: *https://el.wikipedia.org/wiki/%CE%9A%CF%81%CE%AE%CE%BD%CE%B7_%CE%9C%CE%BF%CF%81%CE%BF%CE%B6%CE%AF%CE%BD%CE%B9*

During Ottoman rule **(17th–19th centuries)** that followed, ornate fountains were constructed in the beginning only in the Turkish neighbourhoods. Only a few houses had running water or cisterns and they usually belonged to the Ottomans (Karantzikou, 2004). However, there were several charitable drinking fountains in the town, known as 'sebils' (Ottoman Public fountains) showcasing the fact that water was treated like private property, often overruled in favor of those with wealth and power. (Spyropoulos, Y., 2018) After ensuring the appropriation of a large amount of water resources for their establishments, they distributed the remaining into the public fountains. To satisfy the needs of the Moslems and citizens in general, the Turks built a fountain next to every mosque (Chalkiadakis, E. G., 2012). These fountains served as communal gathering places and sources of drinking water.

During that time, Crete was home to a military and administrative apparatus of considerable size. (Spyropoulos, Y., 2018) A large amount of the island's resources was diverted to fountains next to military camps to supply with water daily the thousands of soldiers on the island. In 1719, almost one-tenth of the capital's (Heraklion) running water was used for the needs of army-related infrastructure, and soldiers were appointed for its management and maintenance. (Spyropoulos, Y., 2018) Another important responsibility of the army was guarding public fountains, a fact that highlights the value attributed to running water by the local administration. (Spyropoulos, Y., 2018)

Figure 51: Morosini Fountain, 1900 during Ottoman rule. Source: *https://www.cretapost.gr/559169/iraklio-i-platia-ton-liontarion-ana-tous-eones-entyposiakes-ikones/*

Sewerage and drainage system

The variety of techniques and approaches to different problems in drainage, water removal and storage, demonstrates a sophisticated understanding of water. The presence of drainage systems within buildings is perhaps indicative of the Minoan attitude to 'grey-water' and sewerage – that it can and should be quickly removed. Evidence for some some kind of drainage can be found at the majority of Minoan sites, ranging from relatively simple water conduits at smaller buildings to vast and complex systems at palaces.

Figure 52: (left) Part of the Minoan water sewerage and drainage system at the Knossos Palace, Heraklion (right) Minoan open yard used for water collection and part of the central sewerage system at the Phaistos Palace, Heraklion, Source: *https://www.slideshare.net/pergeo/brief-history-of-minoan-technologies-a-angelakis*

Figure 53: The cntral court of palace at Phaistos after a rainfall.
"..all the sewers were still working! It was interesting for me to see the water in the drainages and sewers so big that a man could enter. I doubt if there are other examples of ancient sewerages working after 4 thousand years!" Angelo Moss, during his visit in the palace of Phaistos, 20th century-1907, Source: *https://www.slideshare.net/pergeo/brief-history-of-minoan-technologies-a-angelakis*

Dams

Dams stop the flow of surface water in order to protect low-lying land at risk of flooding, create artificial reservoirs, or a combination of both to be able to adapt to the Cretan environment, in which both scarcity and periodic over-abundance of water are present.

In the Minoan era there were seven Minoan dams on Crete at four different sites all of which are constructed within valley cavities, which during the rainy summer months channel floods inside the valley. Minoan dam construction consists of a megalithic wall made of smaller stones and mud in a stream-bed. The pools created by the short walls could have provided a convenient place with fresh water for livestock but also could have been "cross-channel terraces" used as small plots for growing crops using the collected water during periods of mild flow (Chryssoulaki, 2011). It should also be noted, that terraces do not necessarily require drainage channels, as the depth of the soil created by the terrace should be sufficient to retain more water (Betancourt, 2012). The combination of the dams and the improved terraces was therefore an answer to the need to improve the island's agricultural potential. Out of all the Minoan water management systems, the dams are the largest organised system in terms of scale and the most impactful intervention on the landscape and human activities. (Chryssoulaki, 2011) As we can conclude from the following map most of the water management systems were built in the Eastern part of the island.

Water management as a response to climate change

The dams address a number of problems associated with periods of flooding – slowing and redirecting water flow – whilst also collecting temporarily water in reservoirs for later use in agriculture. In another case, dams were constructed as a response to an increase in the local population or the shift to a warmer, drier climate.

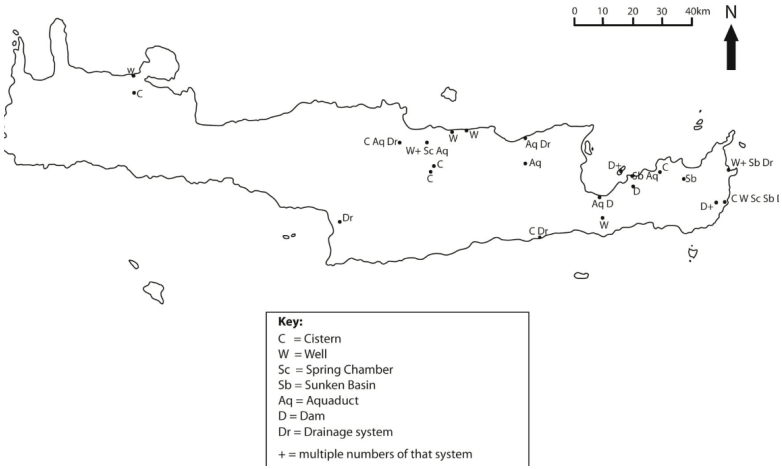


Figure 54: Map of Crete showing distribution of Minoan water management systems, Source: *Houseman, L. (2013). Fluid Metaphors: Exploring the Management, meaning and perception of Fresh water in Minoan Crete.*

During the Minoan era, between 1750–1470 BC, Crete witnessed an intensification in the development of water management systems possibly influenced by changing climatic conditions. Variations in climate during this period, including periods of drought and sporadic heavy rainfall, would make the collection and storage of water a pressing challenge. It is likely that Crete in the past had more rivers compared to its current state. (Houseman, L., 2013)

On the other hand, the construction of multiple wells in the Early Minoan and Middle Minoan periods (3rd Millennium Aridity Event) may be seen as a response to water scarcity. The building of dams during this time served the goal of mitigating the destruction of agricultural land by floodings, as well as exploiting the abundance of water offered by the floods by controlling the speed and direction of flow. (Houseman, L., 2013)

Evolution of the water management system from 17th and onwards

During the Venetian and Ottoman periods, water resources in the Cretan countryside were utilized for both irrigation purposes and to operate water mills. It appears that during the late Middle Ages and more recent times, Crete had richer water resources compared to the present day, although the risk of water scarcity existed. («Ακραία» Καιρικά Φαινόμενα, n.d.)

The most common examples of traditional water management methods were cisterns, wells, terraced agriculture, irrigation channels, community water management systems, geraniums, water mills, and piped water supply systems. Cisterns and wells have been an essential part of Crete's traditional water management for centuries and were continued to be used during the 20th century, particularly in rural areas. Rainwater collected in cisterns and groundwater accessed through wells provided essential water supply for households and agricultural activities.

Geraniums

The potato cultivation in the Lasithi plateau, one of the most important plateaus of the island, started around the end of the 19th century when cereals were grown before. For watering potato cultivation, which is more water consuming than cereals, geraniums were originally used, as copies of the Egyptian SHADUF, one long wooden lever that making possible to pump of water from the well. At the beginning of the 20th century, geraniums began to be replaced by stone-built and mainly wooden windmills. Windmills are not exactly known when they were first used in Crete, however, their existence refers to the Venetian period.

Windmills

Water mills, along with windmills, were constructed throughout Crete during the Venetian and Ottoman eras, with many of them remaining operational until relatively recent times, even into the mid to late 20th century. Typically, water mills powered by flowing water, were used for grinding grain and other agricultural purposes. However, during the summer months, the operation of mills was challenging due to water scarcity. Often, water mills were constructed in groups, one after the other, so that they could all be supplied from the same water source.

Towards the end of the 19th century, because of the water-intensive potato cultivation the construction of the first pumping windmill by Emmanuel Papadakis in 1890, occurred, which combined the kinetic mechanism of the already known grinding windmill, forming the first wind-powered pump. In the beginning, the pumping windmills were wooden, single-winding but later they evolved into metal ones with mechanisms for rotating the shaft in the direction of the wind. The spread of the metal windmill was rapid because for the farmers it made possible the cultivation of the fields and, improved their living conditions. However, since the beginning of the 21st century, their decline and abandonment gradually began, after the appearance of gas-powered pumps.

Wells

The Lasithi Plateau has the largest, smoothest and most fertile plain of Crete and is one of the few plateaus that has a rich groundwater table at a relatively shallow depth, which resulted in each field having its own well. (Livingston Vance Watrous, Blitzer, 1982)

Terraced agriculture (ξερολιθιές / πεζούλες)

One significant landscape characteristic for the 'traditional' Greek agricultural landscape, is cultivation terraces commonly found on steep slopes and used to maximize arable land and prevent soil erosion. Terraces are highly flexible forms of agricultural construction used by farmers in semi-arid environments to convert hillslopes into stepped linear units of relatively flat ground via the construction of a dry stone wall, suitable for cultivation. (Bevan & Conolly, 2011) Besides creating cultivation space, terraces are valuable for the conservation of natural resources, as they reduce the speed of surface runoff water, control erosion if properly maintained and increase water infiltration in the soil. (Rackham & Moody, 1996). Extended terraced landscapes indicate local knowledge of soil and water conditions in an area and particular stone craftsmanship.

At the same time, irrigation channels were constructed to divert water from natural springs or rivers to irrigate crops, often managed collectively by local communities. In many villages, community-based water management systems were established to ensure equitable distribution and maintenance of water infrastructure.

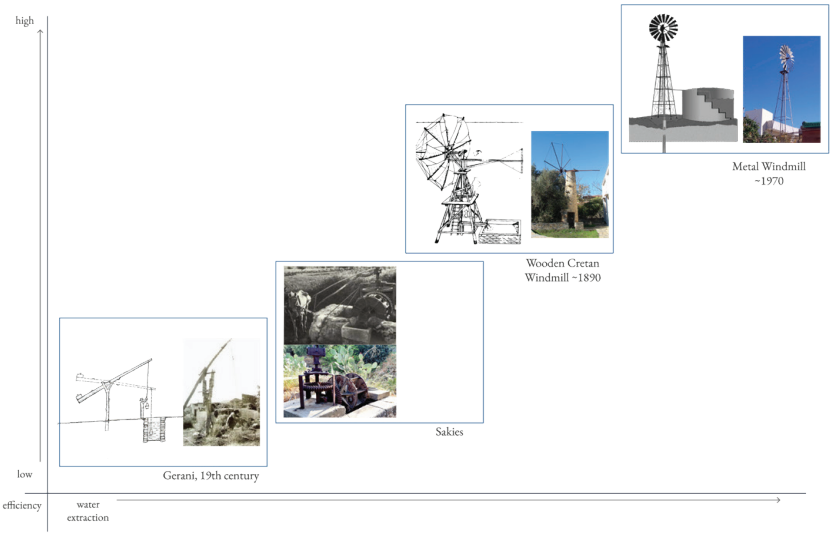


Figure 55: Most important traditional water infrastructure in Crete, designed by author

Figure 56: (left) Well for groundwater extraction (right) Gerani for water extraction, 19th century, sources (left) *https://argolikivivliothiki.gr/2020/06/27/fountains-wells-sterns/* (right) *https://maleviziotis.gr/2022/07/01/%CF%84%CE%BF-%CE%B3%CE%B5%CF%81%CE%AC%CE%BD%CE%B9-%CF%8E%CF%82-%CF%84%CF%81%CF%8C%CF%80%CE%BF%CF%82-%CE%AC%CE%BD%CF%84%CE%BB%CE%B7%CF%83%CE%B7%CF%82-%CE%BD%CE%BD%CF%81%CE%BF%CF%8D/*

Figure 57: Water pumping windmill and water tank at Lasithi plateau, Lasithi, photograph by author

Figure 58: Water pumping windmill at Hersonissos, Heraklion, photograph by author

Figure 59: Terraced agriculture - Xerolithies at Fourni, eastern Crete. Source:
https://www.anatolh.com/topikanea/agiosnikolaos/oi-xerolithies-tou-merabellou/

Figure 60: Terraced agriculture - Xerolithies at Katharo mountain, eastern Crete., photograph by author

Figure 61: Monastery fountain, 1927. Source: *https://www.zarpaneus.gr/%CE%B7-%CE%BA%CF%81%CE%AE%CF%84%CE%B7-%CF%84%CE%BF%CF%85-1927-1939-%CE%BC%CE%AD%CF%83%CE%B1-%CE%B1%CF%80%CF%8C-47-%CF%85%CF%80%CE%AD%CF%81%CE%BF%CF%87%CE%B5%CF%82-%CF%86%CF%89%CF%84%CE%BF%CE%B3%CF%81/*

Figure 62: Filling the pitchers with water, 1927, Prefecture of Heraklion. Source: *Nelly's*, *https://www.zarpaneus.gr/%CE%B7-%CE%BA%CF%81%CE%AE%CF%84%CE%B7-%CF%84%CE%BF%CF%85-1927-1939-%CE%BC%CE%AD%CF%83%CE%B1-%CE%B1%CF%80%CF%8C-47-%CF%85%CF%80%CE%AD%CF%81%CE%BF%CF%87%CE%B5%CF%82-%CF%86%CF%89%CF%84%CE%BF%CE%B3%CF%81/*

Water management in Crete during the 20th century underwent significant changes and challenges, reflecting the island's increasing population, changing agricultural practices, and evolving economic landscape. It started to incorporate modern technologies and practices. Historically, Crete has been an agricultural society, and water management was crucial for sustaining agricultural practices.

In the early to mid-20th century, there was a transition from traditional to more modern irrigation methods including the use of open canals, pipes, and pumps to distribute water more efficiently to agricultural fields. These modern methods represented advancements in technology and infrastructure, reflecting the island's adaptation to changing agricultural and economic needs. Later on, some water mills were adapted to generate hydroelectric power, contributing to rural electrification efforts on the island. Some larger scale water management infrastructure were created including the construction of reservoirs, dams, and water treatment plants to meet the increasing demand for drinking water in urban centers.

Piped water supply systems became more widespread, providing inhabitants with a reliable source of treated water. However, access to piped water remained limited and some rural and remote areas continued to rely upon traditional water resources.

Figure 63: Public cistern used for water supply of the village of Lakonia in the eastern Crete, 1900. Source: *https://www.slideshare.net/pergeo/brief-history-of-minoan-technologies-a-angelakis*

To address water storage needs and regulate water supply, several dams and reservoirs were constructed on the island storing rainwater and water from the rivers during the wet season for later use during dry periods. Dealing with the growing human needs for water, whether for agriculture, energy production, or to meet the needs of cities, as well as the need to deal with floods has led to a development and expansion of dams in number and size. Indeed, the retention of the fresh water that escapes from the rivers to the sea, could largely satisfy human needs. (Εκπαίδευσης, n.d.-b)

Water reservoirs

Water reservoirs are artificial lakes created by excavation and embankment in a selected area with suitable morphological characteristics that collect rainwater that can be used to supply agricultural water needs.

Figure 64: Small scale water reservoir at Ierapetra, photograph by author

Figure 65: Low water levels of water reservoir at Lasithi, created to prevent from flooding and collect the water for agricultural water supply , photograph by author

Figure 66: Traditional water reservoir at Limnes, Lasithi, photograph by author

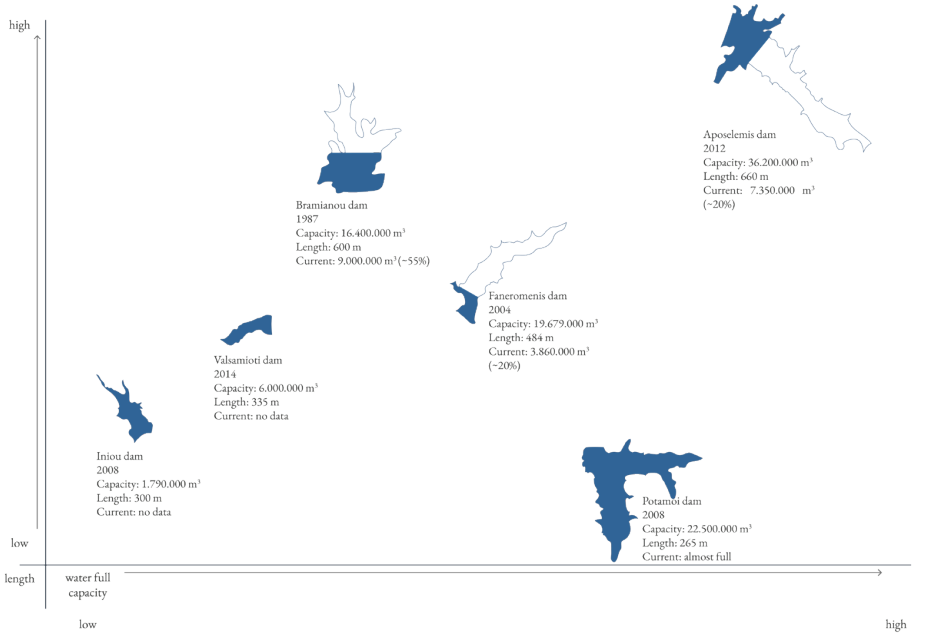
Figure 67: Water reservoir at Vainia, Ierapetra, photograph by author

A dam is a man-made obstruction placed across a river or stream to block the flow of water. They are created to control or reduce the flow of water downstream while collecting and raising the level of the water behind the dam to cover the water needs of settlements or agricultural areas. Dams are usually located in strategic physical locations and are supplied by water from the rain and rivers.

However, dams can have sometimes negative environmental and social impacts such as the social impacts of forced relocation, the loss of good quality land, the problem of water loss in hot and dry areas through evaporation from the artificial lake and canals, and from high leaks in the distribution networks and the occurrence of earthquakes due to the pressure exerted by the large amount of water on geologically fragile soils, and finally that the dams' artificial lakes quickly fill with silt. (Εκπαίδευσης, n.d.)

The first dam created in the island Crete is the Bramiana dam, located near the city of Ierapetra in the southeastern part of the island. It was created in the junction of two seasonal streams, one of them named Bramianos which gave the name on the dam. In 1976, the tender for the construction of the dam was held and its construction began afterwards. The construction of the dam costed approximately 1,000,000,000 dirhams and was completed in 1986, making it one of the earliest hydraulic projects on the island. The dam was built to secure water resources for agricultural activities in the surrounding area irrigating about 45,000 acres, 22,000 within and 23,000 outside the irrigation zone. More specifically, it supplies with water 15,000 acres of greenhouses, 450,000 olive trees and 150,000 Citrus and various trees. (OCTO NETWORKS, n.d.)

This artificial lake in such an arid region, that was created to enhance the regions resilience during periods of drought, soon became a great wetland and migratory bird station. Today, it attracts larger waterfowl populations in Crete characterizing it area as a national park. (Kales, M., July 2013)



*Current situation on March 2024

Figure 68: Largest dams in Crete and current water capacity, designed by author

Figure 69: Bramiana Dam, 2024, completed in 1986, photograph by author

Figure 70: Bramiana dam extremely low water level December 2023, photograph by author

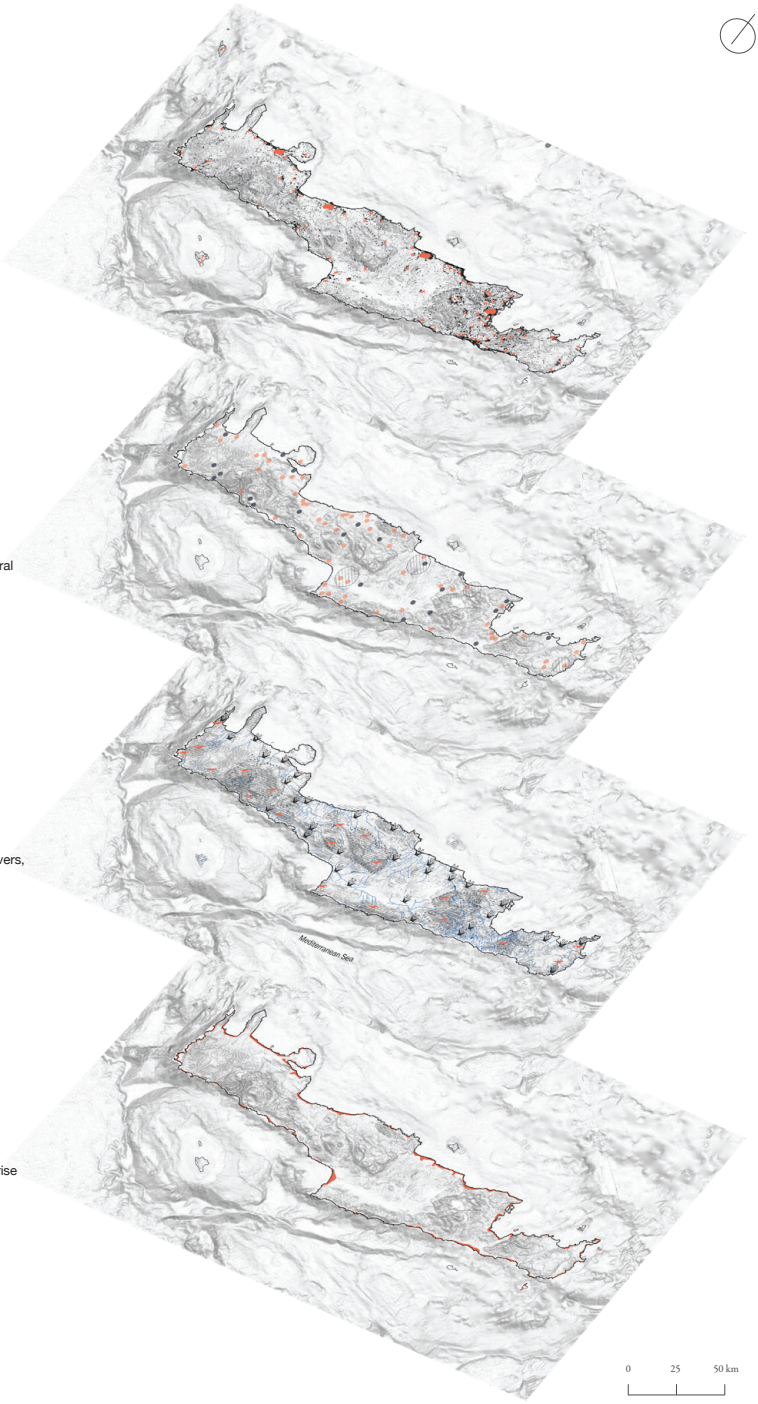
Figure 71: Bramiana dam extremely low water level December 2023, photograph by author

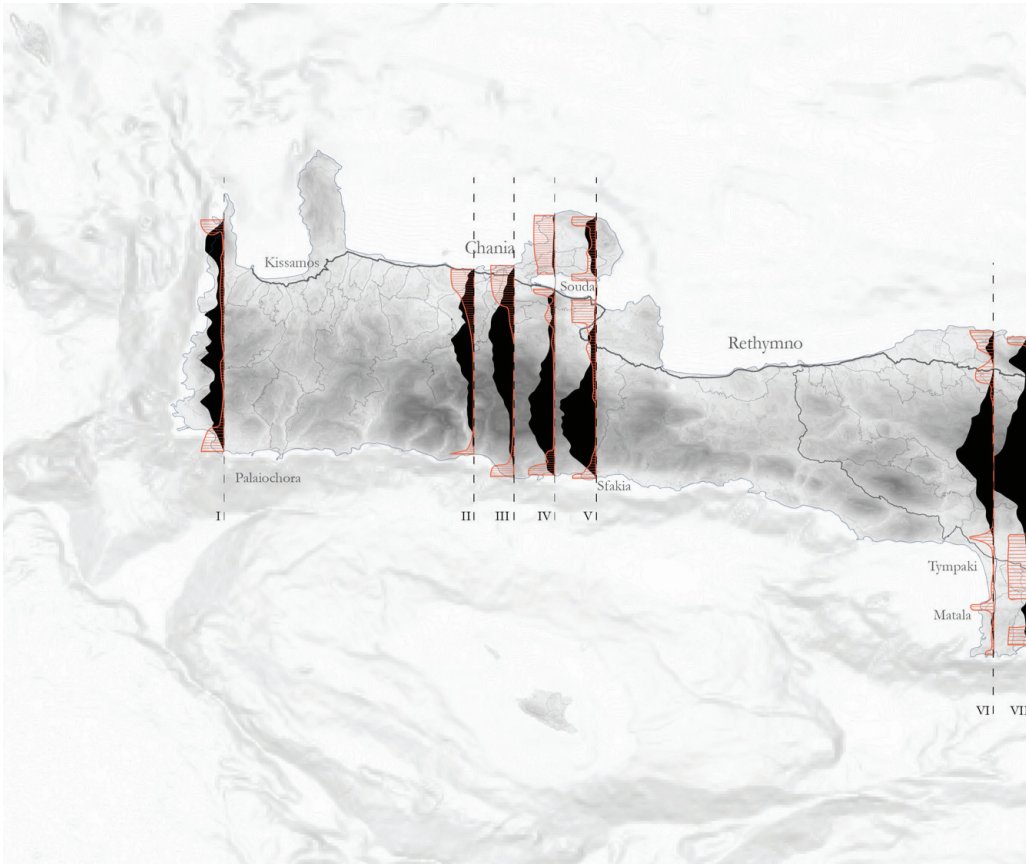
Interconnections between human and non human ecosystems

The communities and agricultural practices on Crete are inextricably linked to the availability and management of water, as well as the preservation of soil fertility. Sustainable water management strategies are essential not only for ensuring the survival and prosperity of these communities but also for safeguarding the island's ecological integrity and preserving its natural heritage for future generations.

The island of Crete has been shaped by several key characteristics, forming a complex network of historical, cultural, urban, and environmental systems. One fundamental element that expresses the complexity of the system is the concentration of the largest urban areas along the Northern coast of the island, and that many of these cities hold significant historical and cultural importance, often including ancient ruins, Venetian fortresses that played a critical shaping role for the landscape transformation.

Additionally, Crete accommodates a variety of unique natural and dynamic ecosystems as presented earlieer, often sensitive to radical changes. All the above features are incredibly sensitive to changes, especially climate changes such as sea level rise and water scarcity that can disturb the ecosystem's equilibrium.


Urban and rural settlements
Areas with historical and cultural importance
Natural elements (wetlands, rivers, Natura 2000)
Affected areas from sea level rise ~10 meter sea level rise
Mediterranean Sea
0
25
50 km


Kissamos
Ghania
Souda
Rethymno
Palaiochora
Sfakia
Tympaki
Matala
I
II
III
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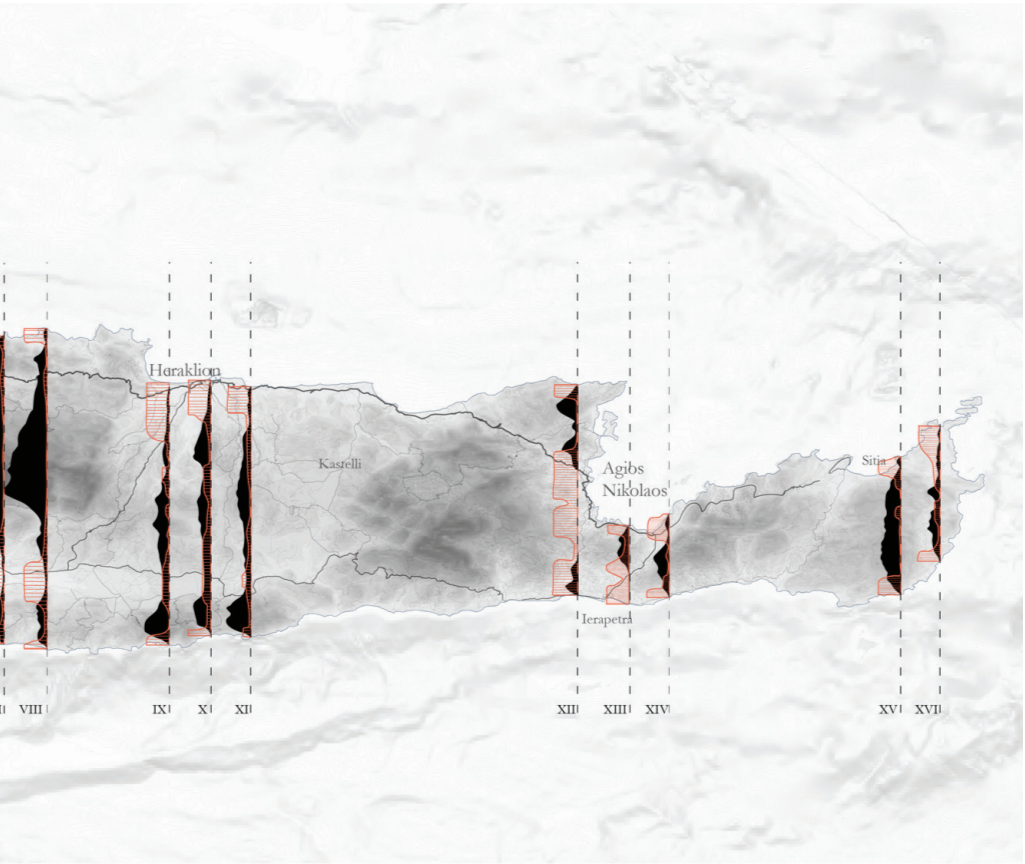
V
VI
VII
0
25
50 km

Topography and population



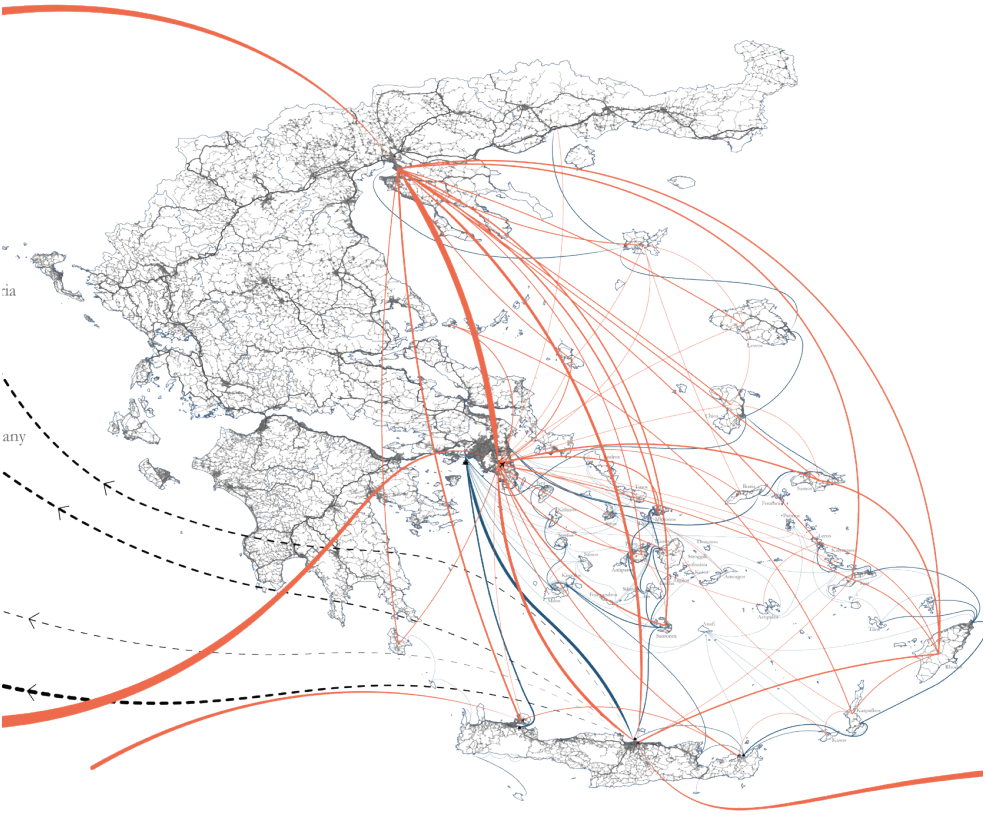
How diverse and different are the coasts with each other?
How is the population of the island influenced by the topography?
Where are the largest cities concentrated?

Economies of the island

Historically, Crete has been an agricultural society, and water management was crucial for sustaining agricultural practices. The development of agricultural ecosystems was essential for the survival and growth of Crete's early inhabitants, with water management playing a critical role in sustaining these practices.

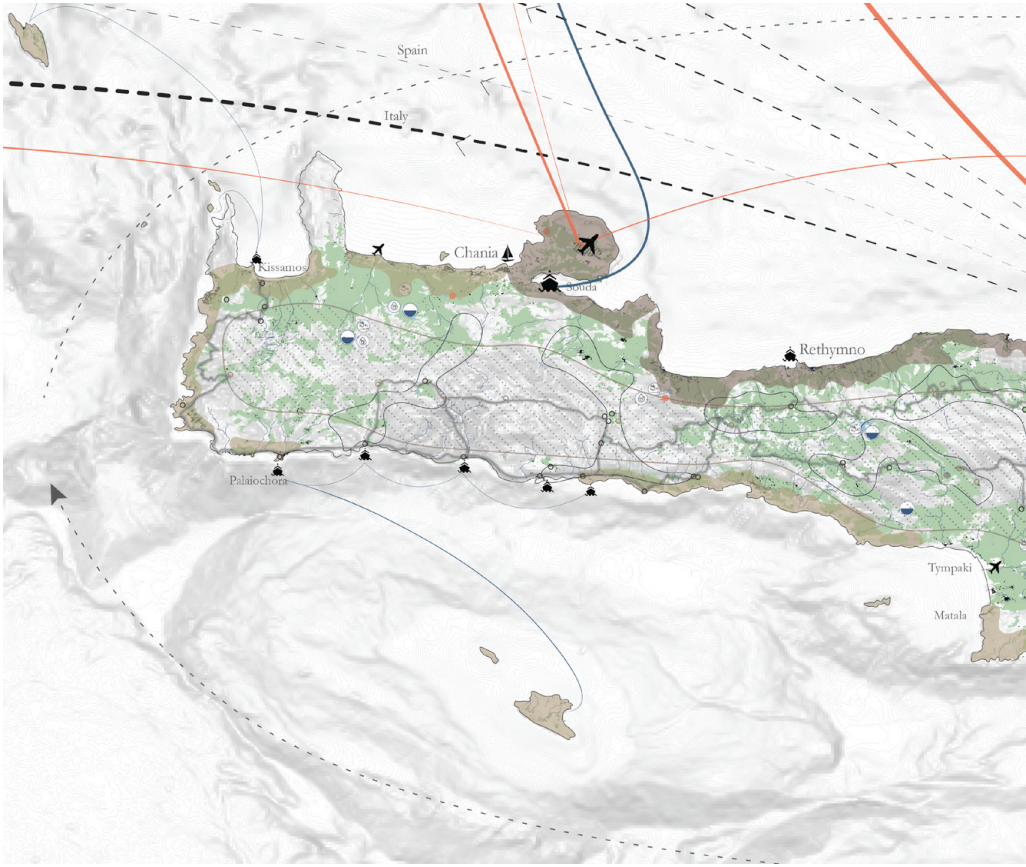
In recent decades, tourism has become a significant economic driver for Crete, and is significantly related to water. Firstly, because Crete is an island surrounded by water with long and diverse coastlines. Especially the northern coast of the island is highly developed and accomodates a large influx of tourists every year. This growth in tourism has brought economic benefits, including job creation, increased income, and enhanced infrastructure. However, the growth of tourism in Crete, particularly during the latter part of the 20th century, added additional pressure on water and soil resources. Increased demand for water in hotels, resorts, and for recreational purposes. In Crete during the summer period the population increases by almost three times the permanent inhabitants. According to the population count of 2021, the population of Crete was 582.846 and the international and internal visitors for the year 2020 were around 1.100.000 and 445.000 respectively, summing up to approximately 1.550.000 people. (Eurostat, 2020) Consequently, the water consumption due to seasonal fluctuations of the population in tourist areas is getting higher, stressing the freshwater supply that occurs usually during the dry season, when tourist demand overlaps with high water demand by agriculture. (De Stefano, 2004) At the same time, tourism development is unequally divided on the island, even between the northern and southern coast, with the northern coast being the most tourism-developed region that has reached its saturation levels. More potential for alternative tourism activities is observed towards the inland, which could be related to agricultural practices and cultivation or ecotourism with unique and diverse landscapes that could support and promote the rural communities.

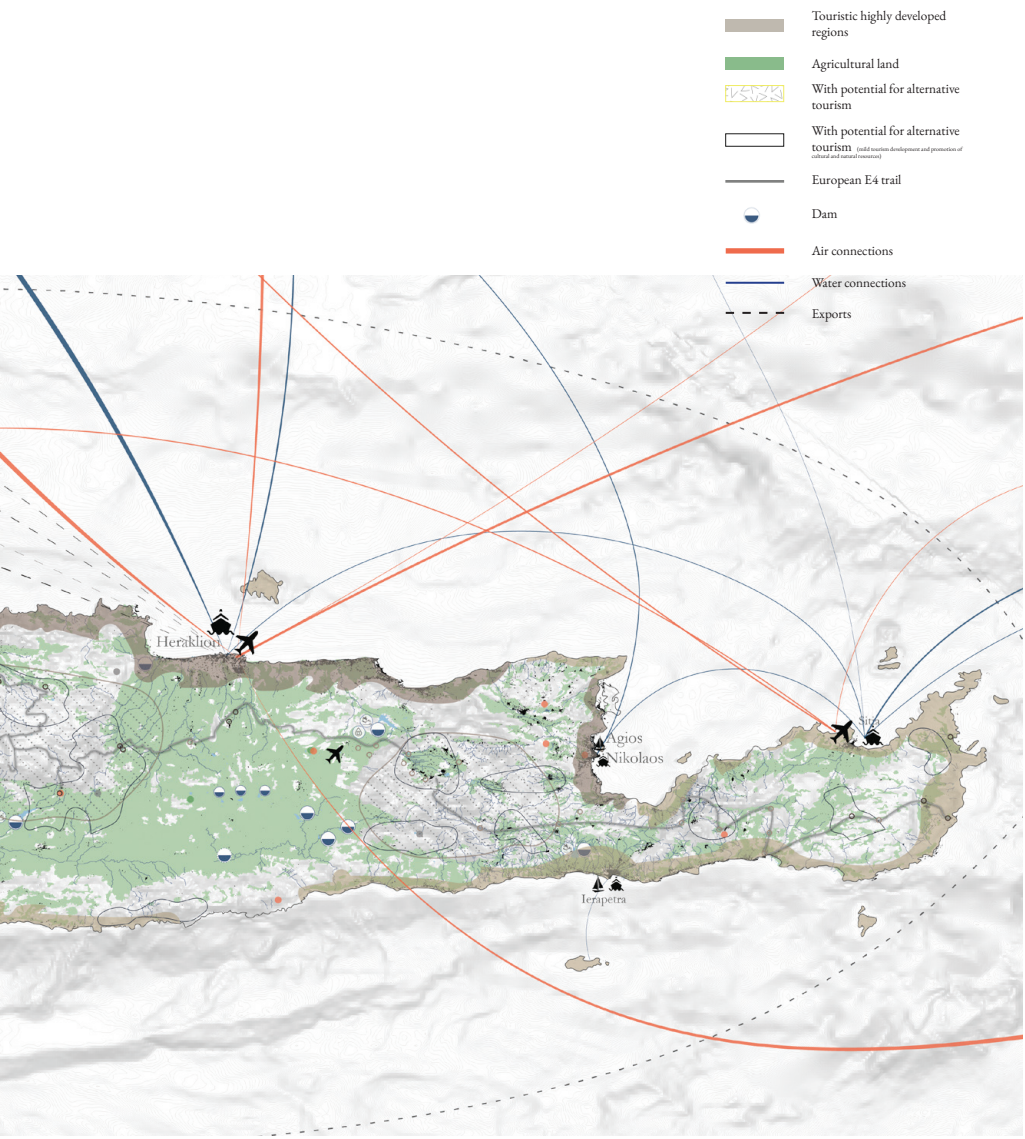
Overall, Crete's economic sustainability relies heavily on its ability to manage its (water, soil) resources efficiently, balancing the needs of its agricultural sector with the demands of an increasing tourism industry. Effective water and soil management practices are key to preserving the island's natural resources and ensuring long-term economic and environmental prosperity for its inhabitants.

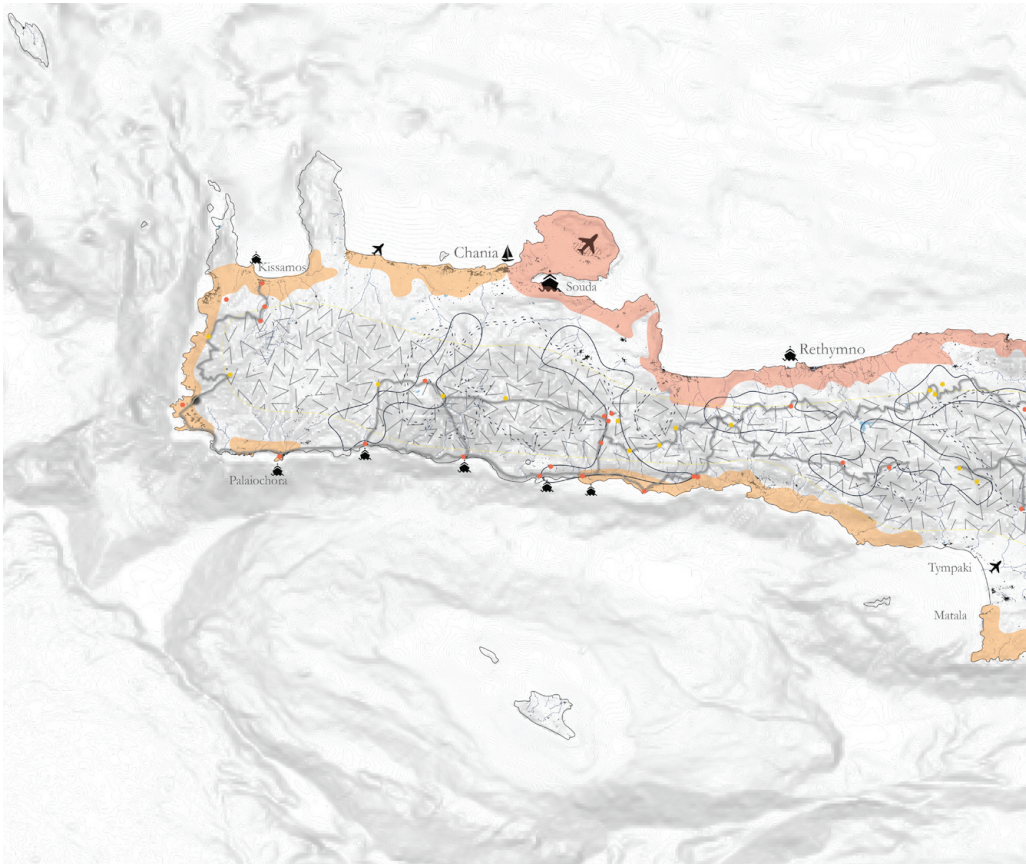


Primary road network
Secondary road network
Local road network
Airport
Main port
Secondary port
Air connections
Water connections
Exports

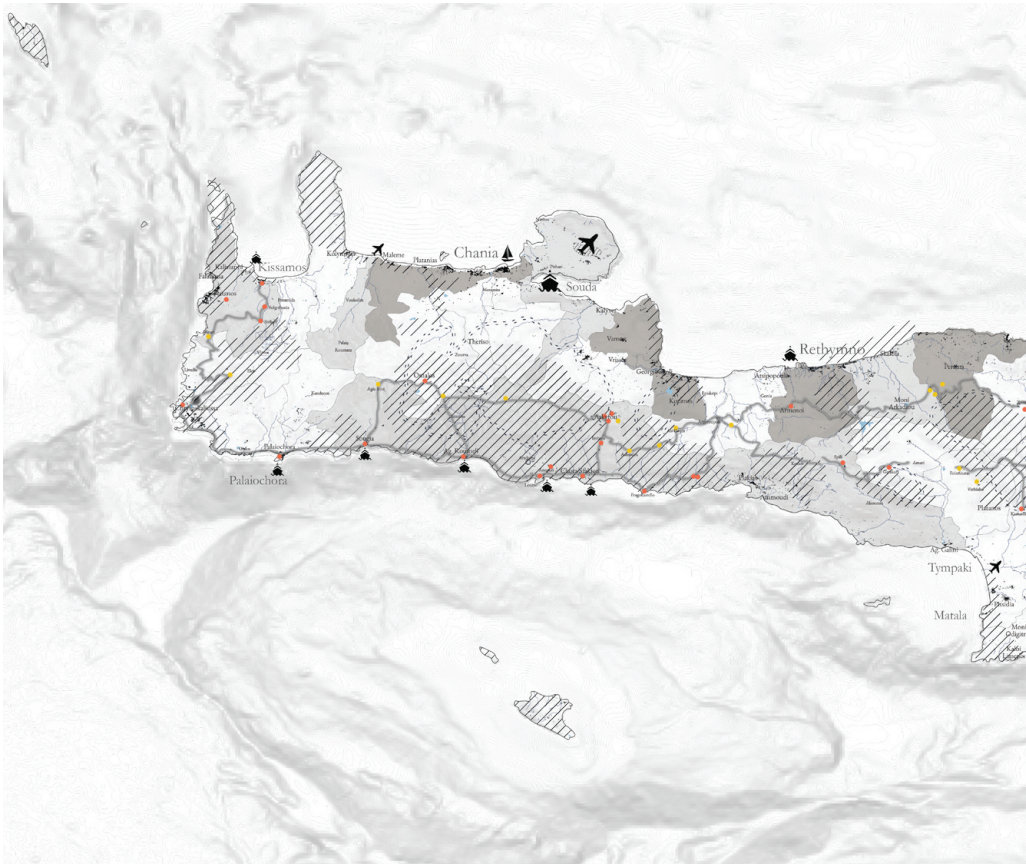
0 100 200 km


Spain
Italy
Kissamos
Chania
Souda
Rethymno
Palaiochora
Tympaki
Matala
0
25
50 km


Touristic highly developed regions
Agricultural land
With potential for alternative tourism
With potential for alternative tourism (mild tourism development and promotion of cultural and natural resources)
European E4 trail
Dam
Air connections
Water connections
Exports
Heraklion
Agios Nikolaos
Sitia
Ierapetra


Kissamos
Chania
Souda
Rethymno
Palaiochora
Tympaki
Matala
0
25
50 km

Touristic Development


Kissamos
Chania
Souda
Rethymno
Palaiochora
Tympaki
Matala
0
25
50 km

Sea exploitation
(Number of beds per km beach),
European trail 4 (E4)

The links between human and agricultural ecosystems of Crete were created when the first inhabitants accomodated on the island about 8,000 years ago and carried domesticated animals and cultivable plants, such as cereals. Historically, Crete has been an agricultural society, and water management was crucial for sustaining agricultural practices. Until today and for many centuries, three are the main crops of Crete including grains, grapes and olives. In fact, olive and grape production was dominant in Crete, not only in modern times, but also for thousands of years before as the first olive and grape crops date back to about 4,000 years ago.

During the period of Venetian and Ottoman rule, agricultural production focused on comparative products driven by the needs of the conquerors. Initially (1320-1450 AD), the interest of the Venetians turned to the cultivation of grapes. In this period, the extremely high demand for wine from the West led to the creation of large irrigation projects (e.g. drainage system on the Lasithi Plateau) or water supply projects such as the construction of aqueducts and the development of new production techniques for the intensification of wine production. Later, during the presence of the Ottomans in Crete (1645-end of the 19th century AD), the vineyards were replaced by olive groves mainly because the international market had increased needs for olive oil, while the cultivation of the olive was less expensive and did not require the care that the grape production did. (Georgopoulou, E., Kyriakopoulou, N., Plumi, T., 2017)

But apart from the olive and the grapes, Crete produces a wide variety of fruits and vegetables, known for their quality. This change in the agricultural production of Crete came after the liberation of the island from the Ottomans gradually resulting in new production, of (citrus) fruits and various vegetables. (Georgopoulou, E., Kyriakopoulou, N., Plumi, T., 2017)

Nowadays, in addition to the most commonly found vegetables (tomatoes, cucumbers, potatoes and peppers), products such as pears, pomegranates, bananas, avocados and aromatic plants such as dictamom are also essential production that characterize the Cretan island. Beekeeping in Crete has been quite widespread since the Minoan era. This is evident from various archaeological finds, such as the clay cells in the Palace of Phaistos and the golden bee symbol in the Palace of Malia. (Georgopoulou, E., Kyriakopoulou, N., Plumi, T., 2017) Finally, although the organized livestock units are few, there is intense activity in the cheese and dairy products, mainly in the mountainous areas.

Nowadays, in addition to the most commonly found products (tomatoes, cucumbers, potatoes and peppers), products such as pears, pomegranates, bananas, avocados and aromatic plants such as dictamom are also produced.

Furthermore, although the organized livestock units are few, there is intense activity in the cheese and dairy products, mainly in the mountainous areas. Another sector that has been quite widespread in Crete since the Minoan era is beekeeping. This is evident from various archaeological finds, such as the clay cells in the Palace of Phaistos and the golden bee symbol in the Palace of Malia. (Georgopoulou, E., Kyriakopoulou, N., Plumi, T., 2017)

In terms of vegetation, Crete is mostly covered by natural grasslands and pastures. Olive groves are until today the most extensive croplands and, together with vineyards and fruit plantations occupy a significant part of the land. Evergreen forests, coniferous forests and Mediterranean maquis cover less than 5% of the island since most of the have been wiped out due to settlement development agricultural expansion and pasture intensification. (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018).

Summarizing, the rich agricultural and livestock production as well as the excellent quality of the products has contributed to the economic development and prosperity of the island. It becomes clear that the things offered by the agricultural ecosystems of Crete to humans are not only economic but also part of the cultural heritage of the island shaping the cultural identity of the traditional societies. For example, during the period of the grape harvest and wine production, the declarations of wine connoisseurship are made, while later during the production of tsikoudia (raki) the famous rakokazana (gatherings) are appointed. In these events, in addition to the economic benefit, the social relations of the local community are strengthened, cultural events (e.g. traditional dances, and ritual festivals) are held at the same time and local customs and traditions are disseminated to the citizens. (Georgopoulou, E., Kyriakopoulou, N., Plumi, T., 2017)

Figure 72: Messara, Gathering ears of corn, 1939. Source: *Nelly's* - *https://www.zarpanews.gr/%CE%B7-%CE%BA%CF%81%CE%AE%CF%84%CE%B7-%CF%84%CE%BF%CF%85-1927-1939-%CE%BC%CE%AD%CF%83%CE%B1-%CE%B1%CF%80%CF%8C-47-%CF%85%CF%80%CE%AD%CF%81%CE%BF%CF%87%CE%B5%CF%82-%CF%86%CF%89%CF%84%CE%BF%CE%B3%CF%81/*

Figure 73: Young shepherdess, Crete, 1955. Source: *Erich Lessing* - *https://www.zarpanews.gr/%CE%B7-%CE%BA%CF%81%CE%AE%CF%84%CE%B7-%CF%84%CE%BF%CF%85-1927-1939-%CE%BC%CE%AD%CF%83%CE%B1-%CE%B1%CF%80%CF%8C-47-%CF%85%CF%80%CE%AD%CF%81%CE%BF%CF%87%CE%B5%CF%82-%CF%86%CF%89%CF%84%CE%BF%CE%B3%CF%81/*

Figure 74: Rakokazano (raki production, gatherings). Source: *https://blog.arolithos.com/category/eshop-with-cretan-products/*

Figure 75: Rakokazano (raki production, gatherings) and cultural identity. Source: *https://www.ekriti.gr/kriti-irakleio-kritika-kai-alla/raki-i-alhimeia-toy-stafylioy-tis-fotias-kai-toy-mproytzoy-foto*

Current dominant land covers

The most dominant land use of the island is agriculture, covering approximately 71% of the total land cover, which comprises an important source of income for many of the island's inhabitants, especially the inland, contributing to Crete's GDP by 13%. Cropland in Crete covers 37.7 per cent of the total land area or an area of 313,376.9 ha (including fallow land) (Kosmas, Kounalaki, Karamesouti, n.d.)

The Prefecture of Heraklion has the most extensive cropland area which is located in the Messara Valley. (Kosmas, Kounalaki, Karamesouti, n.d.)
Crete is also the leader of Greece in greenhouse production, followed by Peloponnese, Macedonia, Thessaly and Central Greece.

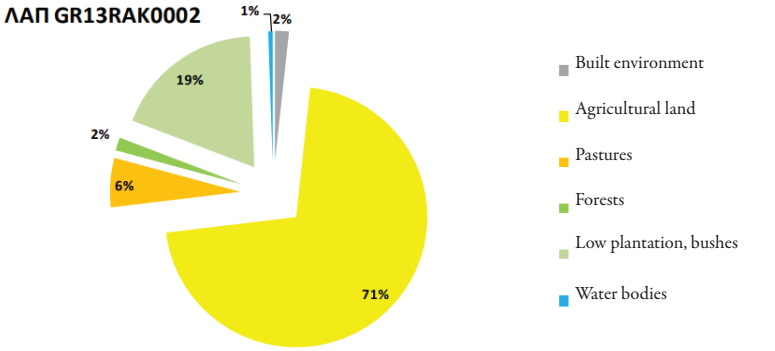
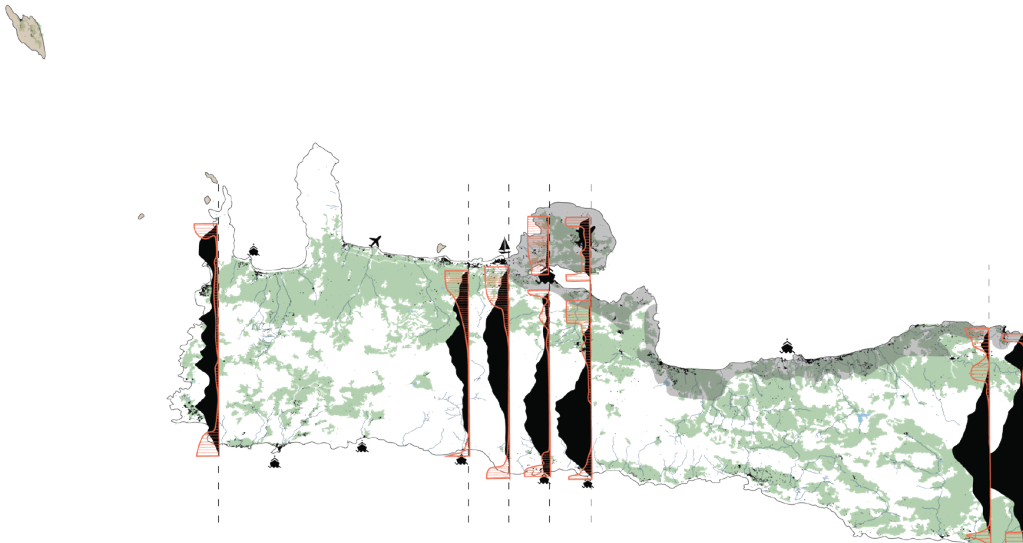


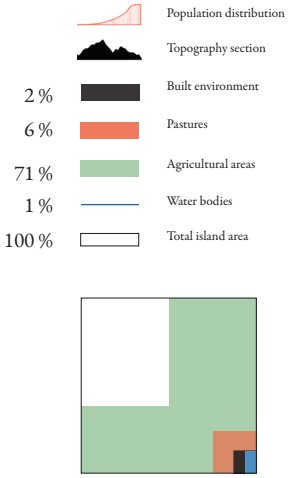
Figure 76: Distribution of land cover per use for Crete, Source: *1st Revision of River Basin Management Plan Crete River Basin District (EL13) (n.d.)*

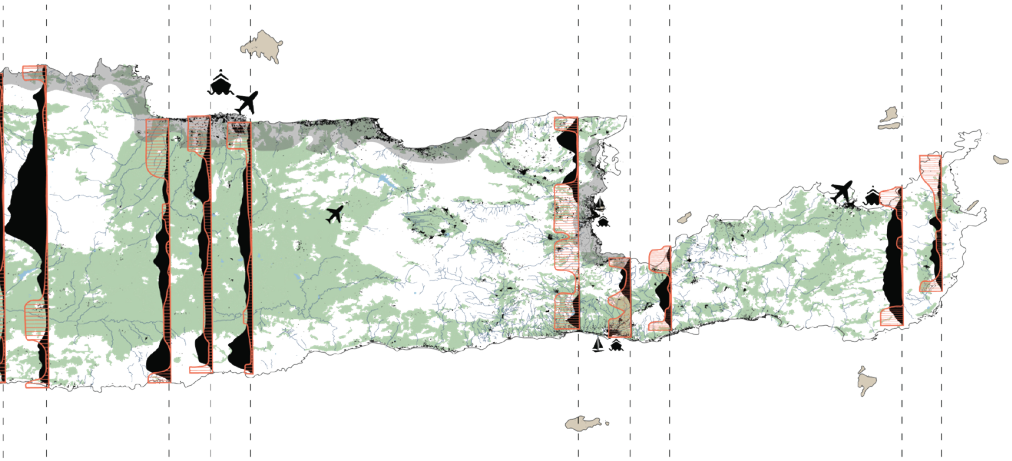
Geographic region	Cropland area (in ha)					
	Total (including fallow land)	Arable land	Garden, raisins	Vines and compact plantations	Crop trees	Fallow land
Crete	313376.9	30017.2	8549.5	25522.8	190082.2	59205.2
Heraklion	145140.8	15198.5	3749.2	19418.8	83770.9	23002.3
Lassithi	55421.6	4911.5	2049.2	2330.3	30628.3	15502.3
Rethimno	51848.5	6204.2	1045.1	1856.1	28605.4	14137.7
Chania	60966.0	3703.0	1706.0	1917.6	47077.6	6561.8

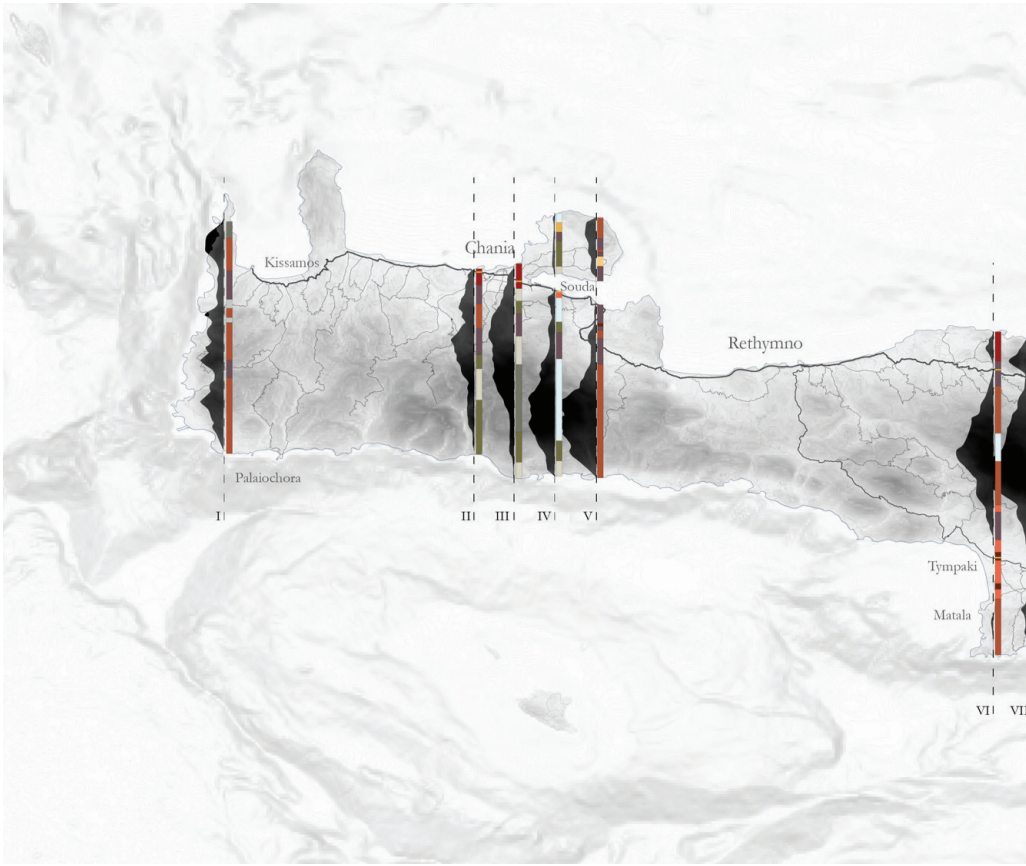
Figure 77: Area of cropland and fallow land in Crete by category and geographic region, 2006 Source: *Greek Agricultural Statistical Service 2006*


0
25
50 km

Dominant land uses






Kissamos
Ghania
Souda
Rethymno
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I
II
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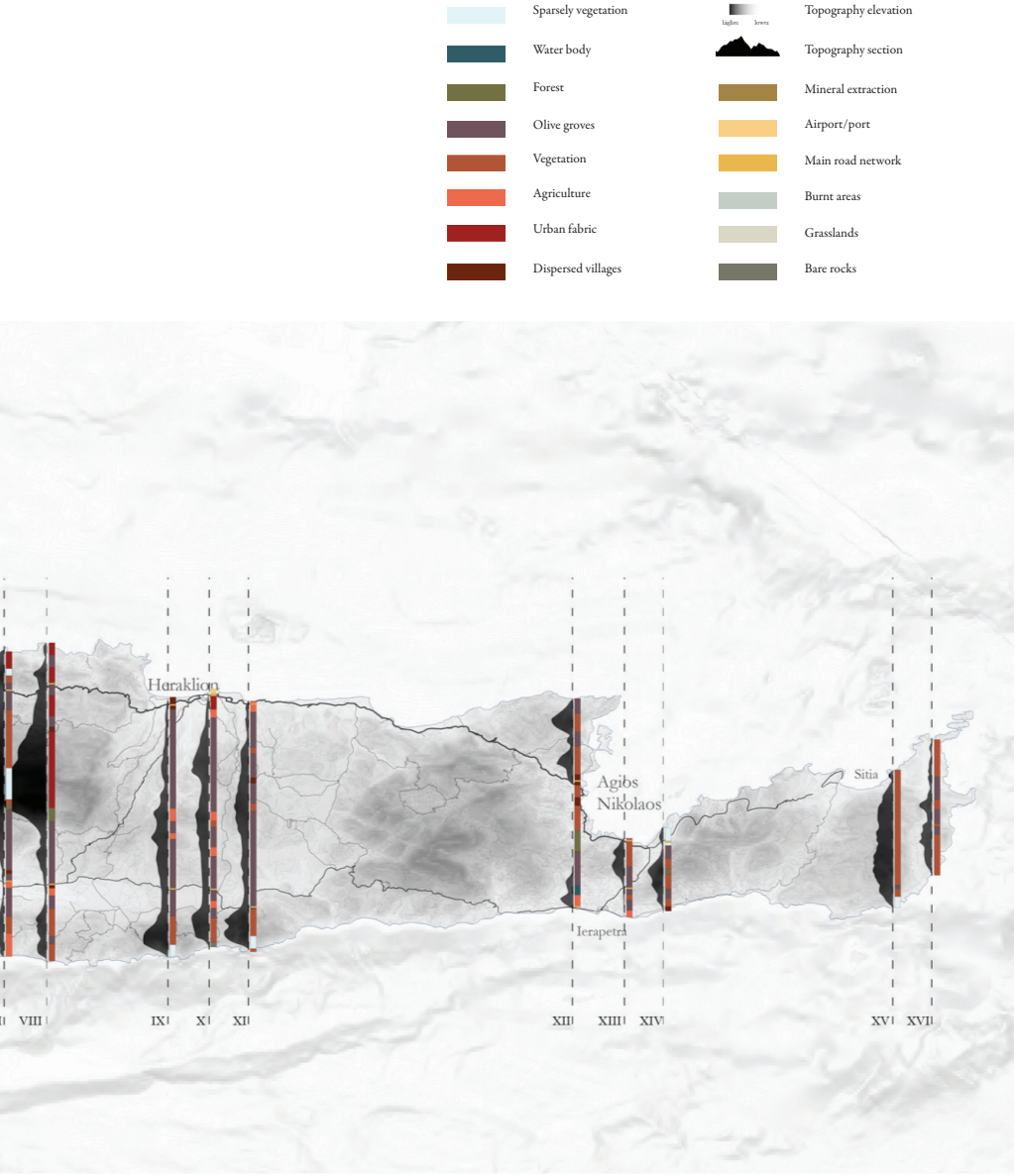
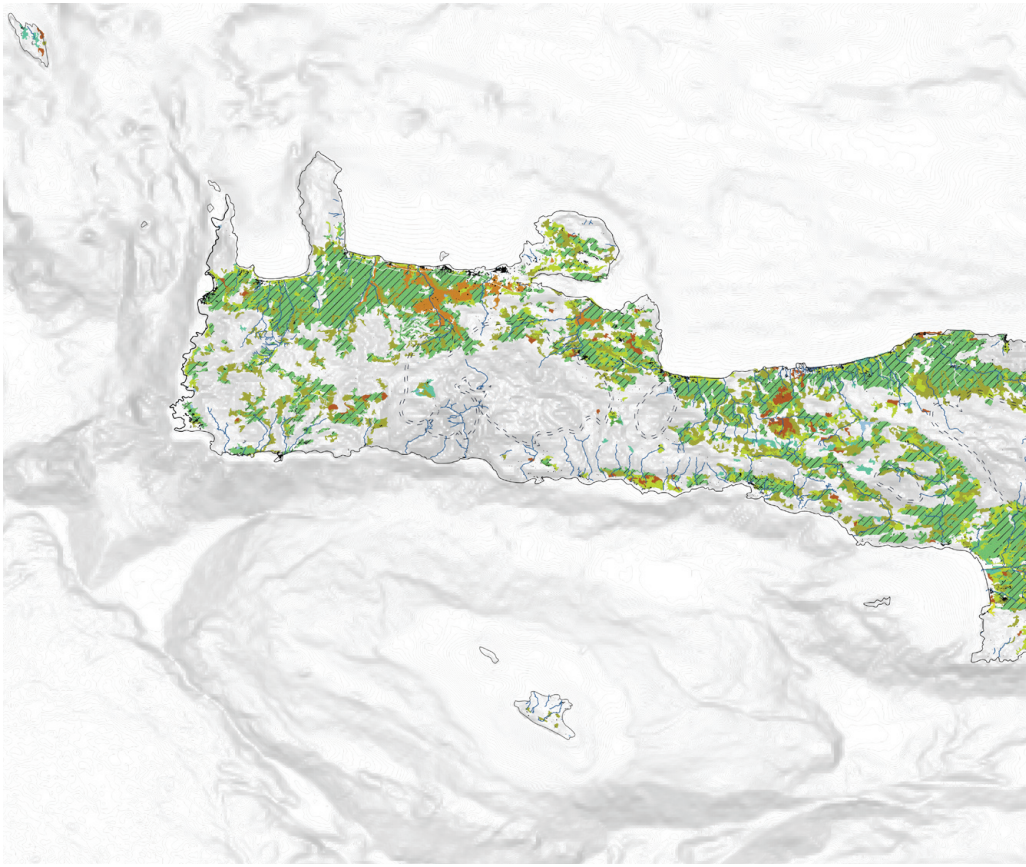
0 25 50 km

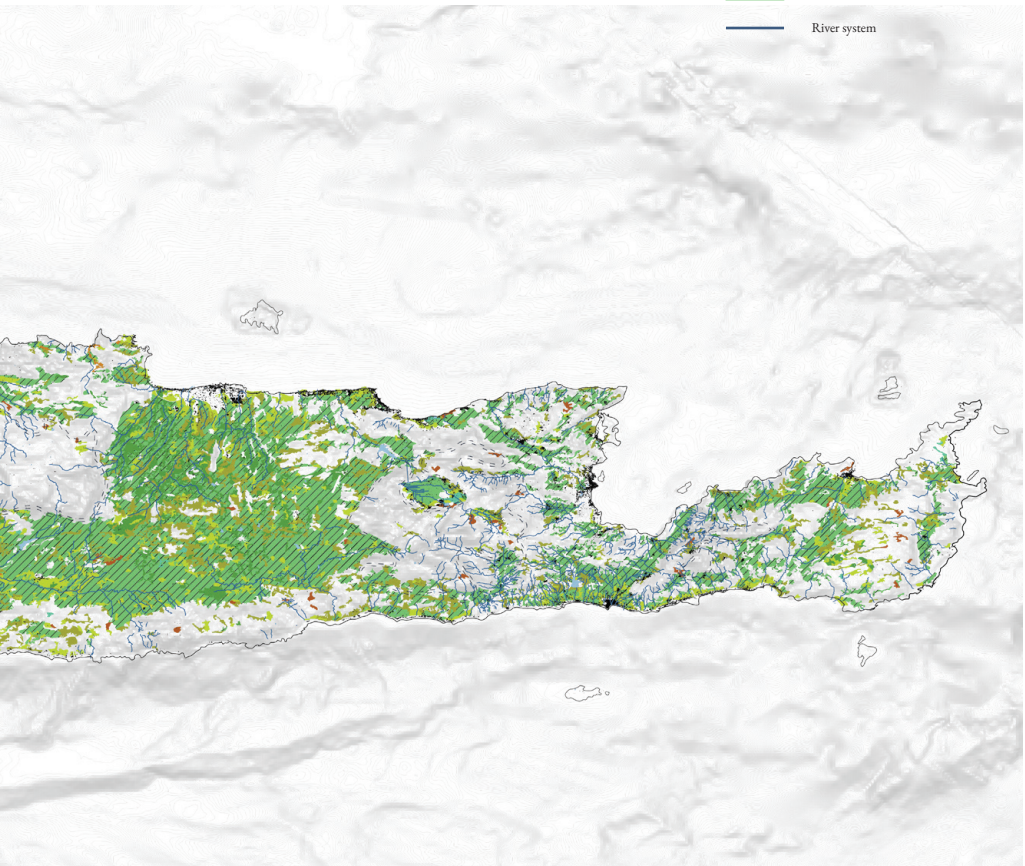
Land use distribution



How diverse and different are the coasts with each other?
How is the zoning of the island influenced by the topography factors?


0
25
50 km

Agriculture types



Agriculture types

The agricultural sector on the island is very economic profit-driven and labour-intensive. This conclusion is even more clear in the areas along the coast that used to have agricultural land use which shifted to tourist development mainly for economic reasons.

Also, olive tree species cover the largest part of the island's agricultural land and can be found across the island. (Kosmas, Kounalaki, Karamesouti, n.d.). They are considered the most important crop, cultivated on all soils and terrain slopes up to altitudes of about 900 m. Olive cultivations usually co-exist with other tree cultivations, such as orange orchards or avocados, and vegetables throughout the island. (Sofoulaki, Tzanakakis, Giannopoulos, Kapellakis, Kabourakis, Chatzistathis, Monokrousos, 2023). The most significant expansion of olive groves occurred during the last forty years, especially in the upper hilly areas by eliminating maquis and shrub vegetation and forests and instead applying more profitable intense cropping systems. Similarly, they abandon olive groves in steep soils of low productivity allowing the natural vegetation to be growing to use the land as pasture which is usually overgrazed threatening the soil with erosion. (Wageningen University & Research-Designing Systems for Informed Resilience Engineering, n.d.)

Similarly, in the last years the farmers are replacing crop types with other more water-intensive, only to gain more profit, such as the citrus plantations that were replaced with avocado since their prices have declined. This situation together with the water scarcity on the island is threatening even more food security undermining island's climate adaptation. Lastly, cereal's number radically decreased in Crete after 1950 and was replaced mainly by olive trees and vines. (Kosmas, Kounalaki, Karamesouti, n.d.).

Traditional agricultural practices have shifted over time partially due to technological advancements that have increased efficiency and productivity. (University of Michigan Urban & Regional Planning Capstone Project., 2009). However, due to high ownership fragmentation of the agricultural land on the island (average size of the fields in Crete is 0.5–1.0 ha) and rough topography, management is unusual on a large scale, and crop picking is almost always taking place in traditional and labour-intensive ways, using minimal mechanical equipment. (SoilCare-For profitable and sustainable crop production in Europe, n.d; Sofoulaki, Tzanakakis, Giannopoulos, Kapellakis, Kabourakis, Chatzistathis, Monokrousos, 2023)

Currently, the eight main intensive agricultural regions are dominated by tree crops (olive, citrus, avocado), vineyards, and greenhouse cultivation (cucumbers, tomatoes, ornamental crops). (Morianou, G. G., Kourgialas, N. N., Psarras, G., & Koubouris, G. C., 2018). More common agricultural products cultivated in Crete are potatoes, onions, broccoli, beans, eggplants, zucchini, and various other vegetables and fruits.

Another economy-driven agricultural practice in Greece, is greenhouse production of mainly tomatoes, peppers, eggplants, zucchini, cucumbers, watermelons, melons, green beans, lettuce and strawberries. According to International Society for Horticultural Science, the total number of greenhouse crops in Greece covers an area of 5,600 ha. and Crete island is the leading region of Greece in greenhouse production.

Finally, there are important differences between the conditions of the western and eastern parts of the island of Crete that influence agricultural activities. The agricultural areas in the western part of the island are characterized by coarse and medium soil texture and are considered as areas where olives, avocado and citrus trees thrive due to the local climate conditions. On the other hand, the agricultural areas in the eastern part of the island consist of fine soil texture and drier climate conditions. The dominant crops in this part of the island are olive trees and grape vines. Among these crops, olives can be considered remarkably drought-tolerant (Koubouris et al. 2015).

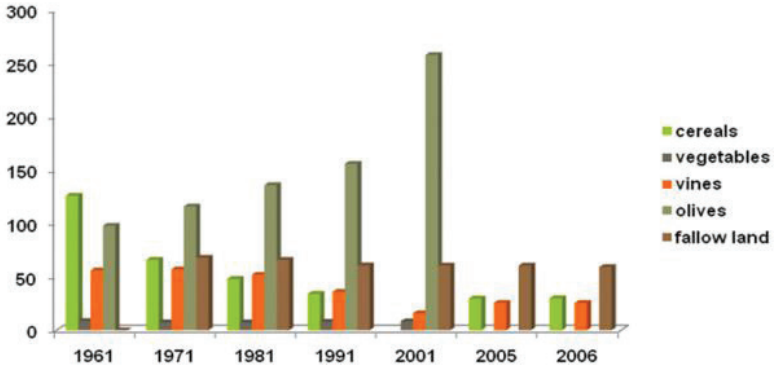


Figure 78: Change in cropland area (ha x 10^3) in Crete over time. Source: *Greek Agricultural Statistical Service 2006*

Figure 79: Main seasonal agricultural types produced in Crete, above: Source: *https://cyclingcreta.gr/villages-and-areas-of-crete-which-are-famous-for-their-products/*

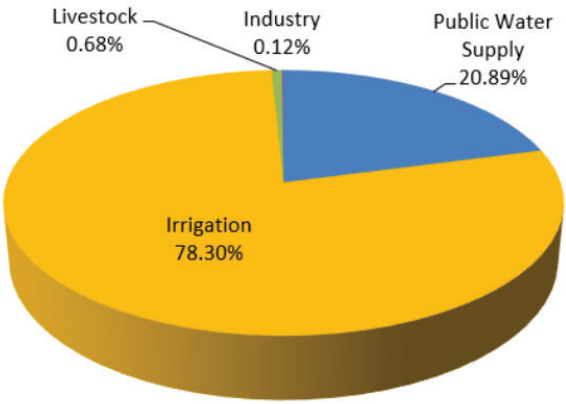


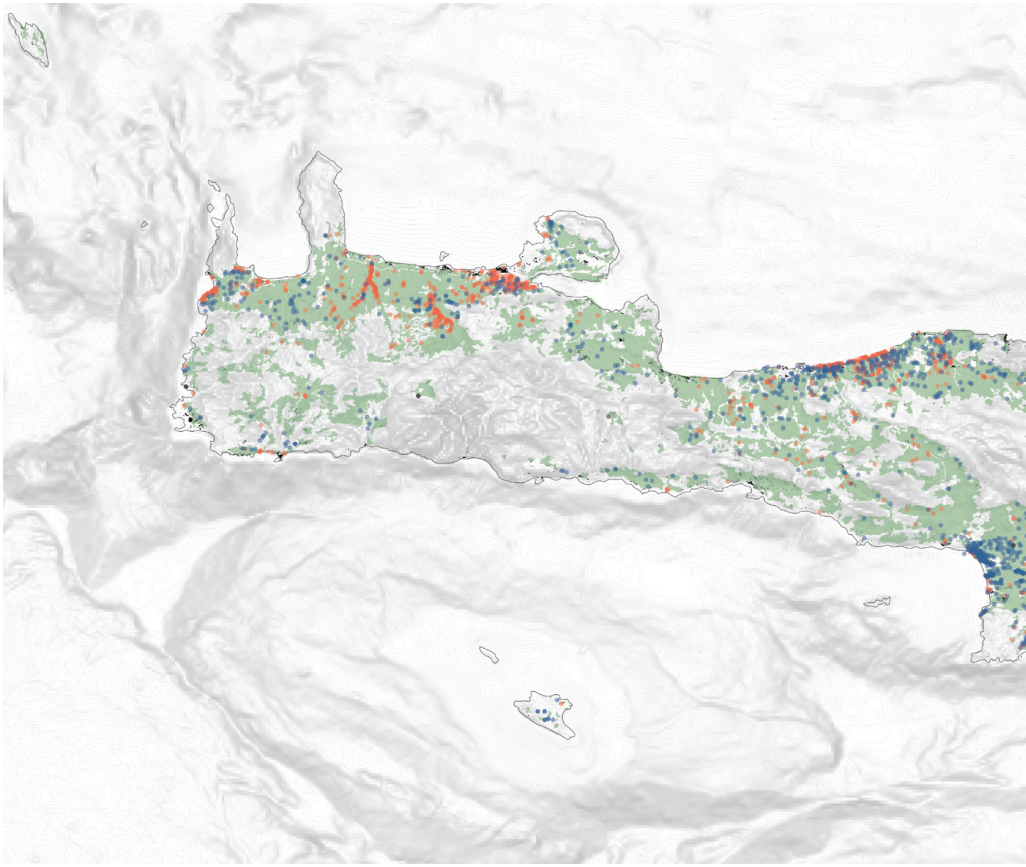
Figure 80: Distribution of water needs per use for Crete RDB (EL13), Source: *1st Revision of River Basin Management Plan Crete River Basin District (EL13) (n.d.)*

Human influences on water resources

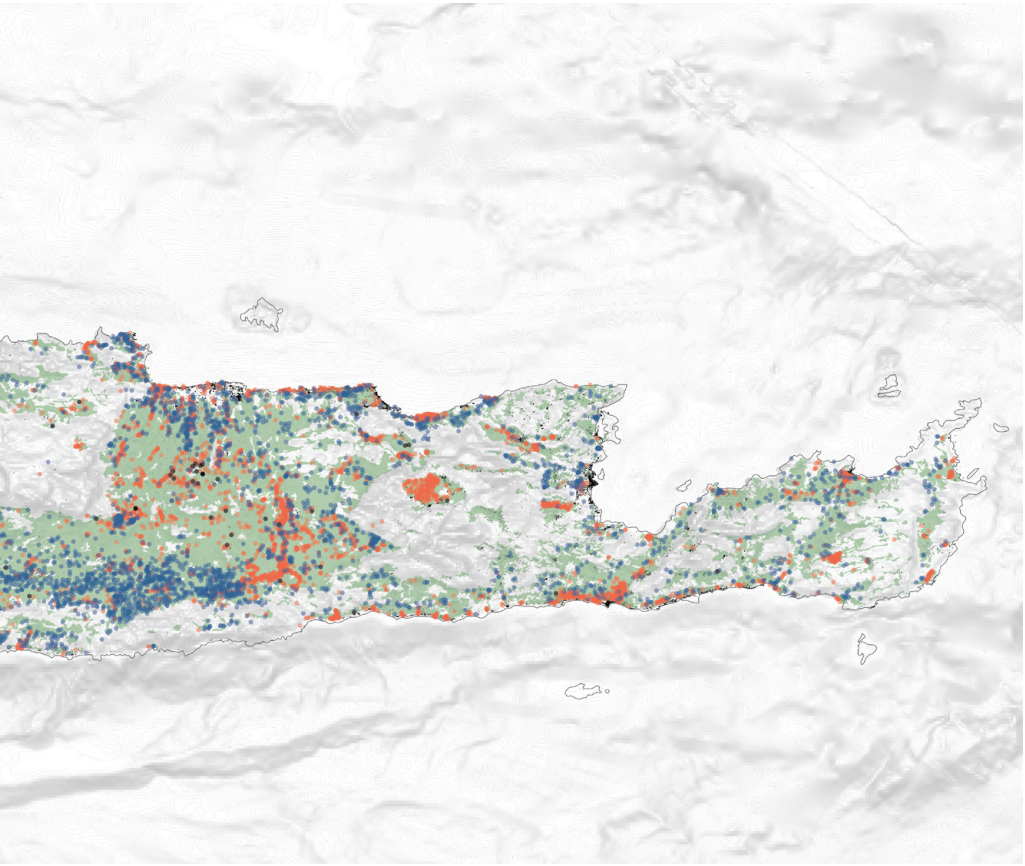
While more land area is needed for the increasing needs of the population, millions of hectares of farmland are lost every year due to inadequate water management and soil degradation, such as poor drainage leading to high salt levels that destroy soil fertility. The use of water from rivers and streams was traditionally used to irrigate fields and to operate watermills to support human agriculture and other activities. As urbanization increased, there was a growing demand for water in urban and rural areas which resulted in the expansion of infrastructure for water supply systems, with the drilling of wells, installation of pipelines, and the construction of water treatment plants.

Similarly, agriculture affects the quantity of water available for human use in two main ways. Firstly, agricultural use on the island demands an enormous amount of water to be sustained, approximately 78 per cent of the total water use, amount that nowadays, cannot always be met. The water amount that will be needed based on mathematical models and climate change for 2040 and 2050 will be significantly higher than in 2020. The 83 million cubic meters of water (needed) for 2020, will end up being about 130 million cubic meters which will be needed for the water supply. Secondly, agriculture is responsible for changes in land use that affect the way that water is collected, stored and released into the environment. Changing natural grasslands or forests into farmland, or plantations, affect the overall availability and cycle of water in a river basin (WWF – Living water. Conserving the source of life, 1986)

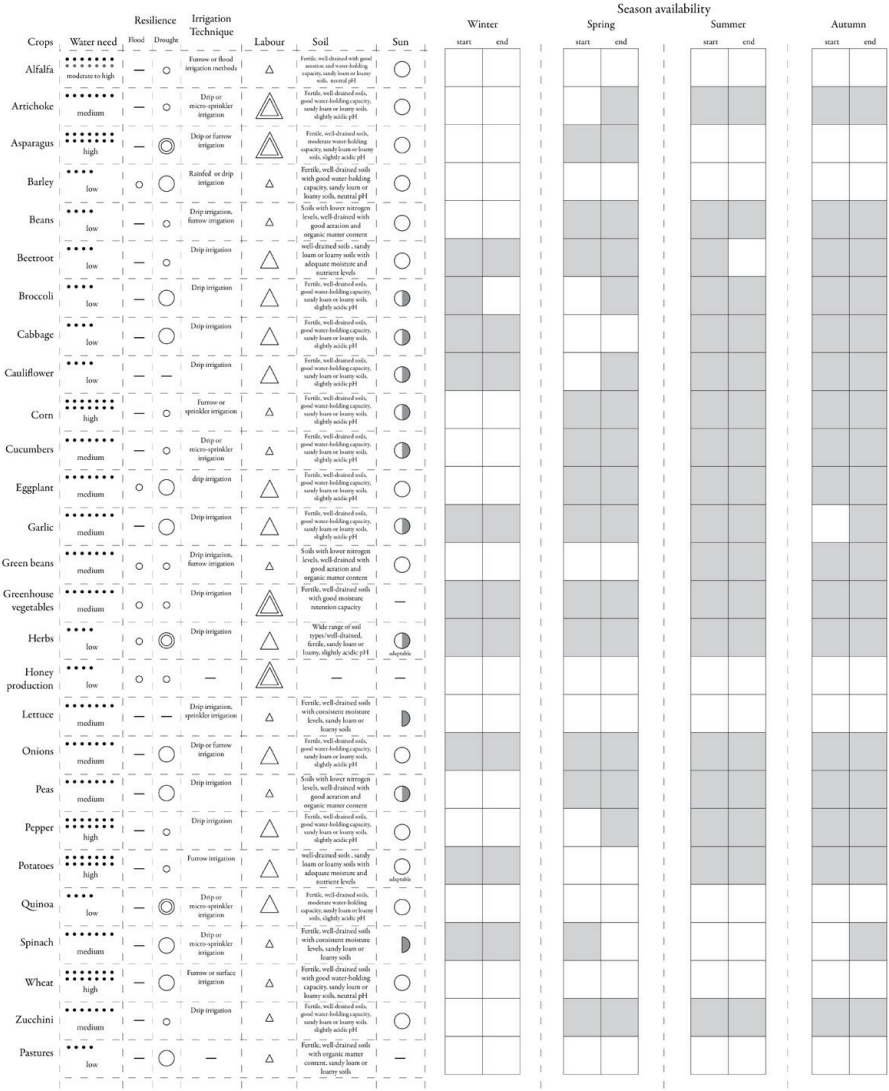
The intensification of agriculture, especially in water-intensive crops like vegetables and fruit orchards, increased the demand for water resulting in excessive water pumping and overexploitation of the groundwater table. This posed challenges in managing water resources sustainably leading to concerns about groundwater depletion and saltwater intrusion in coastal areas. (Pergialiotis, 2003; Karamanos, Aggelides, & Londra, n.d.). At the same time, agriculture is the largest source of pollution, including water pollution, in most countries including Greece and therefore Crete. (WWF – Living water. Conserving the source of life, 1986) More specifically, it is polluting the water with pesticides, fertilizers, or sediments.


0
25
50 km

Agriculture and water extraction



Vegetables, Grains, Other



Fruits

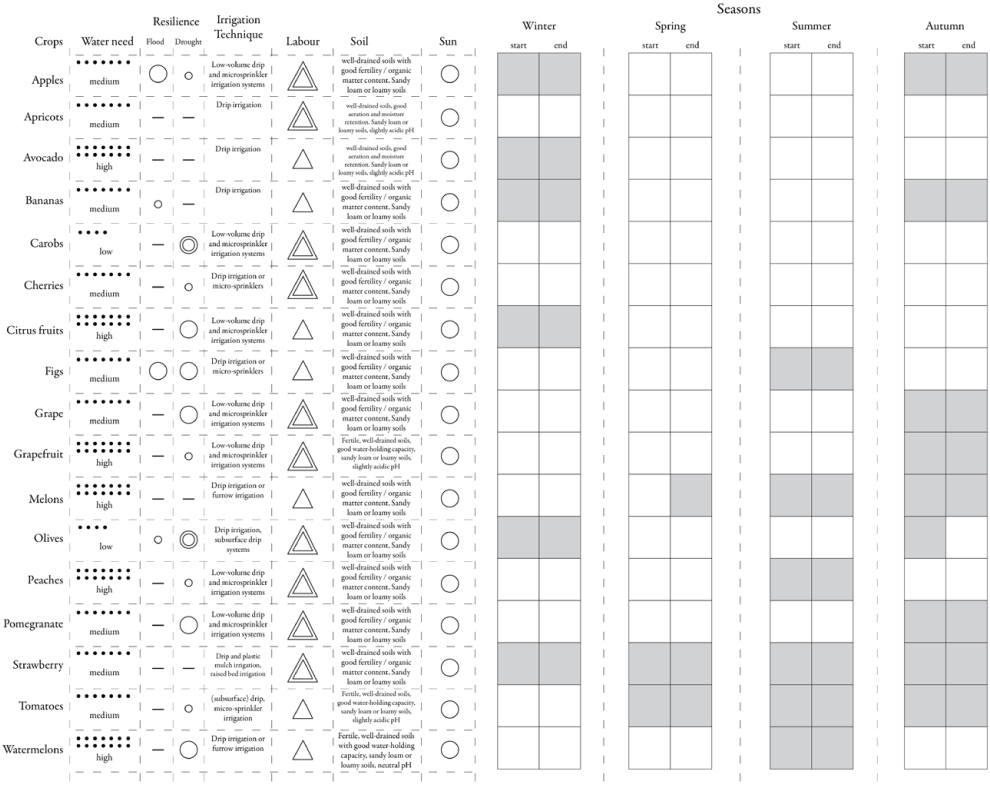


Figure 81: Seasonal calendar of agriculture, designed by author

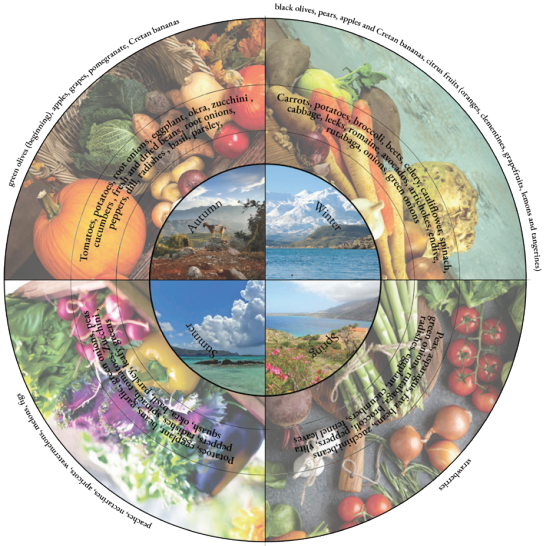


Figure 82: Main seasonal agricultural types produced in Crete, Source: *designed by author*

Impacts of climatic variations on agriculture

The island of Crete, and especially the Messara valley, faces significant problems of water resource over-exploitation due to the intensification and expansion of irrigated cropland, such as olive groves. (Vardavas et al. 1996). Irrigation types on the island differ depending on crop type, local water availability and climate. For instance, olive trees are either regularly irrigated or not irrigated at all, orange groves are often waterlogged and vineyards are often drip-irrigated. An extensive network of pumping stations has been installed since 1984 in which rain-fed olive groves have been converted to irrigated olives due to climate and precipitation changes and yield increase leading to more profit. Because the demand for irrigation is particularly high, the major water demands are taken from underground water systems. 450 million cubic meters of water extracted from the underground water systems of Crete have been exceeded already. (newspaper, n.d.) The consequences are an increase in crop production accompanied by a dramatic drop of up to 20m in the groundwater level in some places and salinity intrusion in the aquifers. (Kosmas, Kounalaki, Karamesouti, n.d.).

In other areas, farmers reduce irrigation in citrus plantations and olive groves due to limited water availability which leads to a loss in farm income. (Wageningen University & Research Designing Systems for Informed Resilience Engineering, n.d.) At the same time, olive and vine orchards on the island of Crete suffer from extreme soil erosion due to less frequent but intense rainfall, farm slope and/or the intensification of tilling processes. (Vozinaki, Alexakis, Tsanis, 2020)

Water losses

As highlighted before, there is a high demand for irrigation water, although, only 27 % of the available agricultural land is irrigated. Moreover, there are significant losses due to seepage, evaporation, leakage, and other factors from the water delivered to the agricultural sites for irrigation and domestic use, sometimes estimated to be 50 % of the delivered water. (Wageningen University & Research Designing Systems for Informed Resilience Engineering, n.d.). To address this issue, significant efforts have been made to promote the efficient use of water by the agricultural sector (Baltas & Tzoraki, 2013; Wageningen University & Research, n.d.).

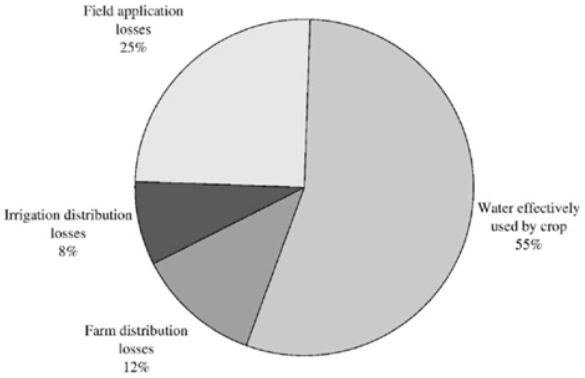


Figure 83: Average irrigation water losses in the island of Crete, Source: *K.S Chartzoulakis et al. / Water Policy 3 (2001) 193-205*

Conclusions

Project Fundamentals

The analysis of the island of Crete reveals a complex and interconnected system of human and natural elements, influenced by historical, cultural, and environmental factors. This project characterizes the island as an altered nature, impacted by natural and human processes with different spatio-temporal dimensions. (Houseman, L., 2013) Among the many pressures and opportunities for water management on the island, there is one key feature that stands out, which is to take advantage of the topography and the areas where water is stored naturally and create water retention and infiltration landscapes, that can store and filter water to meet the demands of the dry seasons.

Another significant conclusion that emerged through the analysis, is the importance of water as part of the culture of the island, associated with notions such as regeneration, fertility, and fluidity that express the close and meaningful connections between communities and water and natural systems. Cultural practices and indigenous knowledge, evident even in Minoan, Roman, Venetian, and Ottoman water management systems, demonstrate water's significance by valuing the ecosystems dependent on it and aiming to restore a new balance to meet the needs of people, agriculture, and the environment. (WWF – Living water. Conserving the source of life, 1986)

However, Crete faces significant challenges due to climate change, particularly related to water scarcity and excess, driven by its diverse geography, climate, and human alterations. The topography and biophysical processes of Crete, including its rivers, springs, and groundwater, are key drivers of water availability. For example, the terrain's karst topography and impermeable geology further complicate water management, as surface water availability is limited and groundwater resources are vulnerable to over-extraction and salinity intrusion. The uneven distribution of precipitation, combined with increasing water demands from agriculture, tourism, and urban development, has created severe water imbalances in coastal and eastern areas, putting additional pressure on limited freshwater resources, including overexploitation and pollution. Climate change applies even more pressure to these challenges, with rising temperatures, changing precipitation patterns, more frequent extreme weather events like droughts and floods, and sea level rise posing threats to settlements, infrastructure, ecosystems, and water resources. Deforestation due to wildfires has also contributed to soil erosion, reduced water retention, and impacted annual water potential.

To address these challenges, a comprehensive and sustainable water management strategy is crucial, considering the island's unique hydrology, climate, and socioeconomic dynamics. Understanding the historical dynamics of water management, along with the cultural values associated with water, can inform strategies for adaptation and resilience in the face of current and future pressures. Protecting and restoring natural ecosystems, like forests, wetlands, and riparian buffer zones, is essential to enhance water retention and mitigate the impacts of climate change.

In conclusion, hydraulic infrastructure on the island has been driven by the need to harness water resources to sustain agriculture, urban settlements, and economic activities, resulting in shaping the island's landscapes and ecosystems. The analysis highlights the intricate interplay between the island's topography, climate, human activities, and water resources, underscoring the need for an integrated and adaptive approach to water management that balances environmental sustainability, economic development, and social equity.

Given the different temporalities involved, it is fundamental to research and design across various scales, not just at the island scale. This project selects the transect of the island, specifically the Isthmus of Ierapetra in the eastern part of the island, as a project case study to investigate further the interrelations and interdependencies of the different systems, including hydrogeology-river systems, agricultural production, soil, and climate. For these reasons, the project proposes addressing the issues of altering human activities and the climate change impact on a local scale with small-scale interventions that secure fresh water in the region and protect against flooding. There is a need to create an integrated water system to collect water for the dry season and distribute water in case of emergencies such as flash floods, river and dam overflows. The creation of small-scale artificial wetlands, such as ponds, canals, and paddy fields, is significant as they are critical environments for habitat creation. (Zalidis and Mantzavelas, 1994; Karamanos, A., Aggelides, S., & Londra, P., n.d.)

Project Case

" Rediscover, in a new way, the Earth we think we know so well. Our role is to move from the horizon line to the thickness of the ground, from the global to the local. "

Aït-Touati, F., Arènes, A., Grégoire, A., Latour, B., & DeMarco, A. (2022), pg. 9

Wells (πηγάδια, στέρνες), Palailoni, Chania perfecture, (~1200-1700),

source: *https://hania.news/2021/01/31/%CE%A7%CE%B1%CE%BD%CE%B9%CE%AC-%CE%A0%CE%B7%CE%B3%CE%AC%CE%B4%CE%B9%CE%B1-%CE%BA%CE%B1%CE%B9-%CF%83%CF%84%CE%AD%CF%81%CE%BD%CE%B5%CF%82-%CE%BC%CE%B1%CF%81%CF%84%CF%85%CF%81%CE%BF%CF%8D%CE%BD/*

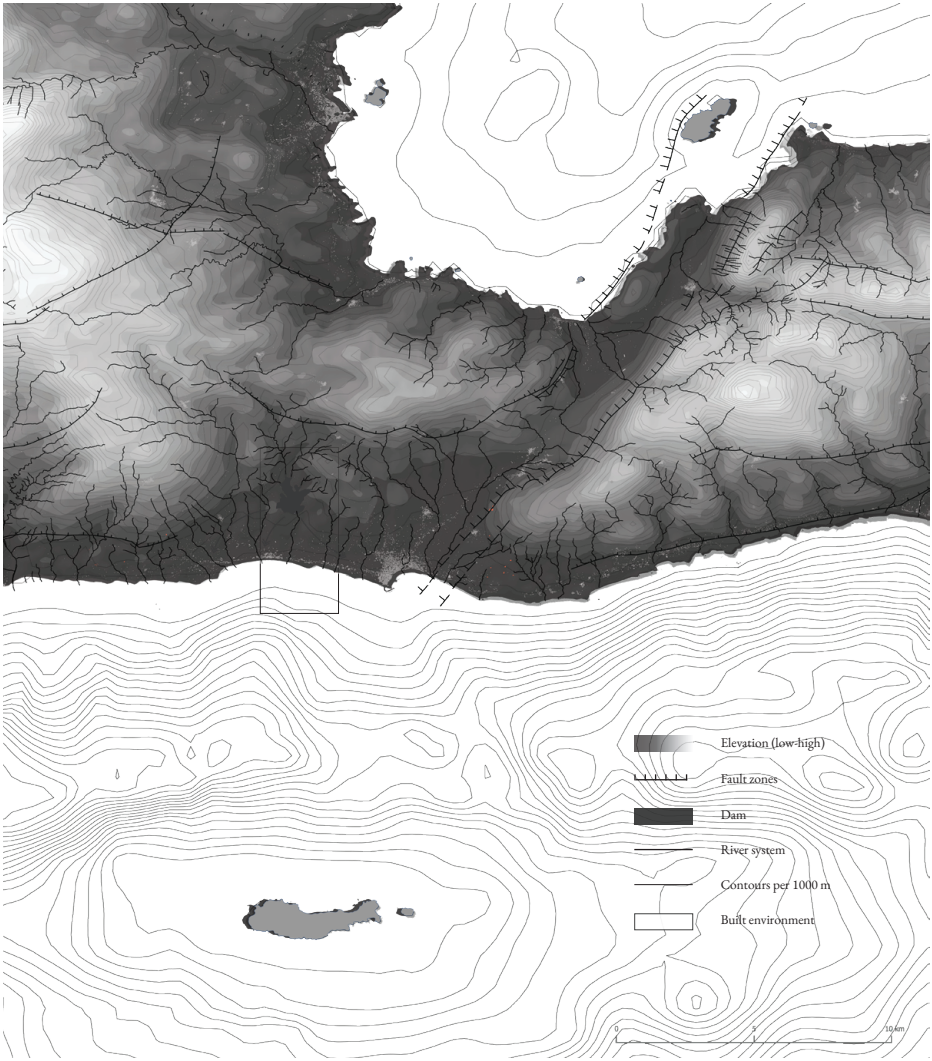
Case study: Isthmus of Ierapetra

The eastern part of the island, a region of rich cultural heritage and ecological diversity, stands at the crossroads of a pressing challenge, while it is being threatened by both of the opposite threats of water scarcity and excess, intensified by the forces of climate change. The eastern part of the island, and more specifically the Isthmus of Ierapetra, that is chosen as a case study for this project, which receives less amounts of precipitation while having extremely high crop irrigation requirements, has a semi-arid climate, making it vulnerable to drought incidents. Ierapetra, in the South, is the region with the largest number of sunny days in Europe and very fertile soil. Another important characteristic of the area is intensive greenhouse crop production. In 1965, they created the first greenhouses in the village of Gra Lygia, and since then, a very large part of the southern coast has been dedicated to greenhouse agriculture, which requires large amounts of water. To support the increasing water needs of agriculture, a large dam was created that collects the water from two seasonal rivers.

Unfortunately, since the water from the dam is not enough to cover the extremely high water needs, groundwater is being overextracted at a very fast rate for both increasing agriculture and human consumption purposes. This has led to the depletion of the aquifer along with salinity intrusion, threatening freshwater resources. (National Geographic, n.d.). At the same time, intense agricultural activities gradually replace natural vegetation and forests and cause soil pollution and degradation, resulting in a high sensitivity to desertification.

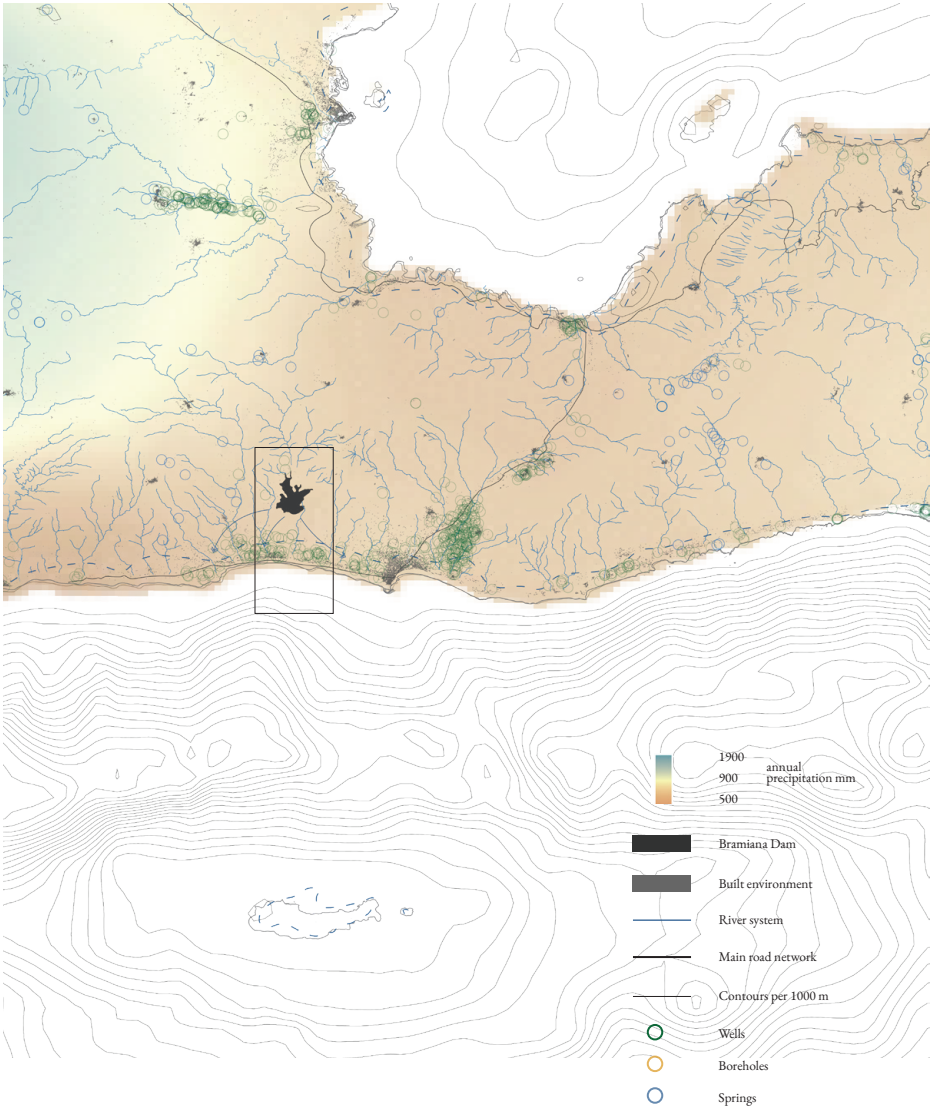
Furthermore, due to the region's large alluvial plains, such as the Ierapetra Plain, there is a high risk of flooding based on historical, current, and future climate impact projections. Catastrophic flooding incidents have happened in the past, for instance in 2019, and the latest in 2023.

Finally, the region, both as part of the island and as the narrowest part of Crete, surrounded by sea, is threatened by sea level rise, which can have catastrophic impacts on the cities and towns of the region, major infrastructure such as the large agricultural production infrastructure, and roads. As the region is experiencing changing precipitation patterns, rising temperatures, and sea-level rise, it faces an urgent need for water-sensitive interventions and actions.


Elevation (low-high)
Fault zones
Dam
River system
Contours per 1000 m
Built environment
0
5
10 km

The isthmus of Ierapetra (Ισθμός της Ιεράπετρας) is the narrowest part of Crete, with a distance of 12 kilometers from the Gulf of Mirabello in the north to the Libyan Sea in the south. It is surrounded by mountain ranges on the east and west. The Isthmus of Ierapetra connects the easternmost municipality, Siteia, to the rest of the island. Its name comes from the largest settlement named Ierapetra, which is located along the south coast.

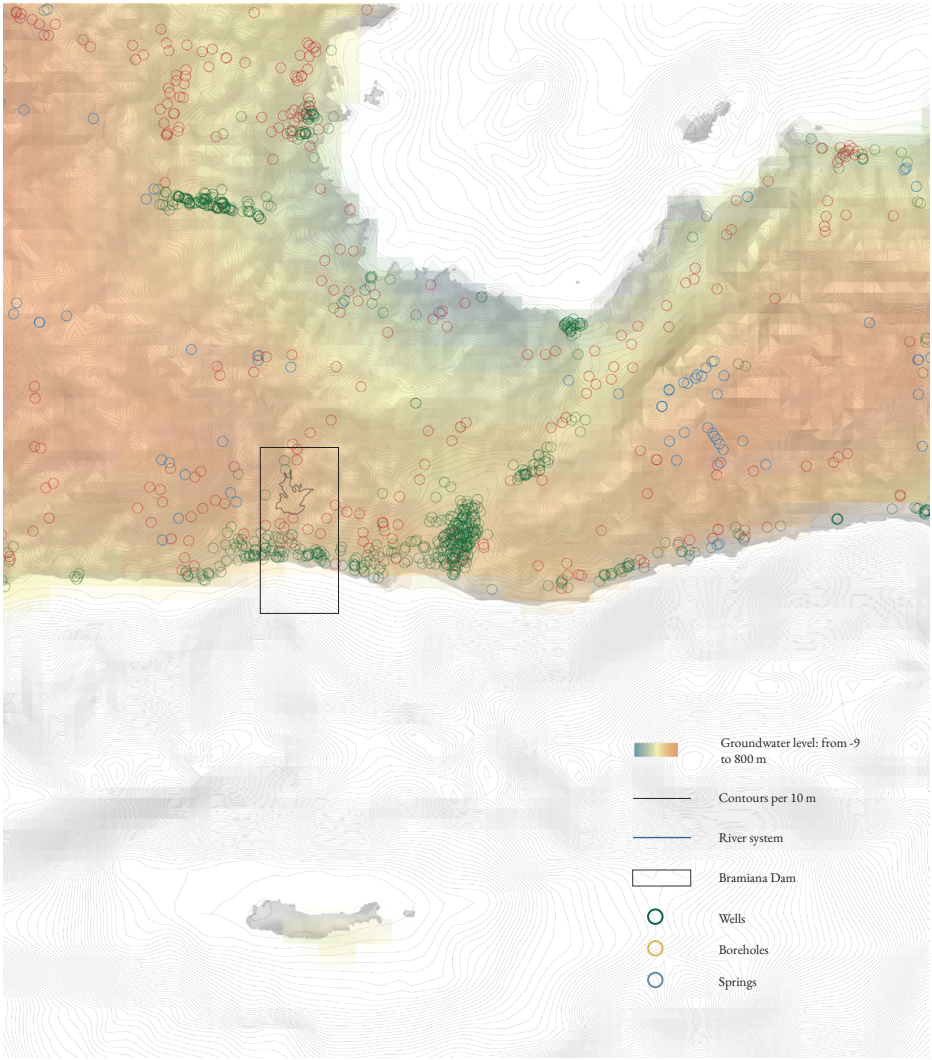
The Isthmus of Ierapetra presents a very interesting and diverse topography and geological formation past. It is part of a system of fault zones that consists of three major fault segments, which have well-exposed Holocene scarps developed entirely from active faulting on the island. The largest fault zone (Ierapetra fault) extends into the sea towards both the north and south of Crete and separates vertically the Ierapetra Kavousi alluvial plain to the west from the Orno-Tripti massifs to the east. (Caputo, Catalano, Monaco, Romagnoli, Tortorici, Tortorici, 2010; Gaki-Papanastassiou, Karymbalis, Papanastassiou, Maroukian, 2009). Another very important fault zone is the Ha Gorge Fault, which extends from Kavousi to Monastiraki, has a total length of about 9 km, and has been active since the Holocene period, with a minimum uplift rate of 0.1 mm/yr. The southern segment interacts with soft rocks and consists of two different parallel segments, creating an unstable zone where landslides are occurring. (Gaki-Papanastassiou, Karymbalis, Papanastassiou, Maroukian, 2009)

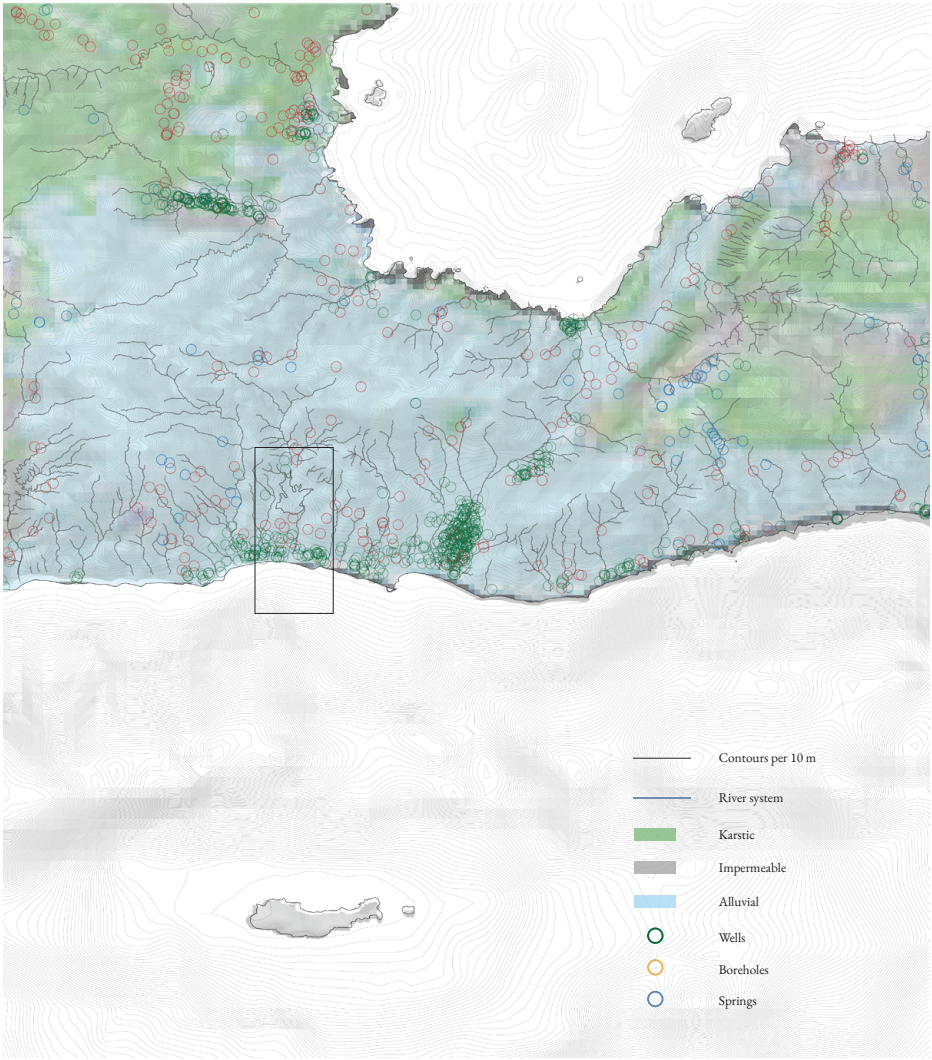

1900
900
500
annual precipitation mm
Bramiana Dam
Built environment
River system
Main road network
Contours per 1000 m
Wells
Boreholes
Springs
0
5
10 km

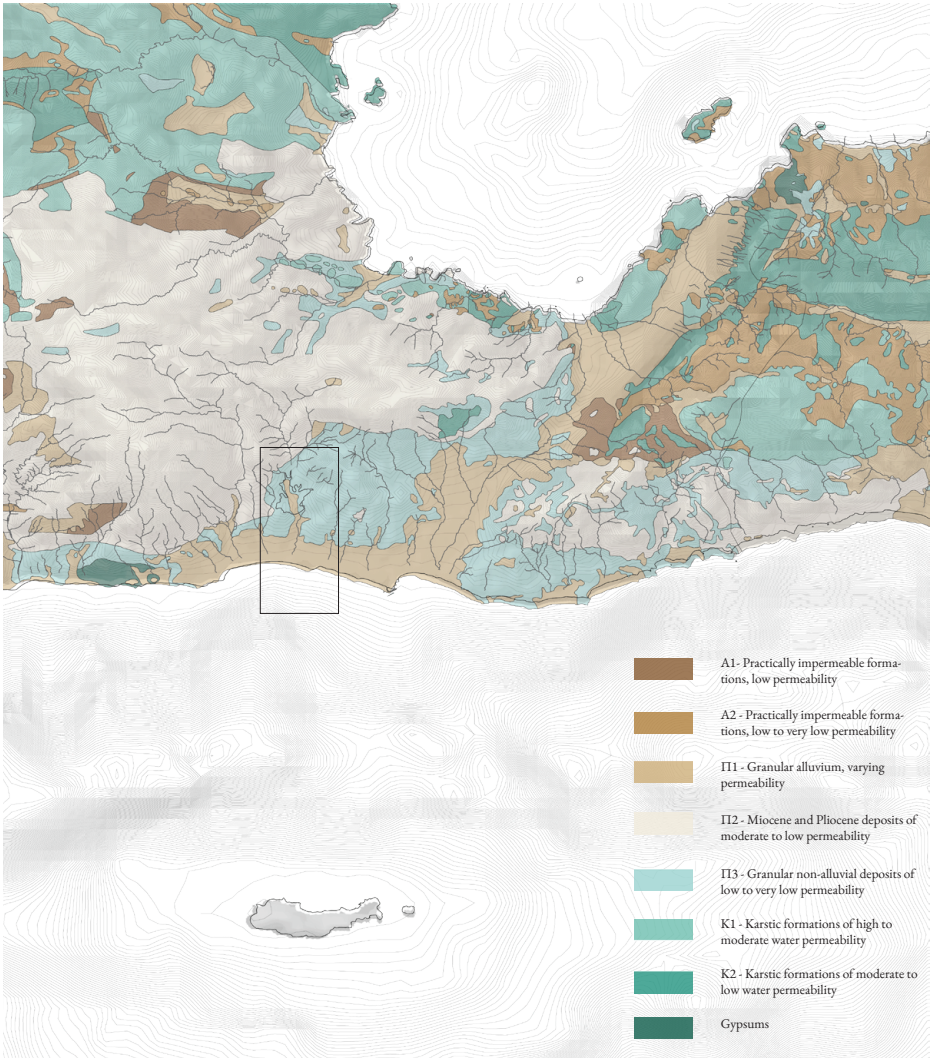
The region has a complex water system with a large number of streams, most of them seasonal or powered by underground springs. It is characterised by a hot semi-arid climate with a mean annual precipitation of about 750 mm which ranges from 500 mm in the east to 1900 mm in the west. The average temperature ranges from 10 °C in winter to 30 °C in summer.

In complex hydrogeological environments such as Crete, Greece, surface water bodies are regulated by seasonal rainfall patterns, resulting in temporary stream flow. Consequently, water needs are predominantly met through groundwater sources. (Tzoraki, O., Kritsotakis, M., & Baltas, E., 2014). In order to support the extremely high agricultural water demands of the area, especially during the summer months, the Bramiana Dam was created at the junction of two rivers. Nevertheless, the majority of the water required for agricultural purposes continues to be extracted from aquifers in some areas, resulting in a drop in the groundwater level.

Figure 84: Precipitation levels through time, source: *https://e-mesara.gr/ta-stoicheia-apokalyptoyn-ton-efalti-tis-anomvrias-kai-sti-mesara/?fbclid=IwAR0d2uCsdKtqB8eGGMVJ_bYFLSMnu4aUX7VSvyiQsunldO4z5Bb438_oNDE_aem_Acd-4Np45ujV1iuZ3qLJgHemPJfiOOVFs1819W6SSPKWSi5okGhVlovl91Wi8-YZbSlm1PgJS2pnm2kR1_vAWaRc1*

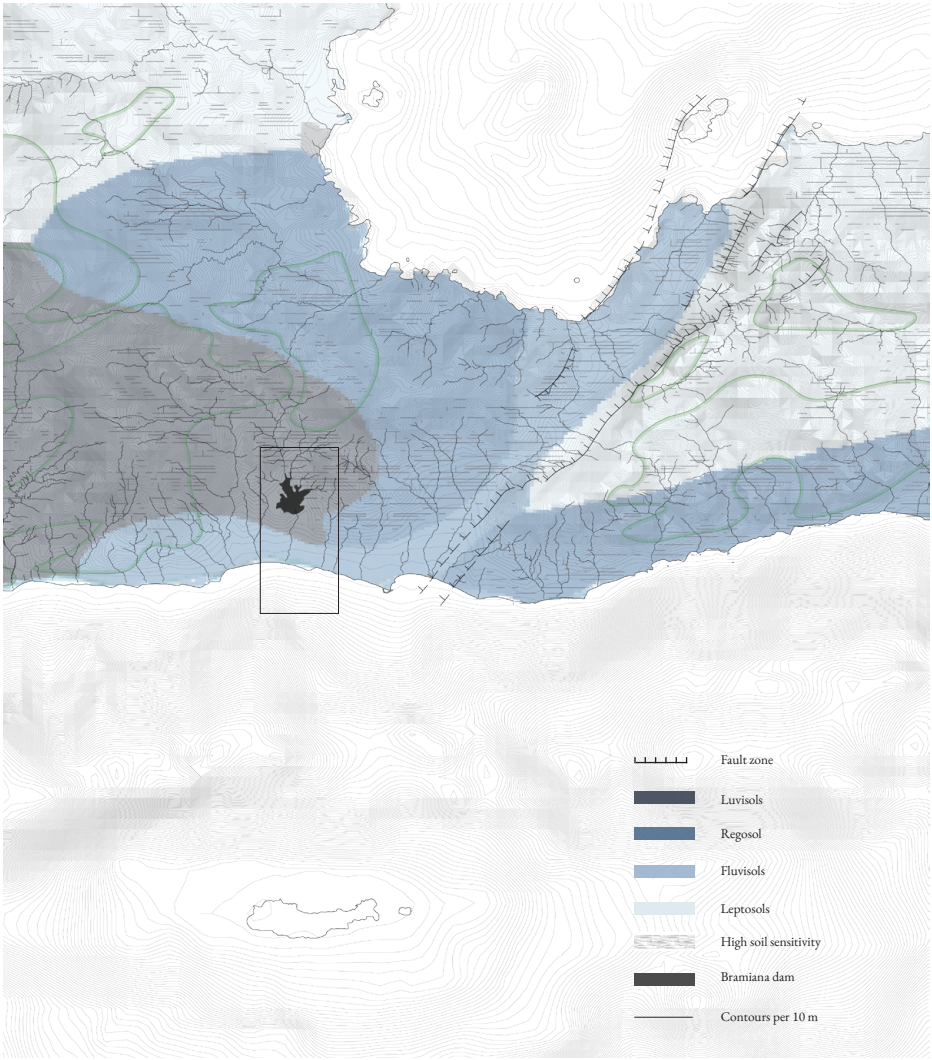

Groundwater level: from -9 to 800 m
Contours per 10 m
River system
Bramiana Dam
Wells
Boreholes
Springs
0
5
10 km


Contours per 10 m
River system
Karstic
Impermeable
Alluvial
Wells
Boreholes
Springs
0
5
10 km


A1- Practically impermeable formations, low permeability
A2 - Practically impermeable formations, low to very low permeability
Π1 - Granular alluvium, varying permeability
Π2 - Miocene and Pliocene deposits of moderate to low permeability
Π3 - Granular non-alluvial deposits of low to very low permeability
K1 - Karstic formations of high to moderate water permeability
K2 - Karstic formations of moderate to low water permeability
Gypsums
0
5
10 km

The geology of Crete mainly consists of limestone, which allows water to penetrate, creating major karstic formations with main features such as the large number of caves, springs, and swallow-holes on the ground. (Foundation of the Hellenic World., n.d.; Chartzoulakis, K., 2001). This phenomenon is what gives life to the island because it is the major water supply, but at the same time, it has implications for its vulnerability to certain climate-related challenges such as sea level rise, salinisation, and desertification. For example, unstable changes in climate patterns, including altered precipitation and temperature, can harm water resources. These are some of the reasons why a geomorphological understanding of the island is essential for managing water scarcity and excess, especially in the context of climate change.

However, there is a significant potential for reforestation and water collection in the area, primarily through the use of water retention landscapes that prevent water run-off and help recharge the groundwater table, thus meeting the water needs of the region.


Fault zone
Luvisols
Regosol
Fluvisols
Leptosols
High soil sensitivity
Bramiana dam
Contours per 10 m
0
5
10 km

The soil is a major component of the island's ecosystem, sustaining its inhabitants and supporting their activities. (Koutroulis et al., 2013). Because of their limited resources, the inhabitants of the island need to take care of them, particularly water and soil, which are the main elements that give life to them and support their activities. Ierapetra, in the South, has a very fertile soil (mainly alluvial soil which is the most fertile soil) that consists of fine soil texture and drier climate conditions. (Iowa Geological Survey, n.d.; Koubouris et al., 2015)

The most dominant soil types in the region are the following:.
Regosol is a very weakly developed mineral soil that can be found in eroding lands, in particular, in semi-arid areas and in mountainous regions. Land use and management of Regosols can vary from capital-intensive irrigated farming but the most common land use is low-volume grazing. Regosols in mountain areas are beneficial for forest cover.
Luvisols have clay-enriched subsoils and are widely used for agriculture. They are fertile and suitable for a wide range of agricultural uses.
Fluvisol is a relatively young mineral soil common in periodically flooded areas such as alluvial plains, river fans, valleys, tidal marshes, and marine deposits. Their characteristics and fertility depend on the nature and sequence of the sediments. Alluvial soil is, in general, the most fertile soil because it has a loamy texture (containing sand, clay, and slits) and is rich in humus, containing organic nutrients that help to increase the fertility of the soil. (Iowa Geological Survey, n.d.).
Leptosols, which are shallow and extremely gravelly soils, can be found mainly in mountainous regions and in areas where the soil has been eroded. The suitability of leptosols in most areas is limited to forestry.

As you can see in the following table, most of the soil types on the island are suitable and very fertile for crop production, according to the European Soil Atlas.

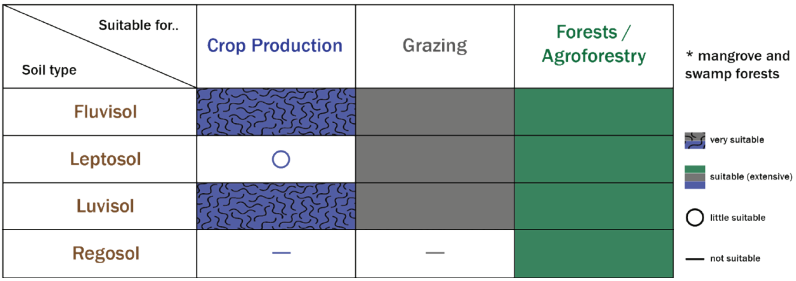
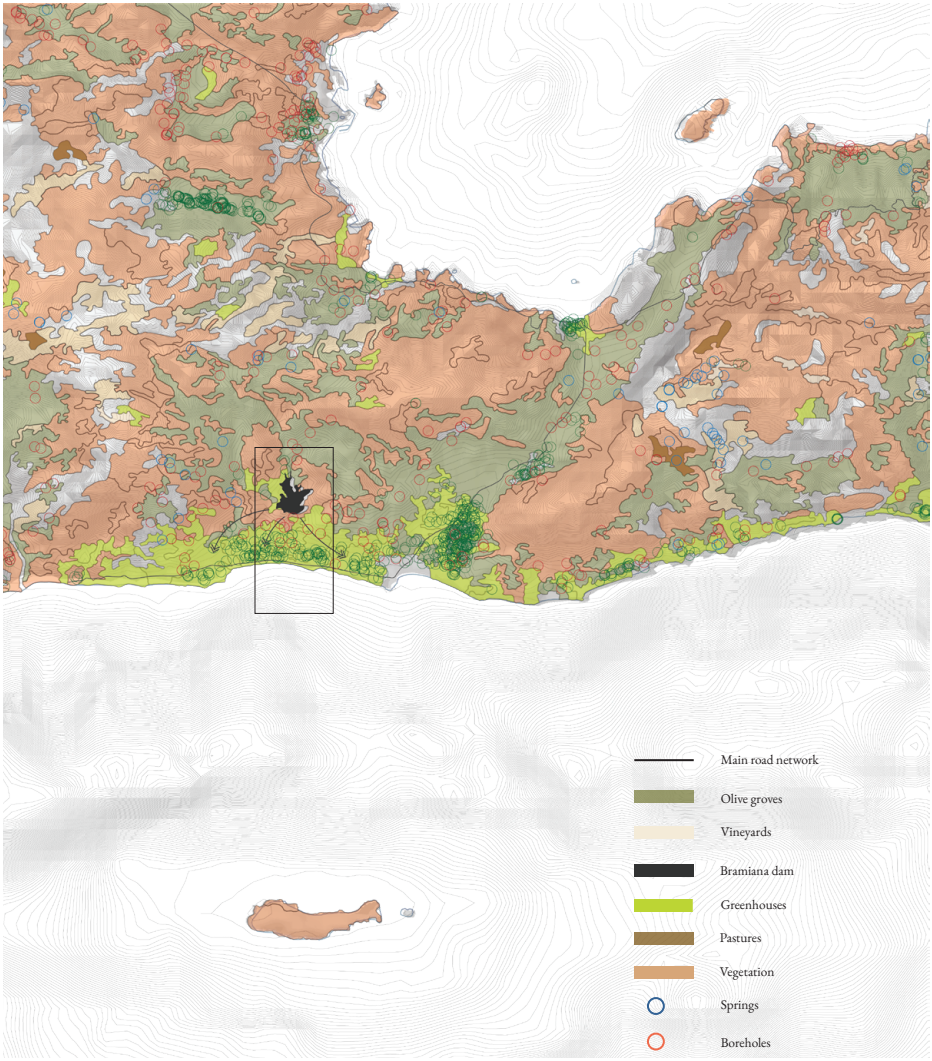


Figure 85: Suitability of crop production, grazing and forest based on soil types, Source: *designed by author based on European Soil Atlas, Vertisols. (n.d.-c). https://www.isric.org/sites/default/files/major_soils_of_the_world/set3/vr/vertisol.pdf*

Agriculture types and water extraction



The Neogene soils, which cover one-third of the surface of Crete, constitute the most appropriate foundation for agricultural activities. These soils resulted from earlier deposits that were concentrated on the seabed and formed an extensive nappe of sea earth and conglomerate rocks.

Agricultural production

The region's economy is mainly driven by agriculture. Historically, the inhabitants of Ierapetra were mainly engaged in agriculture, the cultivation of olives and vines, and fishing. (Τα θερμοκήπια της Ιεράπετρας, 2010). Nowadays, the area's main economic activities are agriculture in the winter (export of fruit and vegetables and olive oil) and tourism in the summer. It is estimated that in the region of Ierapetra, there are more than 12,000 greenhouses and 100,000 olive groves. Tomatoes (a large percentage), peppers, cucumbers, and aubergines are grown in greenhouses and exported all over Europe, mainly to Bulgaria (39%) and Germany (25%). Olive oil is being exported to the USA, Japan, Australia, Germany, Belgium, the Netherlands, and other countries of the European Union. (Fruit Line, n.d.)

The greenhouses were introduced in 1960 by the Dutchman Paul Kuypers and were a milestone in the area's development that changed radically the agricultural orientation and look of the area. The first greenhouses were made of wood and glass, and the first crop that was cultivated was the Kalyviotiko variety of cucumber. (Τα θερμοκήπια της Ιεράπετρας, 2010).

In Greece, the main products grown and produced in greenhouses are tomatoes, peppers, eggplants, zucchini, cucumbers, watermelons, melons, green beans, lettuce, and strawberries. More specifically about the area, the total number of greenhouse crops in the wider area of Ierapetra is 15,500 acres, approximately 25% of the total. 7,200 acres out of the 15,500 are tomatoes, 4,700 are peppers, and the rest are cucumbers, eggplants, pumpkins, etc. As a consequence of this radical development in agriculture, the inhabitants of Ierapetra were considered among the richest on Crete due to the high demand for their greenhouse exports globally. (Wikipedia contributors, 2024)

After 1970, thousands of olive trees were removed from the Ierapetra region to build modern greenhouses with horticultural and flower crops. Olive cultivation took second place due to the low price of the oil, which could not cover the producer's expenses. Most families kept a few olive groves only to ensure the year's oil because the greenhouses gave more profits to the producers. (Newsroom, 2024)

However, a major problem that has arisen from the rapid development of greenhouses concerns the sufficiency of water for irrigation. In 1986, the construction of an artificial lake - dam was completed, which collects water with a capacity of 15 million square meters. The lake is located 5 kilometers northwest of Ierapetra, and it is named Bramiana Dam.

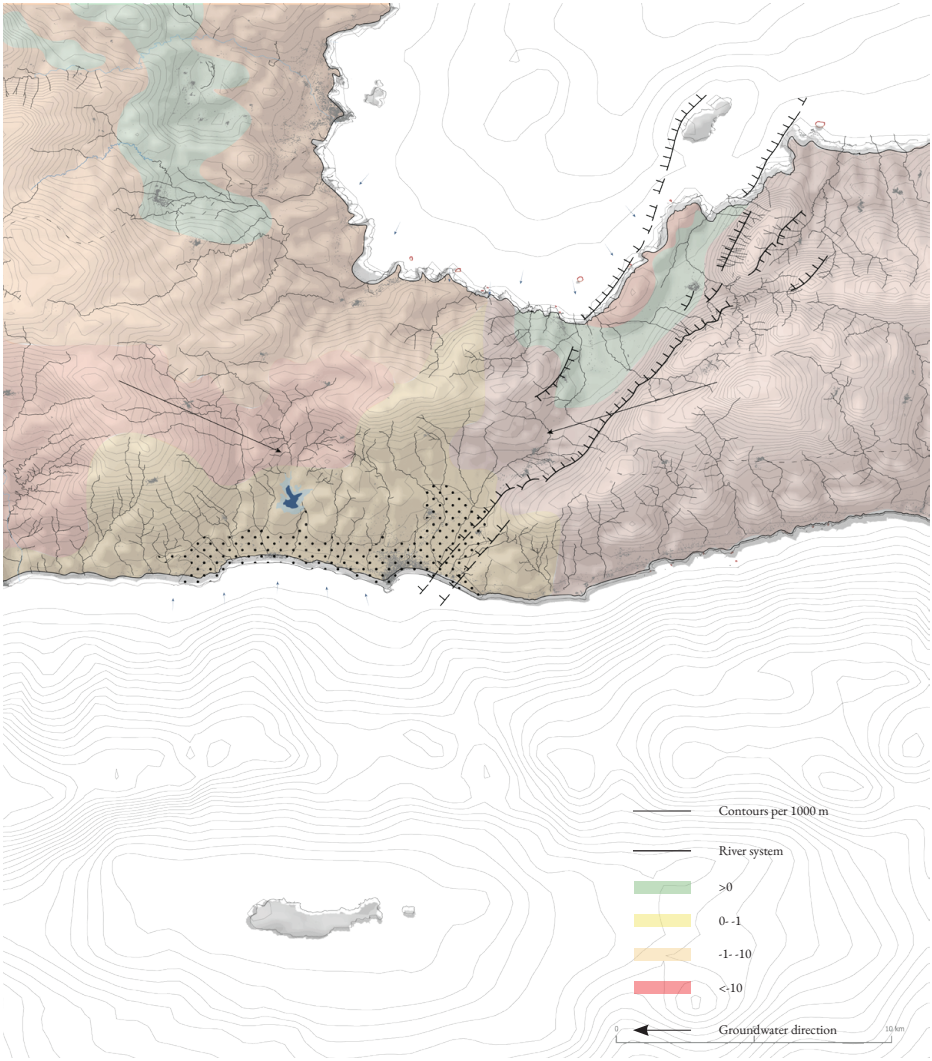
Another significant consequence that the intense cultivation caused was the degradation of greenhouse soils from long-term cultivation. The degradation concerns the high concentration of salts, the high microbial load, and the nitrate pollution of the soil and water. Dealing with these problems is quite difficult and expensive. So it is no coincidence that today modern cultivation techniques that do not require soil (hydroponic crops, crops in substrates) are being developed, with all that this implies in new technologies, new means, and new economic activity in the wider region.

In conclusion, the year 1960 and Cooper's initiative changed the image of the region, both in terms of land use and socio-economic and environmental factors. The result of these changes is an enormous "artificial" surface that covers the landscape of the region. (Τα θερμοκήπια της Ιεράπετρας., 2010)

Irrigation systems

Irrigation systems are using the water resources in alluvial fans, mainly river floods and groundwater recharged by infiltration of rain or river water, to enhance the production of crops. Alluvial fans usually contain rich groundwater aquifers, which, in semi-arid regions, are often used for irrigation of crops, revealing greenery within the harsh desert-like environment. In a similar way, in the area, people sink deep wells in the aquifer of the alluvial fan to exploit the groundwater more effectively. However, because of the intense exploitation of the aquifers, there is a recommendation to the producers not to produce during the summer months due to water scarcity and to save water for the winter cultivations.

Scenario of annual water balance for irrigation under dry hydrological conditions of a 20-year period

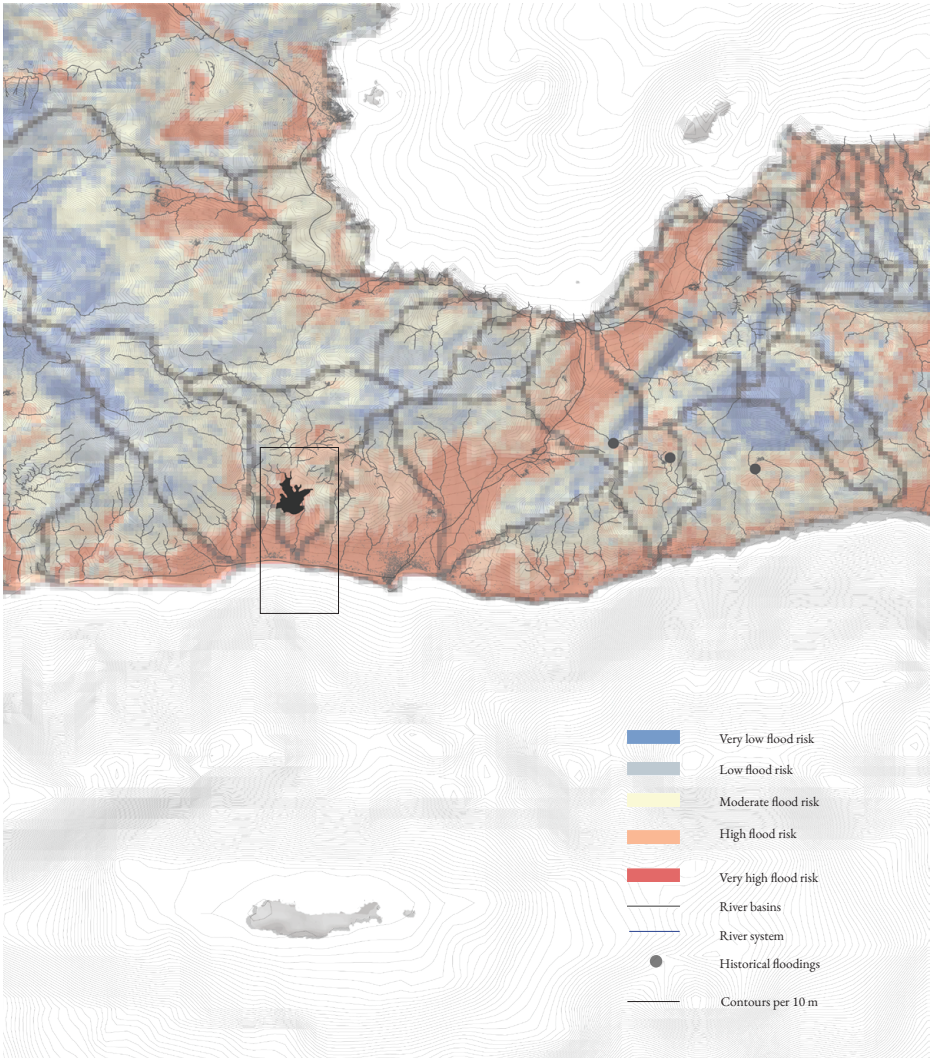


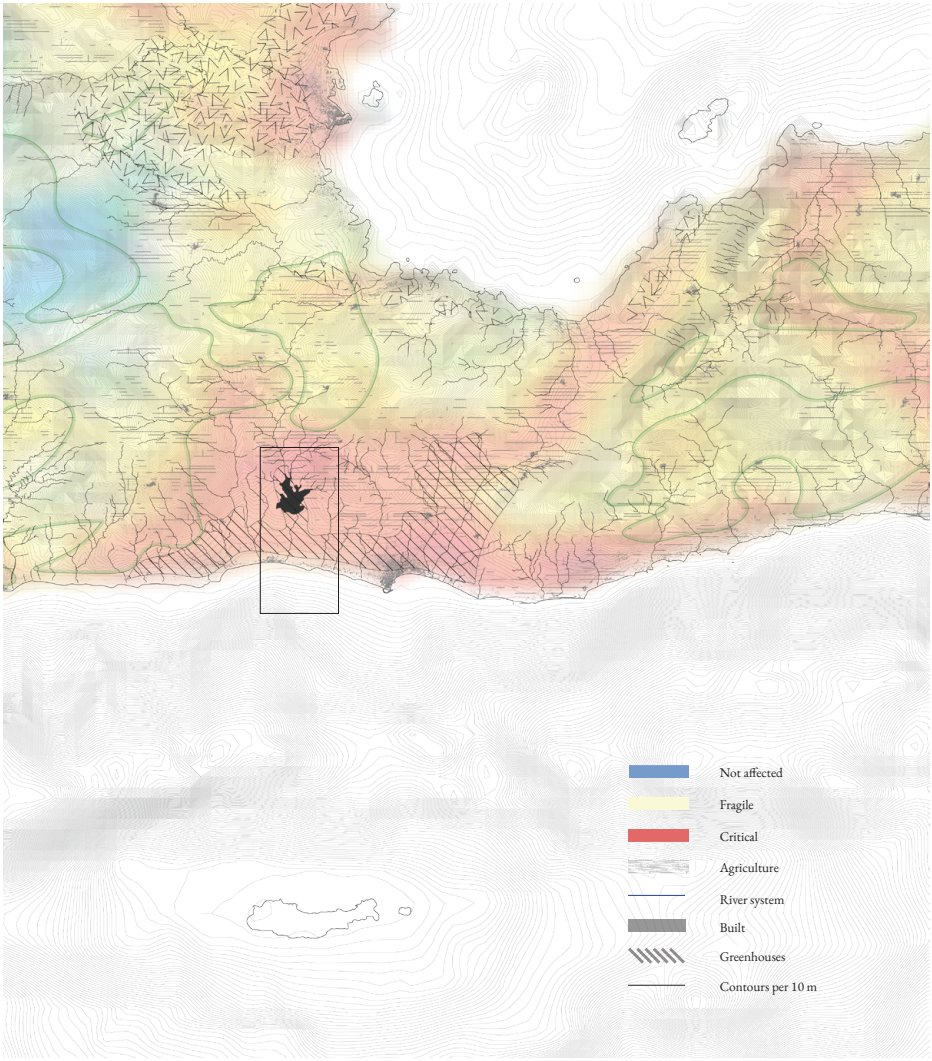
Water scarcity and excess, desertification

Flooding poses a significant threat to the island of Crete, particularly in the Isthmus of Ierapetra due to the region's large alluvial plains, such as the Ierapetra Plain. Historical, current, and future climate impact projections indicate a high risk of flooding, as evidenced by catastrophic flooding incidents in 2019 and the most recent in 2023. The intense and irregular precipitation during the wet season can lead to flash floods, causing substantial damage to infrastructure and agricultural land.

To mitigate these impacts, it is crucial to control and slow down river water flow during flood events. Implementing measures to temporarily store and filter water can help manage excess water and make it available for use during the dry months when water demand is highest. Additionally, restoring alluvial plains is necessary to enhance their capacity to retain water, reduce the speed and volume of water flow, and minimize flood risks. Creating retention basins and wetlands can also act as natural buffers, storing floodwaters and gradually releasing them, thus reducing the immediate impact on downstream areas.

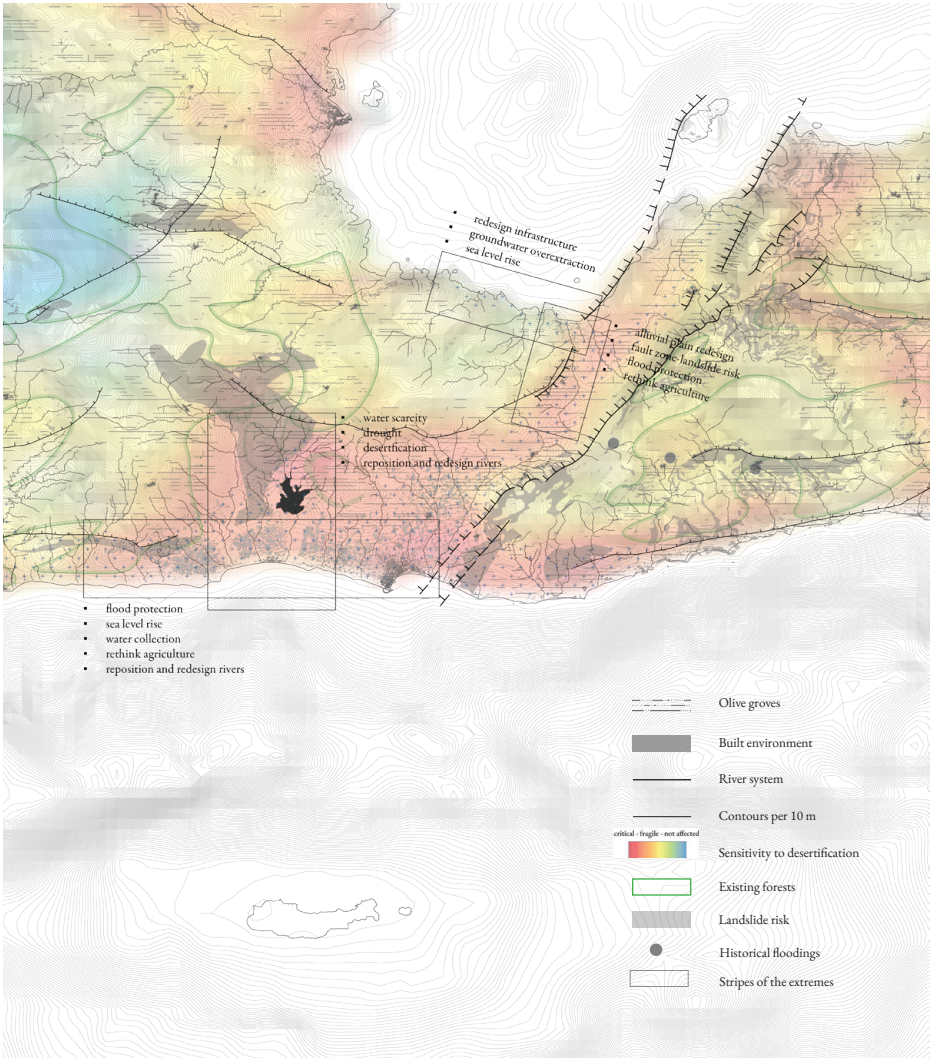
Furthermore, as mentioned before, the climate of the eastern part of the island is considered (semi) arid, characterized by limited rainfall and high temperatures, especially during the summer months, making the area vulnerable to droughts. These climatic conditions, coupled with intensive agricultural activities such as crop irrigation, grazing, agricultural expansion, and urban development that lead to deforestation and eliminate vegetation cover, are applying significant pressure on the natural resources and earth's surface, causing soil degradation and erosion and contributing to desertification. Desertification refers to the process by which fertile land becomes increasingly arid, degraded, and unable to support vegetation and agriculture. Soil erosion is a major concern in semi-arid regions, including Eastern Crete, where rainfall is less frequent but intense. Without adequate vegetation cover to protect the soil from erosion, rainfall removes topsoil, nutrients, and organic matter, resulting in land degradation and reduced agricultural productivity. These changes threaten fragile ecosystems and agricultural lands, making them more sensitive to degradation.


Very low flood risk
Low flood risk
Moderate flood risk
High flood risk
Very high flood risk
River basins
River system
Historical floodings
Contours per 10 m
0
5
10 km

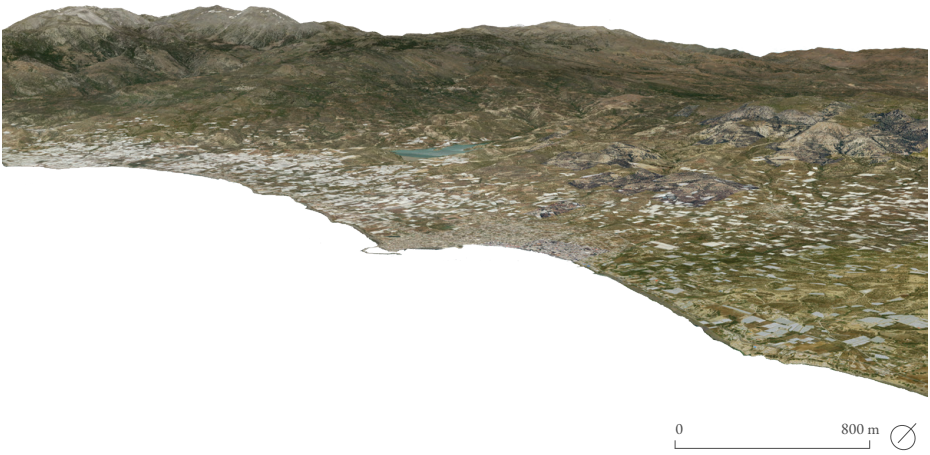

Not affected
Fragile
Critical
Agriculture
River system
Built
Greenhouses
Contours per 10 m
0
5
10 km

On top of the desertification risk map, the most vulnerable areas are highlighted, especially the ones that, apart from desertification, are susceptible to a large number of other factors. For example, the coastal regions are exposed to sea level rise, flash floods, and pollution from agriculture and greenhouses both on land and groundwater, and they require redesign of space, river banks, buffer zone restoration, as well as flood protection measures. Furthermore, these areas face significant challenges related to soil degradation and erosion, necessitating actions in soil restoration and reforestation.

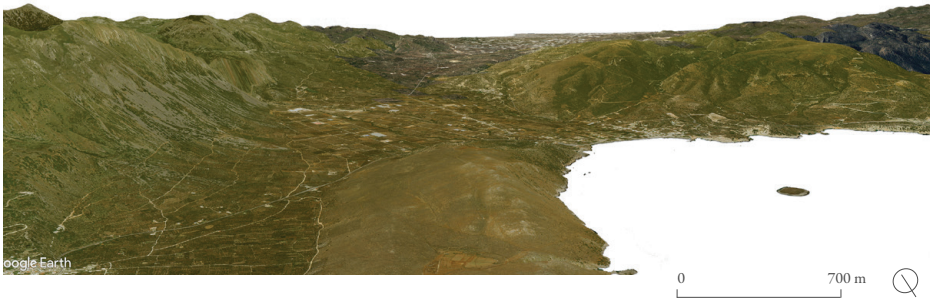
As a result, one of the identified vulnerable areas will be selected later for further testing of the project's design principles. More specifically, the area that is selected is the area that encompasses a seasonal water system of streams and dams along with intensive agricultural and greenhouse operations. Situated along the coast, it serves as a methodological example for studying the broader island system.


redesign infrastructure
groundwater overextraction
sea level rise
alluvial plain redesign
fault zone landslide risk
flood protection
rethink agriculture
water scarcity
drought
desertification
reposition and redesign rivers
flood protection
sea level rise
water collection
rethink agriculture
reposition and redesign rivers
Olive groves
Built environment
River system
Contours per 10 m
critical - fragile - not affected
Sensitivity to desertification
Existing forests
Landslide risk
Historical floodings
Stripes of the extremes
0
5
10 km

Isthmus of Ierapetra transect, Google Earth image



Southern East coast, Ierapetra, Google Earth image



Northern East coast, Pachia Ammos, Ierapetra fault zone, Google Earth image

Figure 86: Northern East coast, Pachia Ammos, photograph by author

Figure 87: Northern East coast, Pachia Ammos, marine terraces, photograph by author

Figure 88: Ha gorge, Ierapetra fault zone, geological diversity, Eastern Crete, photograph by author

Figure 89: Ha gorge, Ierapetra fault zone, geological diversity, Eastern Crete, photograph by author

Figure 90: Ha gorge, Ierapetra fault zone, geological diversity, Eastern Crete, photograph by author

Figure 91: Ha gorge, Ierapetra fault zone, geological diversity, Eastern Crete, photograph by author

Figure 92: Pachia Ammos, Ierapetra fault zone, December 2023, photograph by author

Figure 93: Pachia Ammos, Ierapetra fault zone, December 2023, photograph by author

Figure 94: Landscape dominated by greenhouses in the southern part of the Isthmus of Ierapetra, December 2023, photograph by author

Figure 95: Intensive greenhouse production in Ierapetra region, 2023, photograph by author

Figure 96: Landscape dominated by greenhouses in the southern part of the Isthmus of Ierapetra, December 2023, photograph by author

Figure 97: Greenhouse production, December 2023, photograph by author

Figure 98: Panorama Isthmus of Ierapetra, created by author

Figure 99: Seasonal stream in the Southern part of Isthmus of Ierapetra, materiality, photograph by author

Figure 100: Human alteration in the seasonal stream's banks, photograph by author, photograph by author

Figure 101: Road that crosses a river at Ierapetra (known as an Irish bridge), stays dry when the flow is low, but is designed to get submerged under high-flow conditions such as floods, photograph by author

Figure 102: Seasonal stream in the Southern part of Isthmus of Ierapetra, photograph by author

Intentions

"Neither Nature nor the Others will become modern. It is up to us to change our ways of changing"

Latour, Bruno, 1993a, 145"

Voulolimni: small lake inside the sea, Chania perfecture, December 2021, photograph by author

The project explores the different forms of the Cretan landscape that constitute an altered nature through the lens of water scarcity and climate change, which have impacts both on land and on human systems. The project starts from the territorial scale of the island, creating a narrative of major and minor stories of places, highlighting the stories that should be taken into account to form interventions to prepare the island for the present and future challenges reflecting the past and continuing to the cultural diversities that inhabit the island, those of the sea, the land, and the mountains.

Firstly, this attempt analyses and considers the island of Crete as a living organism that consists of several diverse assemblages of elements and processes, both human and non-human. Each one of them has unique, important stories that need to be heard. Particularly, the project has a focus on water and soil as drivers of change in the economy, reflecting the dynamic nature of the elements and criticising static representation instruments. Therefore, starting from the territorial scale of the island and then focusing on particular smaller regions and scales, this research takes advantage of the agency of design to improve the survival and quality of life from an intergenerational perspective.

Thus, for all life on the island, and human societies in particular, survival requires the capacity to adapt to changing and often unstable environmental conditions. To thrive in such an environment as a whole would require an entire palette of adaptation strategies. (Houseman, L., 2013). My investigation delves into several critical processes that provide us the framework to understand the island's dynamics, resilience, and the interplay between natural and human systems, attempting to create solid research that informs the design proposal of alternative futures for the island.

To propose this alternative future for the island, the project will propose a set of interventions that address some of the critical zones of the island, such as the seasonal rivers, the degraded soil, the fragmented inland with the operationalised agricultural land that coexists with the small settlements, and the southern coast with the extreme climate and steep topography with gorges and caves, to enhance the preparedness and adaptation of the island and its systems.

Therefore, this thesis project will provide an analytical instrument/framework for designing and planning the island that is opposed to the existing way of planning and shift planning instruments. The conclusions of the analysis of this project inform the design and planning processes. The aim is to propose an alternative method of (dynamic) representation, create scenarios and projections for decision-making, and discuss possible futures. Moreover, it will propose possible agendas of action.

Design with time

Spatio-temporal dimensions

Climate Scenarios based on the very high greenhouse gas emissions scenario (SSP5-8.5+ Low Confidence). To indicate the potential impact of deeply uncertain ice sheet processes, a Low Confidence scenario under SSP5-8.5 by IPCC is chosen.

2023

Annual temperature: 0.89 °C
Current sea level: 101 (± 4.0) mm

2040

Annual temperature: 2 °C
Sea level rise change: 0.16 m

2060

Annual temperature: 2.8 °C
Sea level rise change: 0.33 m

**consider 0 during 1993*

Based on :
https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool?type=global,
https://yaleclimateconnections.org/2021/08/the-new-ipcc-report-includes-get-this-good-news/

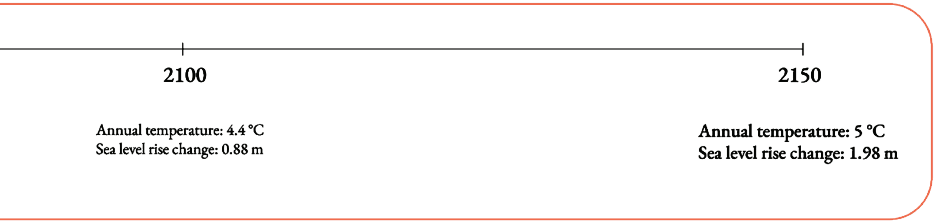
Climate projection

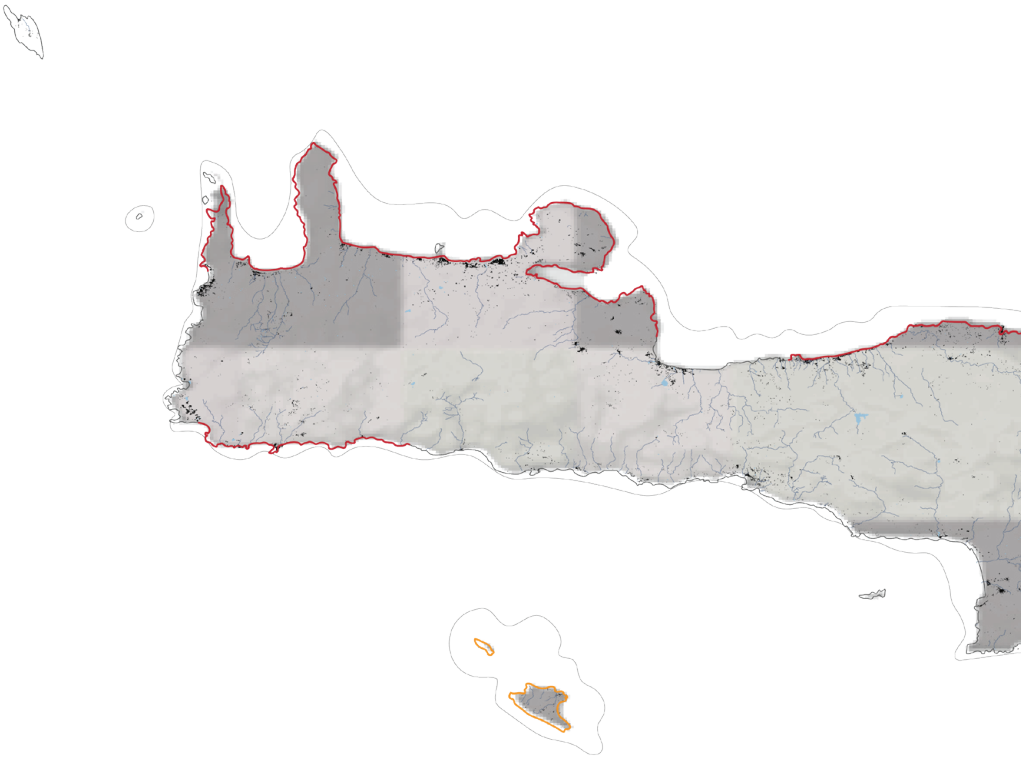
According to the IPCC report, global mean sea level will continue to rise over the 21st century. According to the IPCC projection climate scenarios, relative to 1995-2014, the projected global mean sea level rise by 2100 is, **under the very low scenario** (SSP1-1.9) 0.28-0.55 m, **under the intermediate** (SSP2-4.5) 0.44-0.76 m and **under the very high** (SSP5-8.5) greenhouse gas emissions scenario 0.63-1.01 m. (Climate Neutral Group, n.d.). Moreover, to highlight the potential catastrophic impact of uncertain ice sheet processes, a **Low Confidence scenario** is also considered under SSP5-8.5. (Hong Kong Observatory, n.d.). The current annual global temperature is 0.89 °C and the sea level is 101 (± 4.0) mm. (*considering 0 during 1993).

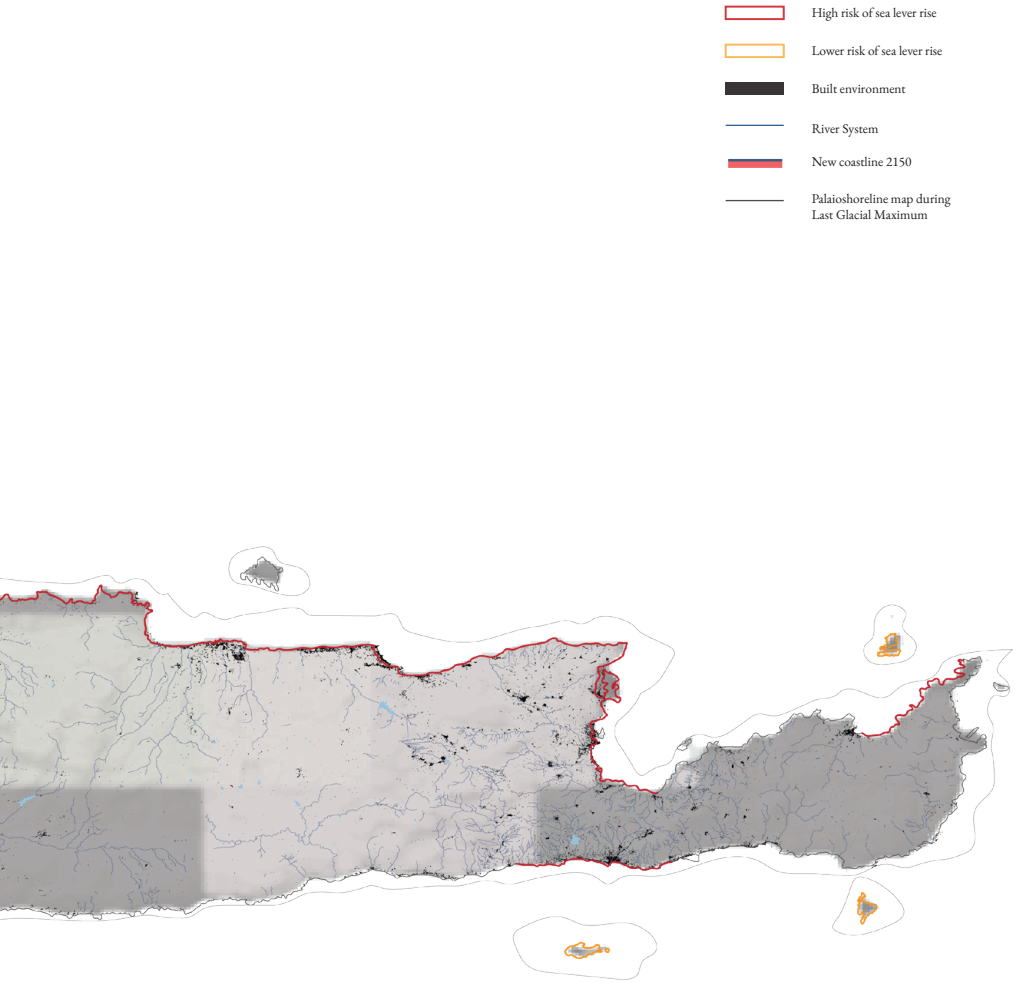
For this project, we adopt the **Low Confidence IPCC scenario under SSP5-8.5** but for the timeframe of 2150. **In this scenario with the future projections, future increased annual temperature of 5 °C and sea level change of 1.98 m increase is expected by 2150**. This is a future scenario to avoid at all costs.

After conducting simulation maps with online tools run by Climate Central which is an independent group of scientists who research the changing climate and how it affects human lives, for this particular extreme climate scenario, we can realize that an average of 50 to 80 meters along the coastline will be lost by 2150, if nothing is done. (Climate Central, n.d.) This will impact major infrastructure and urban areas on the island, especially along the coast and near the alluvial plains.

The island's most vulnerable and critical regions are the water bodies, water infrastructure, transportation networks, settlements and tourism infrastructure, harbours, agricultural land and greenhouse areas, and more specifically, areas with ecological and cultural importance.




0
25
50 km



Heat risk projection, Sea level rise vulnerability, by 2100, Source: *designed by author, Climate Change Knowledge Portal (CCKP), World Bank Group, https://climateknowledgeportal.worldbank.org/country/greece/heat-risk*

As highlighted by the diagrams, the precipitation patterns observed in recent years have become more extreme, especially after 1970. These patterns are characterized by long dry periods and intense flash flooding, which have devastating impacts on the land and societies.

Based on the very high (SSP5-8.5) greenhouse gas emissions scenario, the projected precipitation anomaly is expected to be radical. The amount of projected precipitation will decrease significantly in the next 80 years, particularly between 2080 and 2100.

In the following maps, it is presented that the heat risk of the island is enormous, especially in the eastern part of Crete, a large region that is more vulnerable to heat risks that lead to droughts and desertification. In addition, it should be mentioned that the enduring high temperatures are a considerable cause of health issues, including deaths, especially for vulnerable citizens each year on the island.

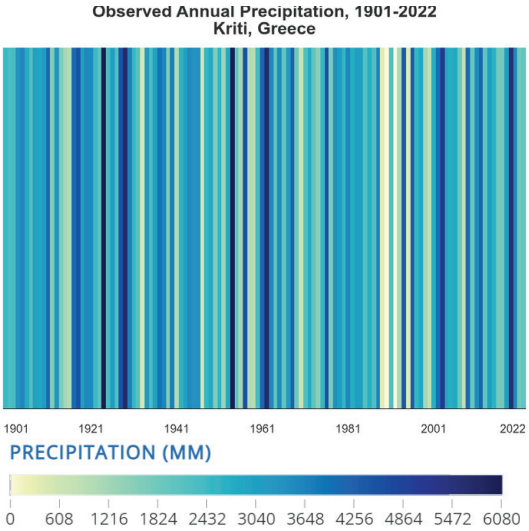


Figure 103: Observed annual precipitation for Crete (1901-2022), Source: *https://climateknowledgeportal.worldbank.org/overview*

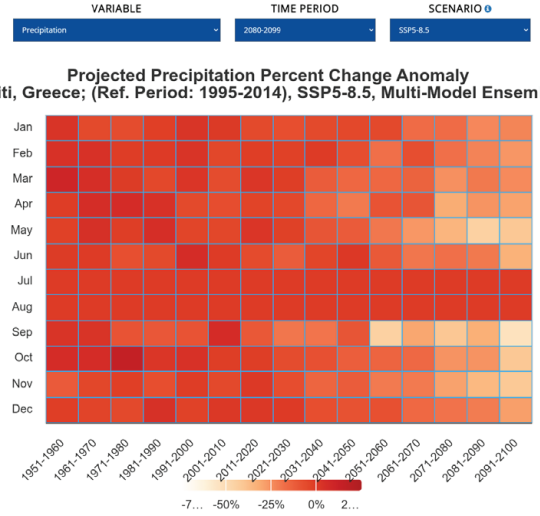


Figure 104: Projected precipitation percent anomaly for Crete, Source: *https://climateknowledgeportal.worldbank.org/country/greece/climate-data-projections*

Conclusions

Case study

In conclusion, the island of Crete stands in a critical position, exposed to the challenges of flooding, drought, and desertification. The island's vulnerability to climate change is intensified by its distinctive seasonality, which influences essential biophysical and human activities such as precipitation patterns, river dynamics, and large tourist influxes. Particularly, the region of the Isthmus of Ierapetra, which is the narrowest part of Crete, demonstrates the island's vulnerability to both water scarcity and excess. The area is highly prone to flooding events due to its large alluvial plains, the dynamics of the seasonal rivers, and the changing precipitation patterns.

Another significant feature of the region is the diverse landscape shaped by geological, hydrological, and anthropogenic processes. The presence of limestone and karstic formations drives groundwater infiltration, providing a crucial water source for the area while limiting surface water availability. Climate change poses a series of significant threats to this system by increasing its vulnerability to salinity intrusion, desertification, and sea level rise, potentially impacting settlements, infrastructure, and agricultural production.

The intensification of (greenhouse) agriculture, driven by the region's favourable climate and fertile soils, has significantly transformed the landscape. While contributing to the local economy, this intensification demands enormous amounts of water, putting pressure on groundwater resources with groundwater extraction rates exceeding natural replenishment, leading to aquifer depletion and salinity intrusion. Deforestation, urban development, and infrastructure have disrupted natural ecosystems, reducing the land's ability to retain moisture and increasing soil degradation, erosion, water and soil pollution, and overexploitation. Intensive agricultural practices have further contributed to this pressure, increasing the sensitivity of the land and soil to desertification.

Therefore, Crete's vulnerability to altered water dynamics and climate change is more than evident, stressing water and soil resources, with implications for ecosystems, communities, land, and cultural heritage preservation.

All the above conclusions emphasize the need to improve and redesign local water management planning and adaptation strategies across different spatio-temporal scales to achieve future water security and sustain the island's communities. The design proposal should prioritize water-sensitive interventions and actions aiming to enhance resilience and sustainability in the region. Simultaneously, the project, through the design proposal, criticizes the static current planning and design instruments in Greece and Crete, which overlook the temporal dimension of the island's processes and the dynamic character of fundamental elements such as water, soil, geology, and climate.

For these reasons, it is essential to rethink and redesign a comprehensive water distribution system, restoring the rivers and their alluvial plains, and designing local water retention and infiltration landscapes to temporarily store rainwater to meet the future needs of human activities. These spatial design interventions will slow down the water flow, especially during intense rain events, recharge the aquifers, prevent complete runoff to the sea, and avoid flooding incidents. At the same time, flood mitigation strategies should be included in the preparedness of the island, incorporating water retention landscapes and enhancing groundwater recharge. Adaptive measures to address sea level rise should include coastal protection structures, land-use planning, and relocation strategies. Integrating coastal protection measures and buffer zones will mitigate the impacts of sea-level rise and protect coastal communities and infrastructure.

Moreover, it is fundamental to reconsider current agricultural practices and the extensive land they cover. There is an urgency to adopt sustainable agricultural practices, that minimize their environmental impacts and restore soil and natural systems through soil conservation measures across scales. Promoting ecosystem restoration and reforestation efforts is crucial to enhancing the region's ability to retain moisture and combat desertification.

By addressing these challenges through a holistic, integrated, and sensitive design approach across different scales, the project aims to foster a more resilient and sustainable future for the Isthmus of the Ierapetra region, addressing water scarcity and excess in the face of climate change and uncontrollable human pressures.

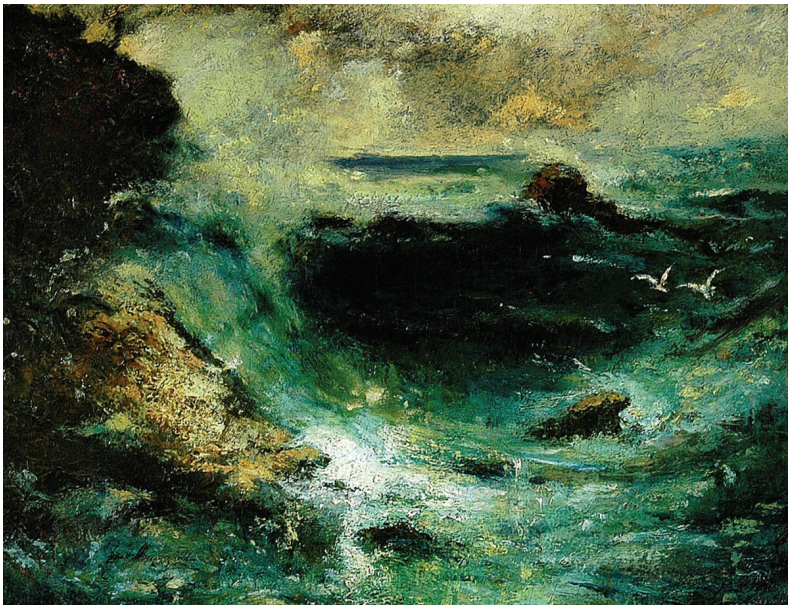
Framing the project

Overall strategy

Design approach

"Our task is to make trouble, to stir up potent response to devastating events, as well as to settle troubled waters and rebuild quiet places."

Haraway, Donna, 2016, Staying with the trouble: making kin in the Chthulucene



Elliott Daingerfield (1859–1932), Troubled Waters, painting, oil on canvas

The scope of the thesis is to empower the island of Crete by enhancing its resilience and climate-adaptive transformation while respecting and preserving its rich cultural heritage. The project's approach emphasizes designing with sensitivity to natural habitats, incorporating the principles of porosity, elasticity, fluidity, and temporality as key guidelines for creating a resilient future for the island.

The thesis aims to criticise the current planning instruments used in Greece, highlighting their limitations in representing the dynamic nature of environmental processes, altered nature, and human activities. By emphasizing the static and constraining representation of space, water, and soil, it repositions the current planning methods and advocates for exploring alternative ways of understanding and addressing spatial and environmental challenges. A particular case study is proposed to demonstrate this alternative approach, allowing for a concrete exploration of how these principles can be applied in space and time with respect to hydrogeomorphological variations and cultural heritage.

A critical component of this project is to fundamentally restore the relationship with the soil, earth, nature, and water, recognizing them as dynamic and active elements essential to the island's survival. To achieve this, the thesis proposes a series of strategic actions operating across three scales and different temporalities, such as human, hydrological, and ecological temporalities that coexist in the same space, elements that current planning instruments fail to incorporate.

Furthermore, the spatial framework of the project acknowledges a diverse range of actors and agencies within these three scales, such as water, soil, and agriculture, who collaborate but also often encounter conflicts due to differing interests and objectives. By addressing these complexities, the project aims to propose innovative and resilient design actions that harmonize the various islands' complex systems and contribute to a resilient and adaptive future for Crete.

The canvas

The project embarks on a critique of existing planning frameworks and operational logics, aiming to expose their shortcomings in effectively addressing the dynamic interactions of environmental processes and human activities in Greece. It challenges the conventional planning instruments currently in use, arguing that they often fail to capture the intricacies and evolving nature of these interrelated systems. In response to these identified limitations, the project proposes an innovative approach to design and planning through:

- the planning and design across three main scales: the territorial scale of the island, the scale of the transect of the Isthmus of Ierapetra, and the local scale of the dam, river, and agriculture system.

- understanding and addressing spatial and environmental challenges, focusing on water and earth (soil) systems and their relationship with human life and activities.

- the study and design of the synergies between different spatiotemporal scales, such as hydrogeological associations with the interconnectedness of water flows across different scales

- the acknowledgment of all actors and agencies (including water as an active agent, terraforming) in the analytical and design frameworks.

- the acknowledgment of the coexistence of different temporalities.

Planning and design across three main scales

The project follows a planning and design process across three main scales: the territorial scale of the island, the scale of the transect of the Isthmus of Ierapetra, and the local scale of the dam, river, and agriculture system, which studies the seasonal rivers in a systematic way. This approach allows for a comprehensive understanding of spatial dynamics and fosters integrated planning across different levels.

Isthmus of Ierapetra Transect Scale
The transect scale serves as a representative cross-section of the island's topography, hydrology, and land use, highlighting spatial and temporal variations in water resources and vulnerabilities. It reflects the complexities of the region's water dynamics and the interactions between natural and human systems.

Local Scale
It focuses on a particular water management system and its immediate surroundings, including water retention landscapes, soil, agriculture, vegetation, and human activities. It systematically studies the seasonal rivers and their interconnectedness with other elements, allowing for detailed analysis and strategic interventions.

Island of Crete Scale
This scale provides a broader context for water resource management, considering regional climatic patterns, geological features, and socio-economic dynamics. Influences water availability, ecosystems, and agriculture. It addresses their influences on water availability, ecosystems, and agriculture, and informs policies and regulations essential for creating resilience.

Understanding and addressing spatial and environmental challenges

The project aims to understand and address spatial and environmental challenges by focusing on water and earth (soil) systems and their relationship with human life and activities. By proposing a case study, the project demonstrates this alternative approach, allowing for a concrete exploration of how these design principles can be applied to the island of Crete, considering the different spatio-temporal conditions. This method promotes integrated and adaptive planning, ensuring a resilient future for the island.

Study and Design of Synergies Across Spatiotemporal Scales

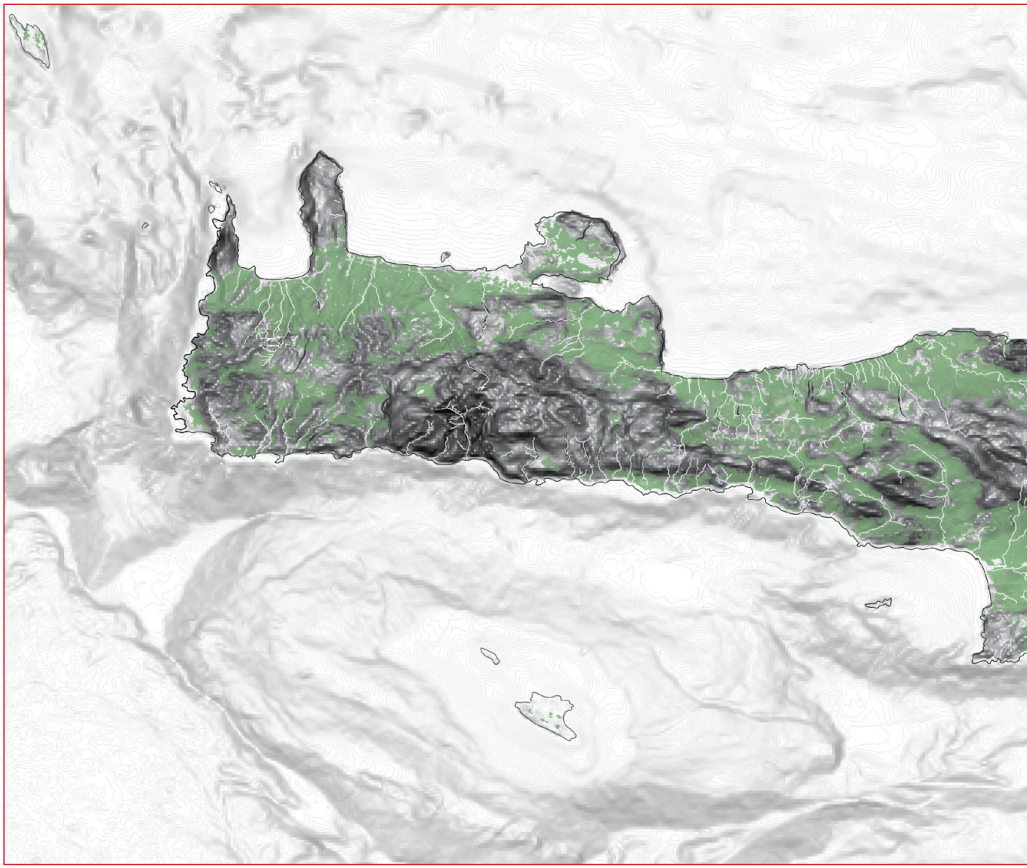
The project emphasizes the study and design of synergies between different spatiotemporal scales, particularly focusing on hydrogeological associations and the interconnectedness of water flows. This involves exploring the island's hydrological cycle together with localized river systems to ensure water availability for both human activities and ecosystems. This integrated approach considers how water flows and storage capacities are influenced by geographical features, climatic conditions, and human interventions, enabling more effective and adaptive management strategies.

Acknowledgment of main actors and agencies in the analytical and design frameworks

Another fundamental aspect of the project is the acknowledgment of the territorial interactions between the diverse actors and agencies involved across the different scales. These include local communities that rely on water for crop irrigation and production, agricultural producers and cooperatives essential for sustaining local agriculture, and regional and local government agencies responsible for regulatory resource management. Additionally, environmental organizations advocate for environmental restoration and regenerative practices, while research institutions conduct studies on hydrology, ecology, climate change, and the socio-economic impacts of water management practices in the area. They collaborate and negotiate across scales to address water-related challenges and opportunities. Finally, in this thesis, water and soil itself are recognized as dynamic and active agents, which are terraforming landscapes through erosion and sediment transport, manipulating hydrological processes, and ecological dynamics.

Coexistence of different temporalities

The project also acknowledges the coexistence of different temporalities, from short-term variations such as seasonal rainfall variability that require immediate and flexible actions to long-term patterns, including climate change impacts, that necessitate adaptive strategies to mitigate emerging challenges. By considering these temporal dimensions, the project aims to create an adaptive and resilient design framework that addresses immediate needs while planning for future preparedness.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Planning and design across three main scales

River system

Agriculture

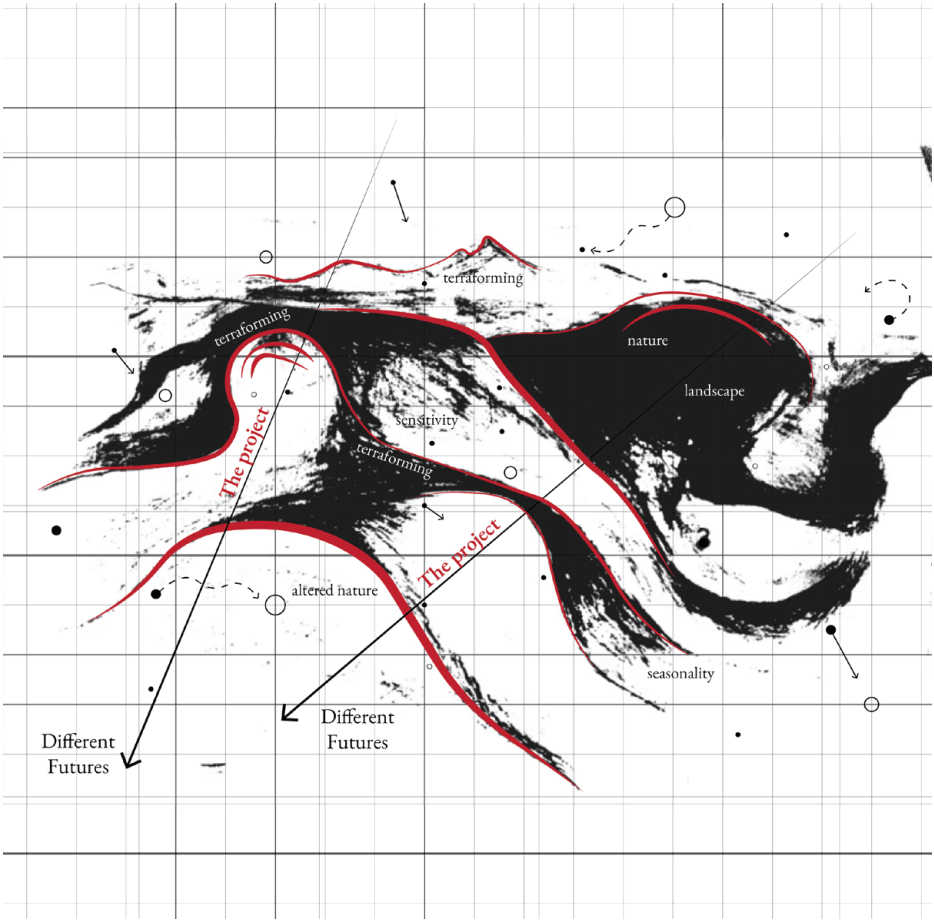
Island scale

Planning and Design Strategy

This project is positioned within the concept of altered nature, aiming to envision a different future for the island of Crete, focusing on terraforming forces and landscape manipulation. The scope is to create a more climate-resilient physical environment where human and natural systems coexist harmoniously.

The project considers the landscape as one of the most important critical interdependent systems that coexist on the island, influencing and being influenced by others. This approach recognizes the dynamic interplay between natural and human systems, emphasizing the need for integrated strategies that address environmental, social, and economic challenges. By analyzing the complex relationships among these systems, the project seeks to identify practices and design interventions that enhance resilience and the adaptive transformation of the island.

By situating the project within the broader discourse of altered nature, it challenges conventional approaches to spatial planning and environmental management, such as the current planning and design instruments in Crete. The ultimate goal is to develop a strategy that not only addresses immediate climate-related vulnerabilities but also promotes long-term resilience for the island's diverse ecosystems and human communities.



Project approach and position, terraforming, designed by author

The most important strategies and actions embraced by this project include effective water collection, flood protection, and ensuring fresh water availability and improved quality. Creating water retention landscapes and preserving ecosystems are essential for enhancing groundwater recharge and combating desertification while regenerating soil health. Redesigning rivers and streams aims to enhance habitat creation, while strategic planning for alluvial plains will balance agricultural use with flood control and environmental protection. Reducing agricultural land and promoting climate-resilient crops will address food security.

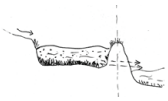
Additional strategies requiring further exploration potential in other projects include alternative use of karstic aquifers, controlling water overextraction, and redesigning critical infrastructure to withstand climate impacts. Finally, coastal areas need redesign to address sea level rise and release parts of the coastline to the sea.

Figure 105: Selection of strategic interventions, designed by author

Water risk management

1. Collect and filter water

vegetation to filter water, stabilize soil, accomodate habitats



sedimentation basins, capture-reuse sediment & improve water quality

2. Store and distribute water

water retention landscapes

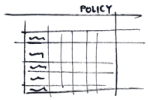
ponds and wetlands to store and manage storm water runoff

Economy shift

1. shift towards regenerative agricultural activities (climate-resilient)

2. enhance agricultural village economy and rercreation

3. policy changes that support sustainable land use, water management, and agricultural practices.



4. alternative tourism activities: eco-tourism

Natural ecosystem restoration

1. reforestation

2. soil regeneration

3. river restoration (riparian buffers,)

Planning and design principles

A wide range of measures are proposed to address water risk management in the area, ranging from small-scale ponds and soil conservation practices to large-scale floodplain and wetland restoration and aquifer recharge initiatives.

Two main priorities can be set in relation to adaptation and resilience in the water risk management sector (Bergkamp et al., 2003). Firstly, current and future risks and uncertainties associated with such climate-related problems need to be addressed to safeguard people and societies from floods, droughts, and other extreme weather events due to climate change. Measures to reduce the risk of more frequent, lower-intensity floods are crucial. Improving water availability during periods of scarcity and drought should focus on managing runoff, regulating flow regimes naturally, and recharging soils and aquifers through increased infiltration. This can be achieved by implementing strategies such as afforestation, land-use planning, and floodplain, river, and wetland restoration. In view of the increasing impact of climate change, natural water retention strategies can address climate change adaptation and mitigation by facilitating natural carbon sequestration and storage.

The second priority should be to protect and restore ecosystems that provide critical land and water resources and services, aiming to maintain and restore natural capacities that protect from the impacts of increased climate variability and extreme events. Enhancing water quality involves mitigating pollution through methods like filtration.

Seasonal variations, resilient, dynamic landscape

Take advantage of the topography to harvest water and use it throughout the year

Water retention and infiltration landscapes

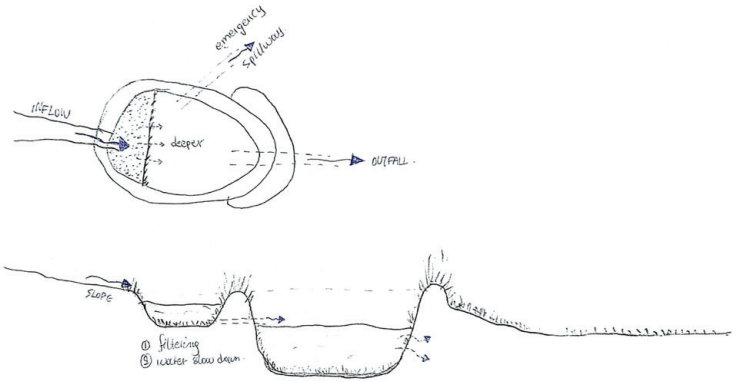
Water retention and infiltration landscapes capture and filter water, taking into account the local topography of cavities and low-elevation areas where water naturally accumulates. Through vegetation-based filtration systems and sedimentation basins, these landscapes improve water quality and reduce pollution. Vegetation-based filtration systems also contribute to soil stabilization and provide habitat.

Water retention and infiltration landscapes have the potential to provide multiple benefits to the landscape and communities, including reducing the risk of floods and droughts and creating habitat diversity. (European Commission. Directorate General for the Environment., 2014) Their main focus is to enhance and preserve the water retention capacity of aquifers, soils, and ecosystems, aiming to improve their quality. (European Environment Agency, 2021).

Wetlands and river restoration, including riparian buffer zones

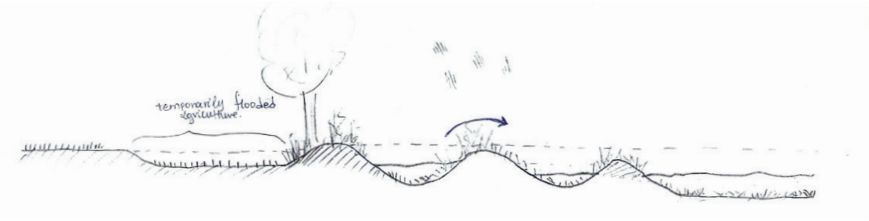
There is also the need to reconnect and restore river floodplains and disconnected stream meanders and establish riparian buffers to absorb floodwaters, reduce erosion, and protect adjacent areas from inundation during periods of high water flow. Combined with the creation of swales, ponds, and wetlands to store excess water during heavy rainfall and distribute it gradually, this integrated system will prevent flooding, promote groundwater recharge, and supply the higher water demands during the dry season. (European Commission. Directorate General for the Environment., 2014) Swales, shallow vegetated channels designed with gentle gradient terrain slopes, can slow and redirect stormwater runoff, and identifying low-lying areas for pond implementation will help store and manage stormwater runoff. Moreover, wetlands, areas where water covers the soil or is present either at or near the surface, should be developed in regions where water naturally accumulates.

Finally, areas with high permeability rates are designated for enhancing groundwater infiltration. In those areas, it is crucial to reduce the built-covered surfaces and promote natural land cover with vegetation. The introduction of plants and trees is fundamental as they enrich the subsurface with water and nutrients, thereby improving soil and water quality that has been degraded by human activities such as intensive agriculture.

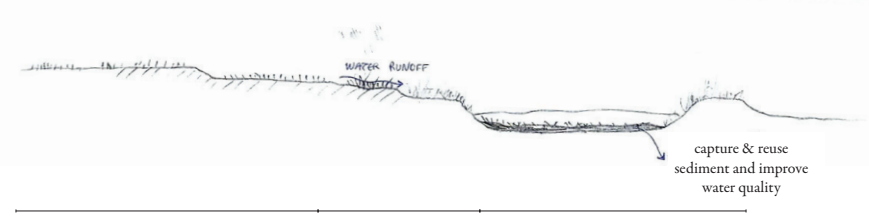


water infiltration / detention basin (store and gradually release water)

Water risk management interventions, designed by author



agricultural fields | temporarily flooded agriculture | water retention basin | connection in case of water inundation (diversion) | water retention basin



agricultural fields | buffer zone | sedimentation basin

Water risk management interventions, designed by author

Agriculture is a major contributor to pressures on Europe's water resources. The impact of agricultural activities on the aquatic environment is closely linked to specific farming practices. The use of fertilizers (nutrients), pesticides, and water on crops promotes plant growth and prevents pest or disease damage. However, intensive livestock farming produces excess nutrients and ammonia emissions, exacerbating environmental pressures. These agricultural pressures contribute to a range of impacts on surface water and groundwater bodies, including pollution, poor water quality, alteration of water flow regimes, and modifications to channel morphology. These challenges must be urgently addressed in order to sustain ecosystems and livelihoods and to build resilience against climate change impacts. (European Environment Agency, 2021).

Simultaneously, the global challenge is to feed a growing population without undermining the environment and resources on which food production depends. Ensuring food security, which includes available, affordable, and safe food, requires the development of sustainable and more resilient farming systems that are more diverse and require fewer resource inputs. (Gerten et al., 2020). Land-use conversion for water quality improvements is one such measure, as highlighted by the European Commission. Embracing regenerative agricultural practices that reduce environmental impacts, promote soil health, and save water is crucial for the long-term health of both agriculture and the natural environment (European Commission. Directorate General for the Environment, 2014).

Regenerative agricultural activities (climate-resilient), temporarily flooded agricultural zone

Enhance agricultural village economy, sustain food production

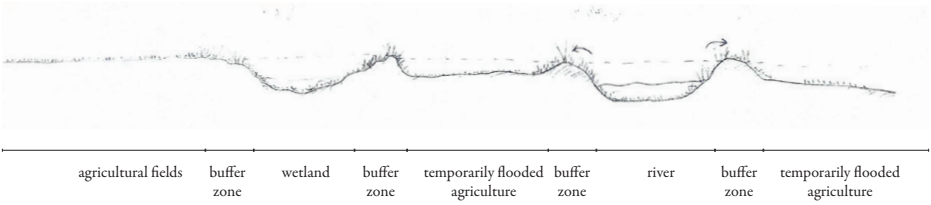
Riparian buffer zones and temporarily flooded agriculture

A central component of the proposed strategies involves river restoration to enhance carbon sequestration through reforestation and soil restoration, which contribute to climate mitigation efforts by reducing greenhouse gas emissions. The project acknowledges the spatio-temporal variability in this region by identifying vulnerable areas susceptible to flooding and proposing new agricultural typologies. More specifically, it proposes temporarily flooded agricultural zones designed for crop cultivation during dry months while also serving as reservoirs for excess water during winter. These zones would support soil restoration through remediation plants, filling a current gap in planning and design instruments that compromises the resilience of the area's water, soil, and agricultural systems.

Water-use efficiency in agriculture

Measures can also be taken to improve the area's'microclimate'', for example, by planting trees for shade or windbreaks, using plant wastes to enhance the organic matter of the soil, and increasing water retention. Such measures can improve productivity and benefit biodiversity. It is also important to grow crops suited to the location and season to maximize the benefits of available water. (Living Waters: Conserving the Source of Life, n.d.)

Water-efficient equipment, irrigation scheduling, and improved infrastructure (e.g., lining of canals, repair of leaking pipes) Additionally, implementing water-efficient equipment, irrigation scheduling, and improved infrastructure (e.g., lining of canals and repairing leaking pipes) can by far enhance water management and conservation efforts.



Resilient agriculture interventions, designed by author

Regenerative agriculture practices

It is fundamental to shift towards more regenerative agricultural practices that preserve and improve soil and land health while enhancing ecosystem diversity. Conservation agriculture stands out as a key approach, a farming system that promotes minimum soil disturbance (e.g. minimum tillage or no tillage), maintains permanent soil cover, and incorporates crop residues (increasing organic matter content). These practices not only benefit farmers by stabilizing crop production but also lead to lower costs for machinery and labor (European Environment Agency, 2021).

Climate-adaptive crops

Moreover, sustainable agriculture emphasises the need to adopt a range of more natural resource-efficient practices and cultivate climate-adaptive crops (Oberč and Arroyo Schnell, 2020). For example, in the face of climate change on the island of Crete, it is important to adopt less water-intensive crops, select crops or varieties/hybrids with a lower water demand and resistance to droughts, or implement water-saving crop and soil management. (European Environment Agency, 2021).

Agroforestry

Agroforestry is the deliberate integration of trees or shrub vegetation with agricultural crop systems (which could also be pasture). (Nair et al., 2008) There are different types of agroforestry practices in Europe involving silvoarable, forest farming, riparian buffer strips, silvopasture, improved fallow and multipurpose trees. (Mosquera-Losada et al., 2009). This approach often enhances land productivity by optimizing the capture of resources such as solar radiation and water more efficiently than separate tree or crop systems. Furthermore, agroforestry provides significant ecological benefits by improving various ecosystem services such as nutrient retention, erosion control, soil carbon sequestration, pest control and fire risk reduction. Additionally, agroforestry contributes to cultural services by enchancing recreational opportunities, aesthetic values, and preserving cultural heritage. (Nair et al., 2008)

Crop rotation

Crop rotation is the practice of planting different crops regularly on the same plot of land to enhance soil health, optimize soil nutrients, and manage pest and weed pressure. A simple rotation may involve two or three crop types, and complex rotations might integrate a dozen or more. Crop rotation helps return nutrients to the soil without relying on synthetic inputs.

Furthermore, crop rotation interrupts pest and disease cycles, enhances soil health by increasing biomass through the diverse root structures of different crops, and increases biodiversity. (Rodale Institute, 2020) Diversified crop rotations further improve water and nutrient efficiency, facilitating better water infiltration and reduced runoff. Furthermore, there is a need to reconsider and adjust the timing of sowing and harvesting and adopt improved crop rotation practices such as diversification, intercropping, and cover crops to develop a resilient and robust agricultural system.

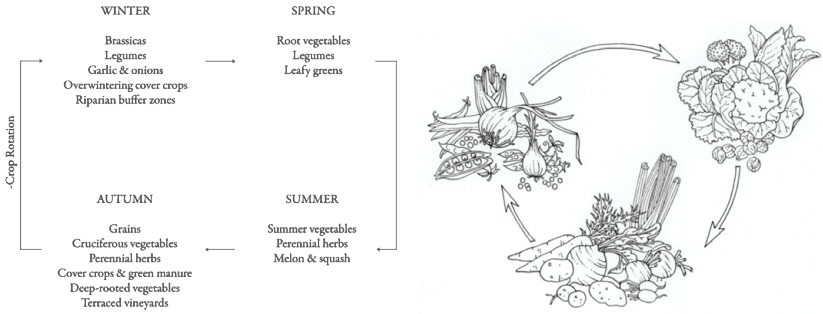


Figure 106: Proposed crop rotation, Source: (left) *designed by author,* (right) *Lizzie Harper, L. (2022). Crop rotation plan. Natural History Illustration for books, magazines & packaging. https://lizzieharper.co.uk/image/crop-rotation-plan/*

Winter

Temporarily flooded agricultural zone (wet)

Broccoli

Spring

Chickpeas

Carrots

Summer

Eggplants

Green beans

Autumn

Herbs

Wheat

S	Winter	Spring	Summer	Autumn
	More rain, cool season	sporadic rain, warm season	drought, hot season	sporadic rain, warm season
GROUP	BRASSICAS	ROOT VEGETABLES	SUMMER VEGETABLES	GRAINS
CROPS	broccoli, cabbage, cauliflower, brussels sprouts,	potatoes, carrots, beets, radishes, turnips, onions, garlic, sweet potatoes	tomatoes, cucumbers, bell peppers, eggplants, zucchini, green beans, okra, watermelon	wheat, barley, corn, rye, oats, sorghum, millet
GROUP	LEGUMES	LEGUMES (drought tolerant)	HERBS	CRUCIFEROUS AND DEEP-ROOTED VEGETABLES
CROPS	beans, soybeans, chickpeas, peanuts, lentils, lupins, grass peas, mesquite, carob, tamarind, alfalfa, clover	chickpeas, lentils, cowpeas, fava beans	dittany of Crete, thyme, rosemary, oregano, sage, marjoram, mountain tea	carrots, beets
GROUP	GARLIC AND ONIONS	LEAFY GREENS	MELONS AND SQUASH	COVER CROPS AND GREEN MANURE
CROPS	garlic, onion	lettuce, spinach, kale, arugula, cabbage, watercress		
GROUP	OVERWINTERING COVER CROPS	RAINWATER HARVESTING SWALES	SUMMER VEGETABLES (heat tolerant)	TERRACED VINEYARDS
CROPS	winter rye, winter wheat, crimson clover, winter peas, winter oats		tomatoes, cucumbers, zucchini, bell peppers, eggplant, green beans, corn, summer squash, okra	
GROUP	PERENNIAL FRUIT TREES		DRIP IRRIGATING ORCHARDS	PERENNIAL HERBS
CROPS	apple, pear, peach, plum, cherry, apricot, fig, citrus trees, pomegranate, olive, almond, avocado		apple orchard, citrus orchard, pear orchard, olive orchard	rosemary, thyme, sage, mint, oregano, chives, lavender, lemon balm, lemongrass

Figure 107: Seasonal variations of crop rotation proposal for the island of Crete, designed by author

Efficient and effective ecological restoration is urgently needed to counteract habitat and biodiversity degradation, the negative consequences of intensive agricultural practices, and urban and infrastructure development. (Atkinson et al., 2022)

Future-aimed restoration should acknowledge the dynamic and uncertain environment of the future and reconnect landscape elements to improve ecosystem functions and services. These services benefit human and natural ecosystems by improving water quality, securing fertile and stable soils, forming drought and flood buffers, increasing habitat diversity, and sequestering carbon. Sustainable soil management as part of ecosystem restoration strategies can enhance soil fertility, reduce dependence on inorganic fertilizers, and enhance soil water retention, reducing vulnerability to droughts and flooding. (European Environment Agency, 2021).

Beyond tangible benefits, restoration promotes public engagement through direct participation, which increases understanding of ecosystems and their benefits, strengthening human communities. A particular example is community forestry and afforestation of upstream catchments, efforts aiming to retain water infiltration in the soil.

Reforestation efforts

River restoration

Soil Regeneration Strategy

Soil conservation practices such as crop rotation, intercropping, conservation tillage, contour farming, terraces, and strip cropping are essential farming practices and management strategies that aim to control soil erosion by preventing or limiting soil particle detachment and transport in water or air. Cover crops are an effective soil conservation practice that reduces soil and water erosion and runoff, enhances nutrient concentration, and overall improves soil health (European Environment Agency, 2021). The construction of an earthen embankment along common elevation contours (terraces) produces elevated terrace structures that can directly reduce wind erosion by eliminating wind velocity. Permanent tall grass vegetation or annual forage and cereal cropping on these terraces can further mitigate wind velocity. Additionally, terraces, along with contour tillage and cropping practices, control water runoff and enhance water storage and infiltration in the soil. (Duncan and Burns, 2012)

Conservation tillage is a method that leaves crop residue on the soil surface, improving water infiltration into the soil and reducing soil erosion. Residue management is generally the preferred method for controlling wind erosion for most crops and climates.

All the above practices, when combined with crop rotation, diversity, and integration with livestock and trees (agroforestry), can be incredibly beneficial, especially for areas with highly degraded soil. Furthermore, soil conservation practices are closely linked to water conservation, contributing to water quality improvement, decreased runoff, and increased infiltration potential. (Baumhardt, R.L. & Blanco-Canqui, H., 2014)

Remediation plants

Another important part of the strategy to restore and regenerate soil quality, especially in polluted or degraded areas, is soil remediation. Particularly, one type of remediation, phytoremediation, is a cost-effective green technology based on the use of plants to remove, metabolize, or adsorb inorganic and organic contaminants in soil and groundwater. This can happen through specific plant/crop types (phytoremediation plants) that have several capabilities, including extracting contaminants from the soil through their roots (phytoextraction plants), stabilizing contaminants in the soil and preventing their migration (phytostabilization plants), and plants that remove contaminants from water bodies or soil (rhizofiltration plants) (Mahjoub, Borhane., 2014).

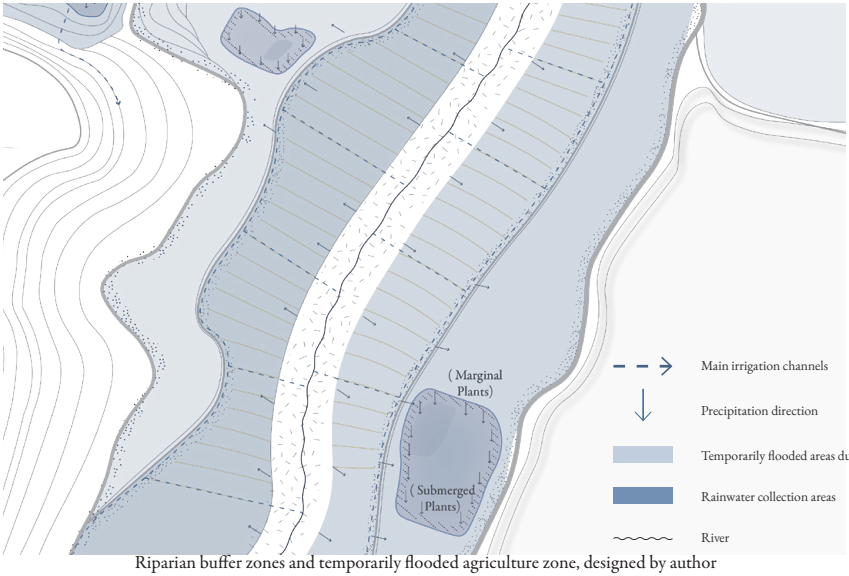
Landscape approaches

The landscape approach provides another perspective on ecological restoration, aiming at enhancing environmental sustainability and resilience in agricultural and natural ecosystems. Landscape natural elements such as buffer strips, field margins, and riparian vegetation manage water runoff along the rivers, protecting agricultural areas from flooding. Hedgerows and wooded strips further contribute by providing habitats for biodiversity and promoting soil stability.

Simultaneously, constructed wetlands, ponds, and sediment traps contribute to water management by capturing and filtering pollutants, thereby improving water quality downstream. These measures also support groundwater recharge and enhance local water storage, benefiting irrigated regions. Wetland, floodplain, and river restoration efforts, such as re-meandering rivers, are vital for flood risk mitigation, biodiversity conservation, and maintaining the area's hydromorphological conditions. By improving nutrient recycling and restoring surface groundwater exchange flows, these restorations can enhance local groundwater recharge and water storage, which is particularly valuable in regions like Crete that rely on groundwater or groundwater-fed surface water bodies. (European Environment Agency, 2021). These initiatives also facilitate recreational activities and sustain agricultural productivity, ensuring long-term ecosystem health and human well-being.

Riparian buffer zones and temporarily flooded agriculture

A central component of the proposed strategies for the island of Crete, involves river restoration to enhance carbon sequestration through reforestation and soil restoration, thereby contribute to climate mitigation efforts and reducing greenhouse gas emissions. This strategy includes the establishment of riparian woodlands along the rivers, the restoration of floodplains, and the creation of wetlands within these zones for different parts of the sub-basin. In these vulnerable zones along the rivers that during the wet months are getting flooded, a new agricultural typology is proposed: the temporarily flooded agricultural zone. This typology contributes to both soil restoration and resilient agricultural production, through agricultural practices during the dry months and employing remediation plantations to restore soil health during wet winters when flooding occurs. It is crucial to remove all built structures and intensive agricultural practices from these vulnerable river areas and to remediate contaminated and degraded soil to restore the floodplains.

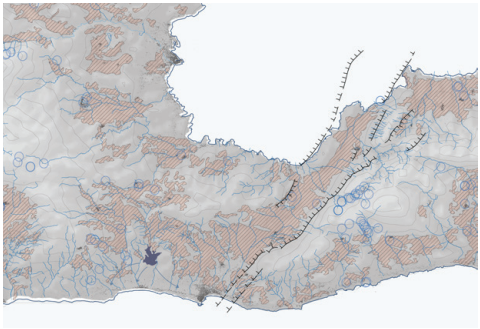


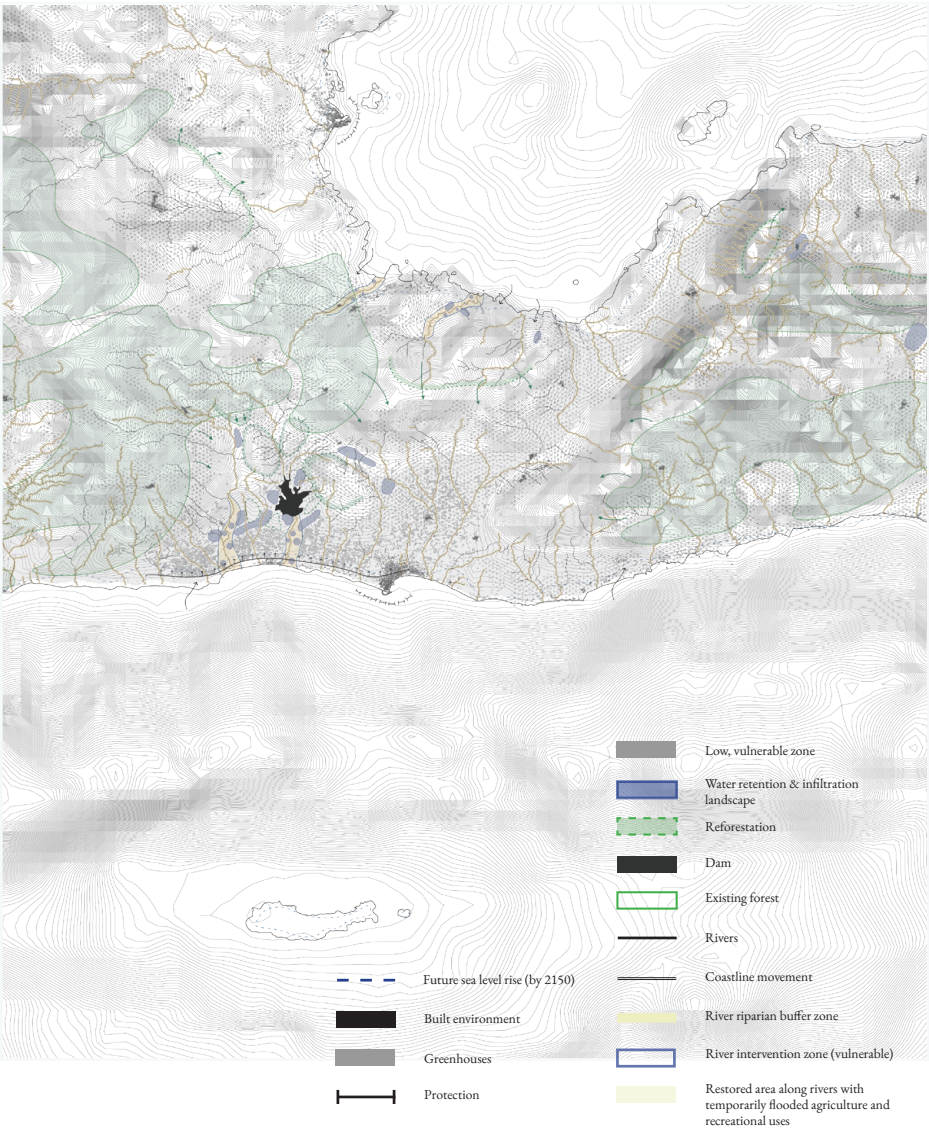
Riparian buffer zones and temporarily flooded agriculture zone, designed by author

After the development of the strategy and design guidelines, as a first step, a smaller-scale region is chosen for in-depth application of these principles. Addressing issues of water scarcity and excess requires implementing water retention landscapes, soil remediation and reforestation efforts to reverse degradation, and promoting more climate-adaptive and resilient agriculture on a more local scale to acknowledge the interconnectedness of the systems that constitute space and improve the interraction between nature and humans. For a more detailed exploration of these interventions, an even smaller scale is being introduced later to present a comprehensive design proposal and the terraforming forces initiated by the project.

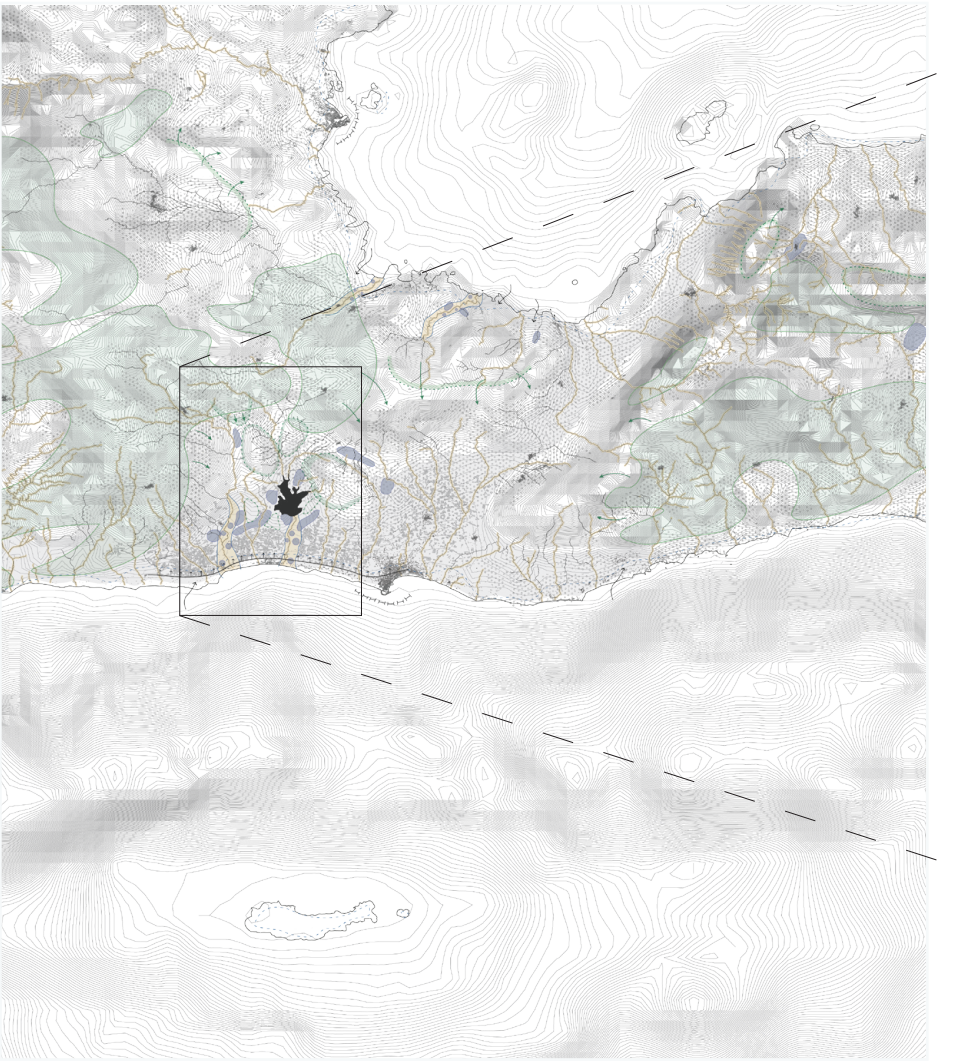
The area of the transect (Isthmus of Ierapetra) was chosen due to the fact that it combines most of the important complex systems found across the island, such as a dam, intensive agricultural practices, degraded soil, and significant seasonal rivers. This area is also one of the most vulnerable regions on the island due to its semi-arid climate and extreme climate variability. Combined with soil degradation and pollution resulting from intense agricultural practices that over-exploit soil and groundwater resources to supply their needs, these factors threaten the habitability and resources of the area, particularly during the dry seasons, exposing the area to the risk of droughts and desertification.

At the same time, the area is vulnerable to flooding due to river overflow during flash floods and the absence of water retention landscapes in the alluvial plain. Similarly, the built environment does not promote groundwater table recharge, and instead, the largest amount of rainwater runs off to the sea, threatening both soil and critical infrastructure and causing significant damage.

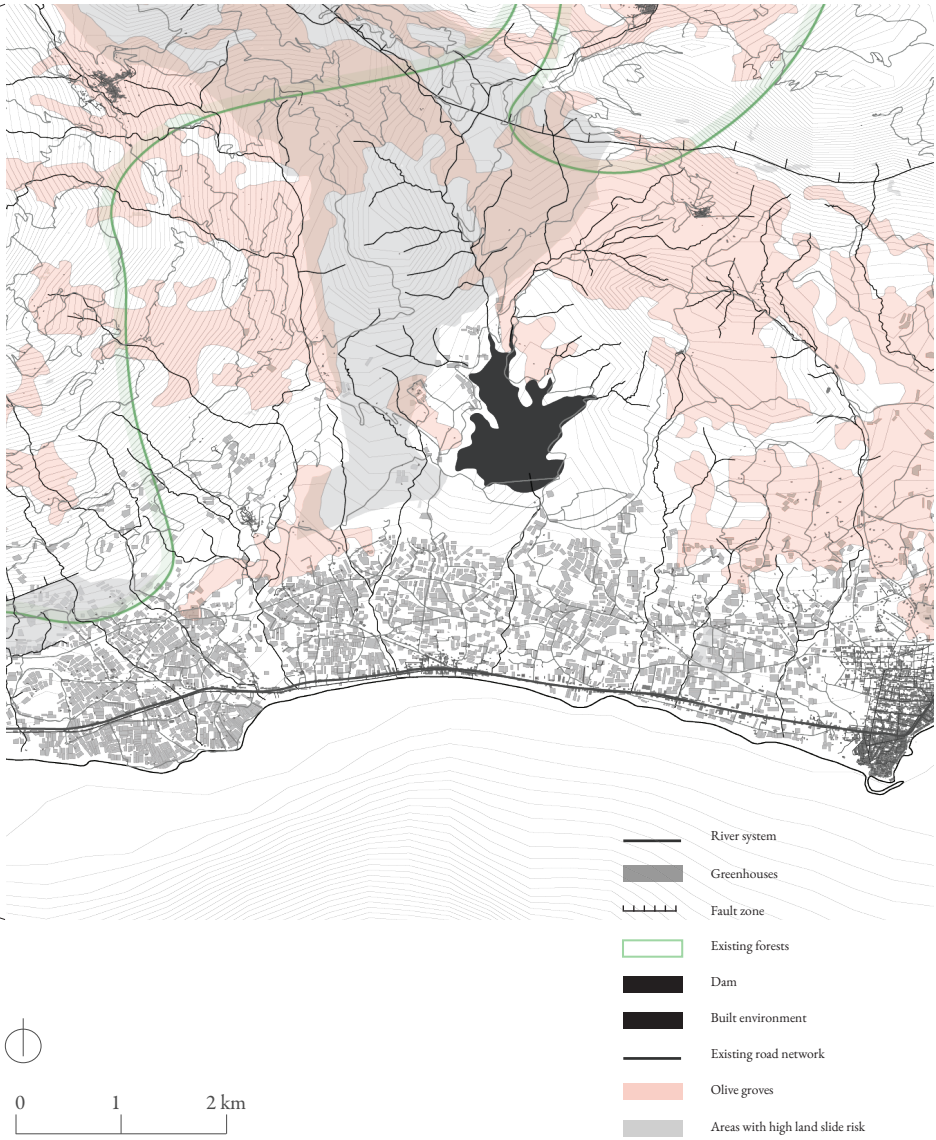




Design strategy, designed by author



0 5 10 km



Smaller scale region, existing situation, designed by author

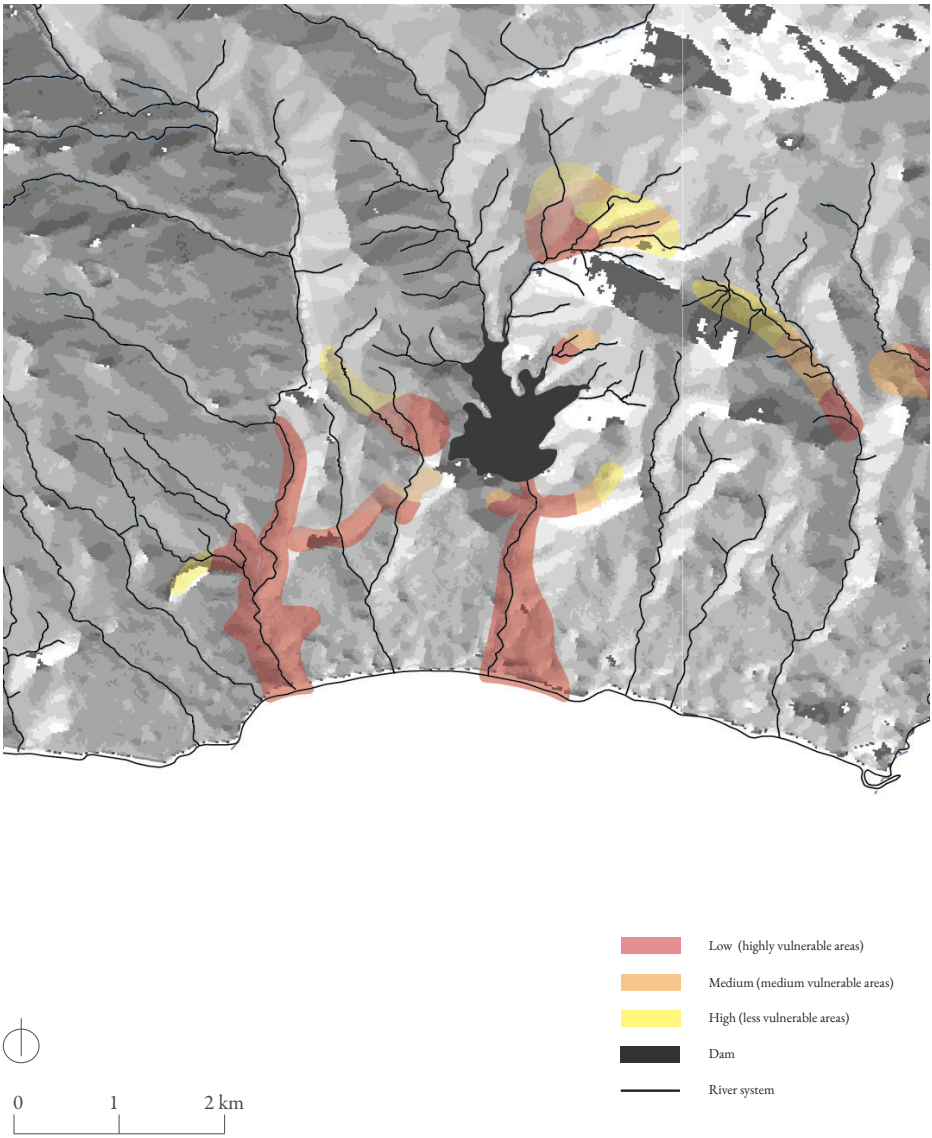
Alteration by humans, designed by author

Water retention and infiltration landscapes

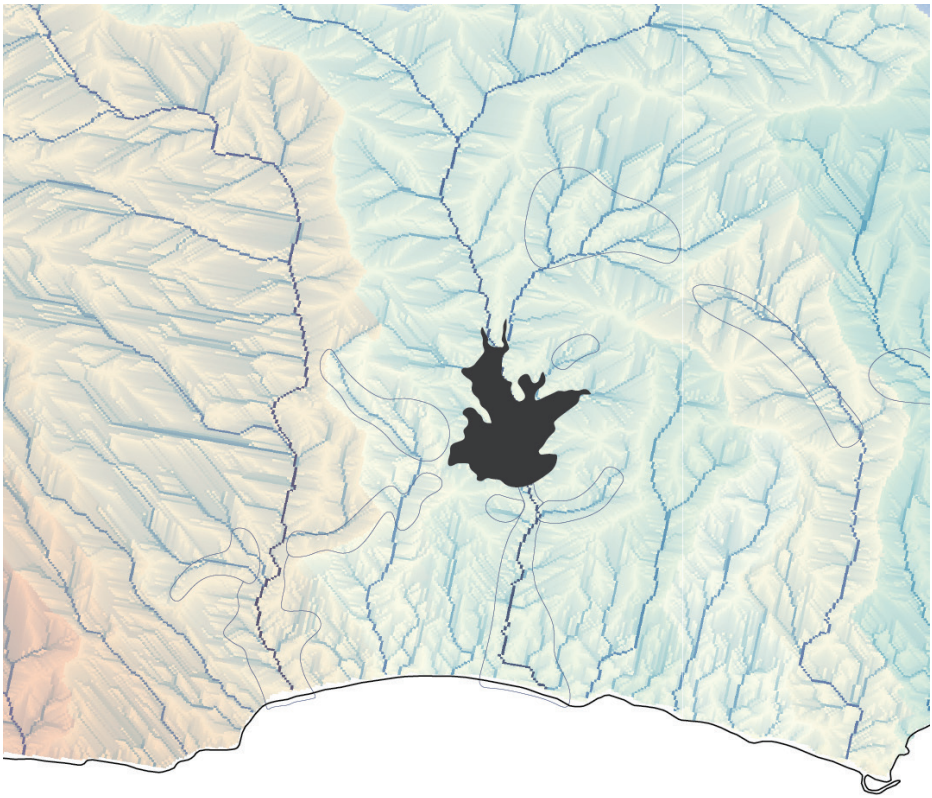
During this process a hydrogeological study is being conducted to decide the suitable locations for the water retention and infiltration landscapes taking into account the existing topography, which includes cavities and low-elevation areas where water naturally accumulates. Additionally, the study evaluates the permeability of the deeper soil layers to enhance water infiltration.

More specifically, areas with very low permeability are identified as suitable for water collection, while areas with high permeability rates are designated for enhancing groundwater infiltration. In those areas, it is crucial to reduce the built-covered surfaces and promote natural land covers with vegetation. The introduction of plants and trees is fundamental as they enrich the subsurface with water and nutrients, thereby improving soil quality that has been damaged by human activities such as intensive agriculture.

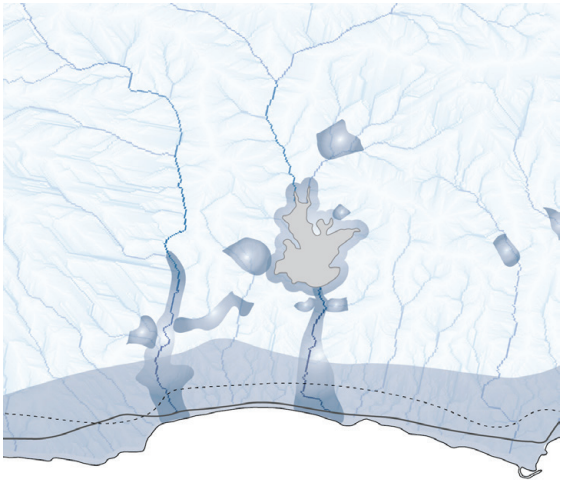
Hydrogeological study to identify areas for water collection and infiltration, designed by author



Smaller scale region, water dynamics and risk assessment, designed by author



Smaller scale region, river basins and water flow accumulation, designed by author



Winter (December-February): The winter scenario will be the most vulnerable to intense flooding due to heavy rainfalls. During these months the groundwater table infiltration needs to be enchanced and overwintering cover crops, vegetation and trees should secure and protect soil from erosion and flooding caused by excessive winter rainfall.

Autumn (September -November) in Crete lately, is the season that suffers from extreme flooding after winter, due to the heavy rains that occur in this part of the year.
*The crops that are planted in this level are fruit trees, that are semi-resilient to flooding, but will be flooded just once, in extreme situations.

Winter and often autumn months

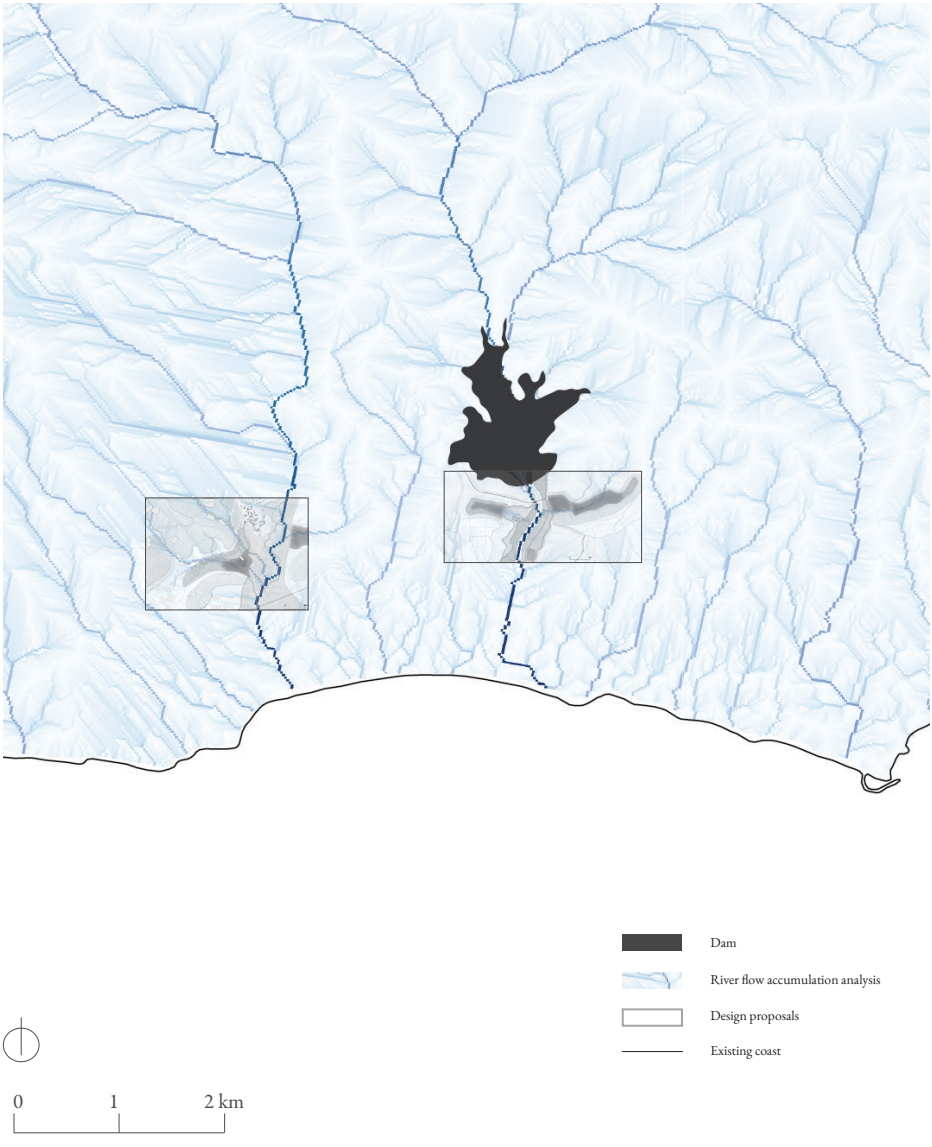
Spring (March-May) floodings, caused by the ice and snow melt from the mountains are not as extreme as the winter ones, flooding just the nearby lands to the river. (*The crops that are cultivated in this level mainly consist of vegetable species, as their resilience to flooding is quite high)

Summer (June-August): This period often experiences minimal rainfall which together with the highest water demands due to agricultural and tourism activities, are leading to water scarcity and drought conditions. For this purpose the retention and infiltration basins are designed to help irrigate the land and secure fresh water availability, retaining the excess water of the winter.
(*The crops that are planted in this level are drought-tolerant crops, such as certain vegetable types: asparagus-broccoli together with herbs, olives, fruit trees)

Summer and spring months

Flood risk
Water accumulation
Future sea level rise level
Main road network
Island coast

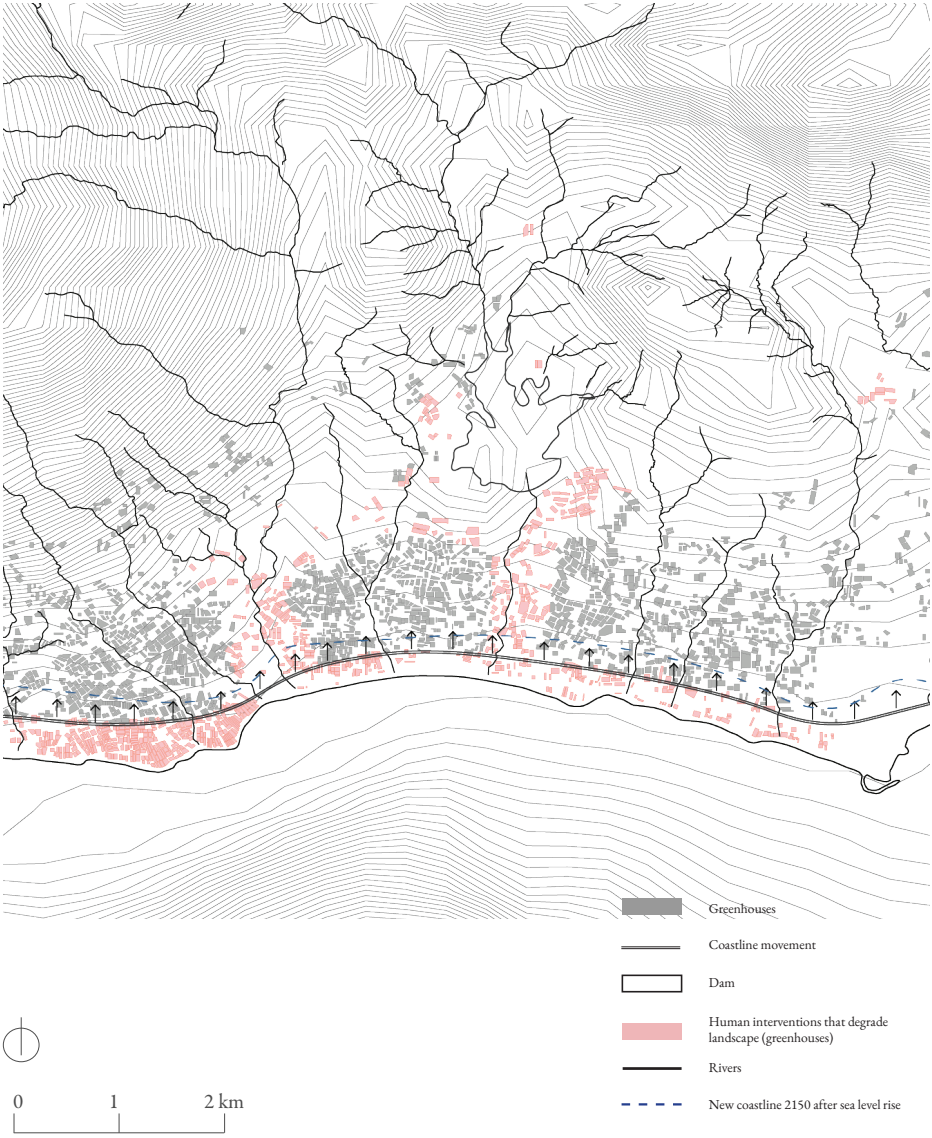
0 1 2 km



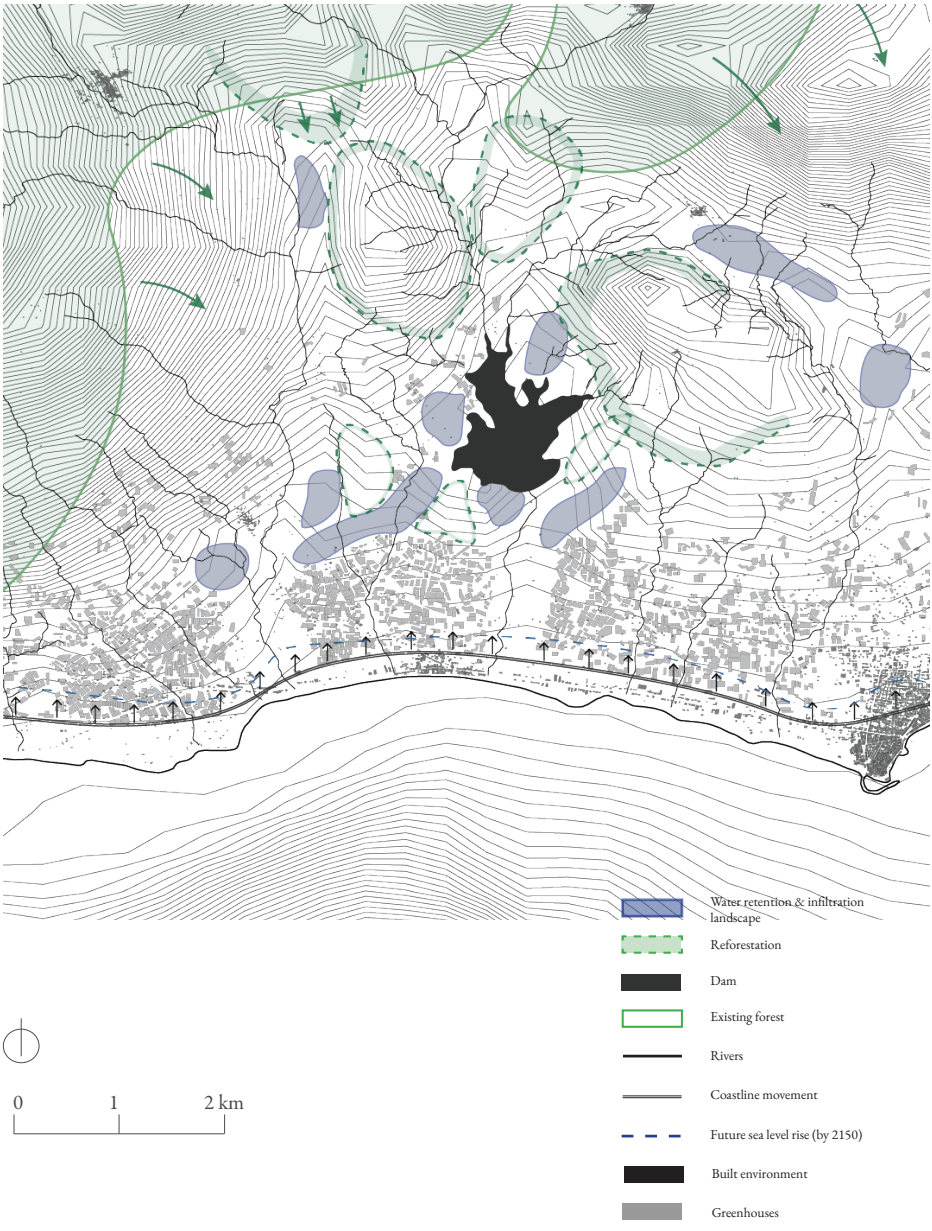
Smaller scale region, water flow accumulation and areas with design proposal, designed by author

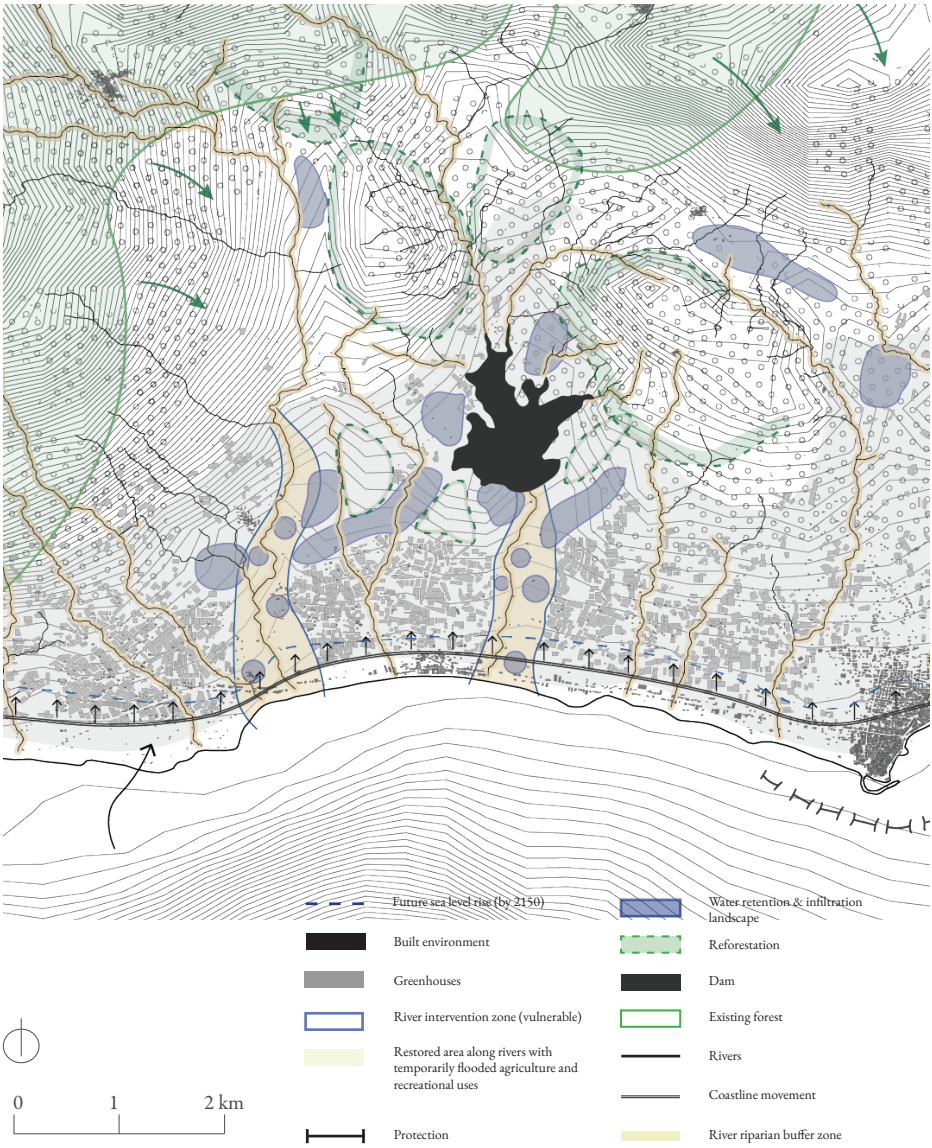
Water distribution concept, designed by author

Identification of water-related intervention areas, designed by author



Focus on the human elements that altered irreversibly the landcape and need to be removed, designed by author


Water retention & infiltration landscape
Reforestation
Dam
Existing forest
Rivers
Coastline movement
Future sea level rise (by 2150)
Built environment
Greenhouses
0
1
2 km



Smaller scale region, integrated design proposal, designed by author

S	Winter	Spring	Summer	Autumn
	More rain	sporadic rain	drought	sporadic rain
MAIN STRATEGY	Water excess, floodings ↓ Water filtration, store and distribution, flood mitigation	Water scarcity ↓ Restoration/Concervation	Water scarcity, droughts ↓ Water harvesting and store	Soil erosion ↓ Soil erosion control
INTERVENTIONS	Flood mitigation strategies to capture and slow down runoff (swales, bioswales, or retention ponds)	River restoration to improve streamflow dynamics, and restore the ecological balance of water bodies	Water collection and distribution by creating retention, filtration basins or wetland	Soil erosion control measures (terracing and cover cropping) to prevent soil loss
	Implement soil erosion control measures like planting cover crops	Engage and educate community to raise awareness about water conservation and ecosystem restoration	Establish efficient irrigation technologies and enhance water productivity in farming practices	Engage and educate community to raise awareness about water conservation and ecosystem restoration
	Enhance groundwater recharge by creating infiltration basins or permeable surfaces	Drought-resistant native plant species (landscape/agriculture) to reduce water demand and maintain soil moisture levels	Drought-resistant native plant species (landscape and agriculture) to reduce water demand and maintain soil moisture levels	Soil restoration practices (remediation in phases-different locations, in water, along rivers, in cultivation soil, in former forests)
GENERAL GUIDELINES	Seasonaly multifunctional open space			
	Landscape restoration (rivers, reforestation, etc.)			
	Soil restoration (remediation in phases)			
	Flood (temporarily) parts of the land (agricultural areas) in case of flooding			
	Enhance groundwater recharge			
	(Seasonal) crop rotation			
	Water permeable surfaces to promote water infiltration			
	Educate community to raise awareness			

Figure 108: Seasonal strategies, design interventions, designed by author

Introducing wet agriculture practices, such as paddy cultivation and integrated wetland farming, in the areas along the rivers prone to winter flooding, can significantly enhance agricultural resilience and adaptation to climate change. These areas can serve multiple purposes seasonally. For instance during winter months when these areas are usually flooded winter crops or rhizofiltration plants can be established to filtrate water and improve its quality but also to slow down water flow, thereby mitigating potential flood damage.

Identifying and embracing temporarily flooded areas as strengths and seasonal variations within the agricultural and nature restoration system is fundamental. Farmers need to be educated and trained on how to effectively manage land and vital resources such as water and soil. At the same time there is a need to explore and adopt climate-adaptive agricultural practices suitable for both wet and dry conditions, ensuring a holistic approach to regenerative agriculture and ecosystem restoration.

Wet agriculture practices

Communities must be actively involved in natural ecosystem restoration strategies and need to care about soil, recognizing that their land and soil are vital resources upon which their livelihoods depend.

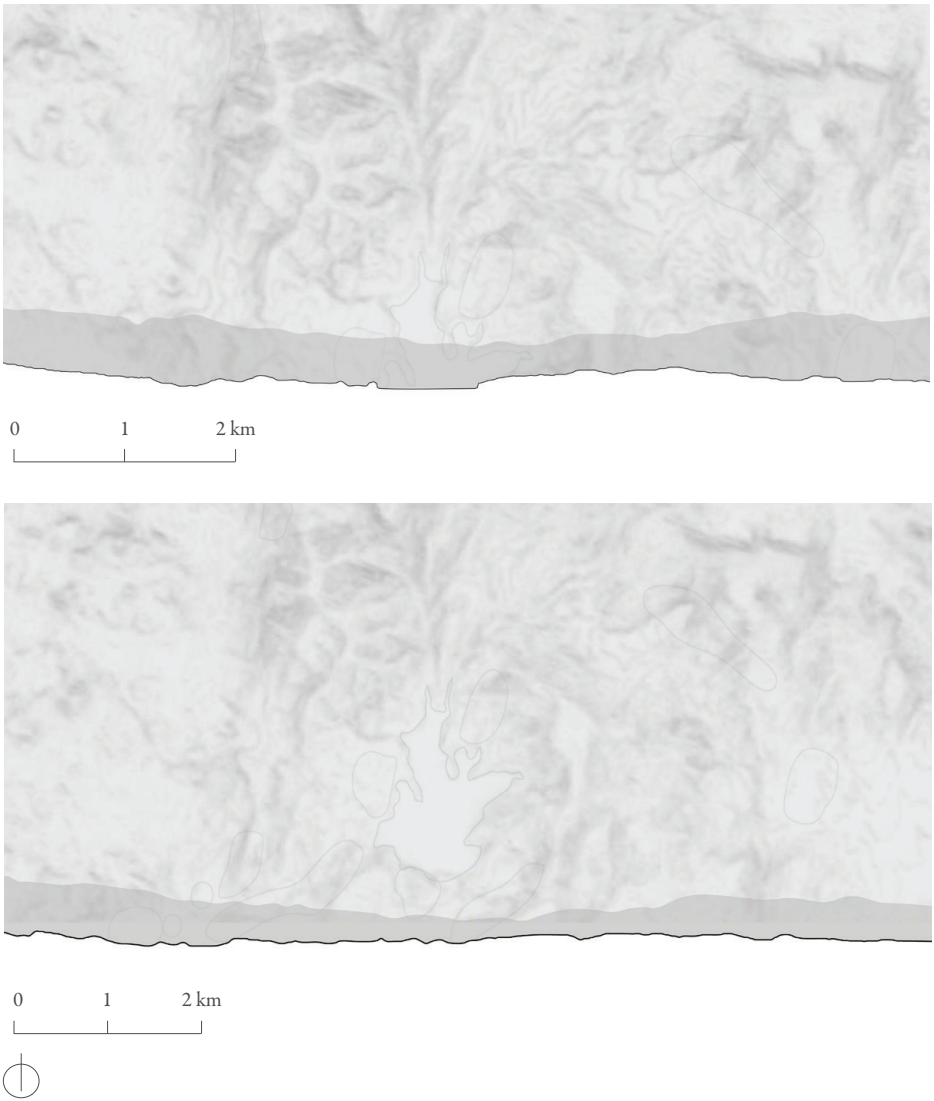
Reforestation and agroforestry significantly enhance soil quality, prevent erosion, and create microclimates that protect crops from extreme weather, thus contributing to climate change mitigation through carbon sequestration.
Trees stabilize the soil, reducing the risk of erosion and flooding, and improve water infiltration and retention while enhancing crop resilience and productivity. These practices promote a harmonious relationship between humans and the natural environment. It is essential for communities to understand that soil quality is fundamental to sustaining their (agricultural) activities. Therefore, it is their responsibility to care for and maintain soil health.

Reforestation - Agroforestry

Water harvesting techniques, including rainwater retention and infiltration landscapes, secure fresh water availability and mitigate flooding, promoting sustainable agricultural and domestic water use. Additionally, these techniques create recreational areas that benefit both residents and tourists, thus strengthening the local economy.

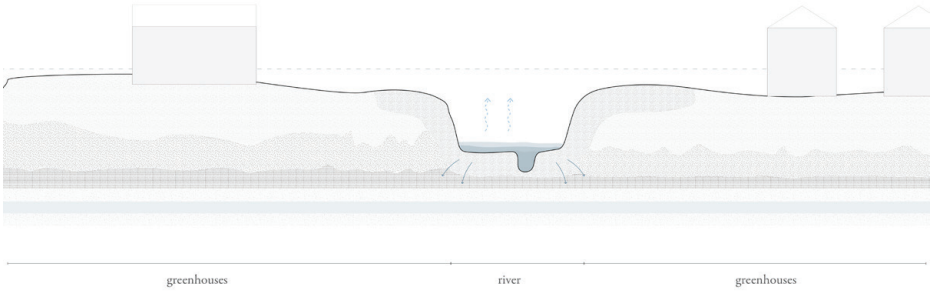
This approach fosters a symbiosis between natural and human ecosystems, enhancing environmental sustainability while supporting economic development.

Water harvesting and community engagement

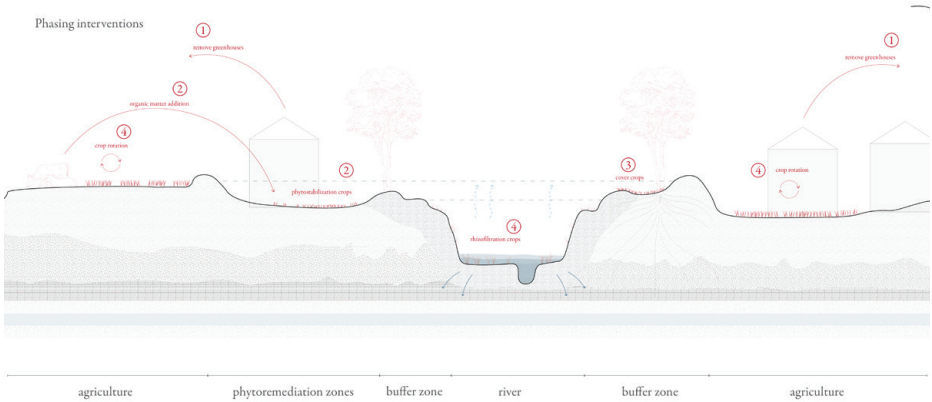


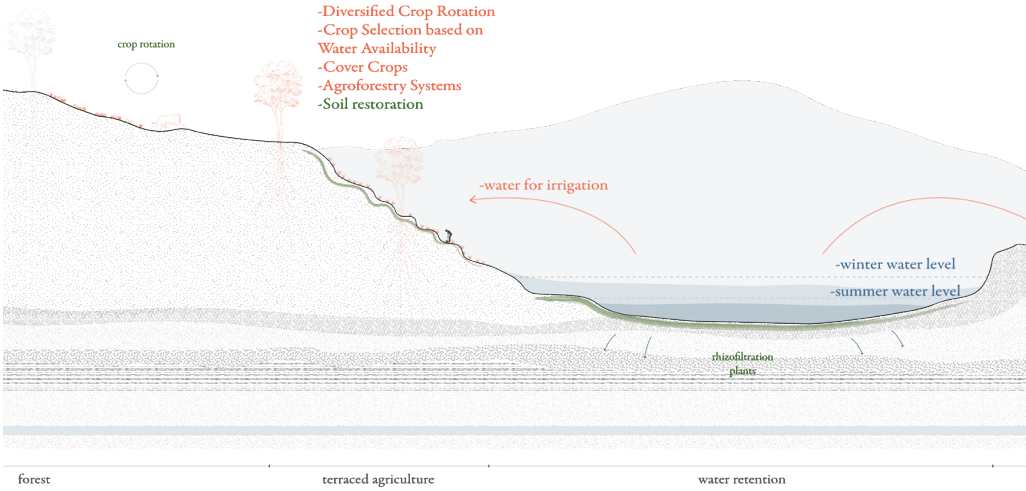
Terraforming landscape sections, designed by author

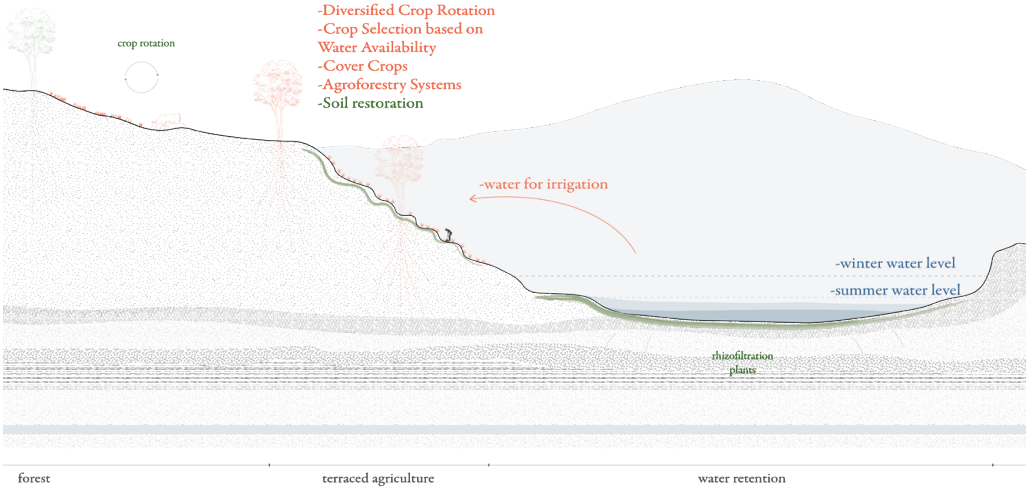
Exhausted landscape

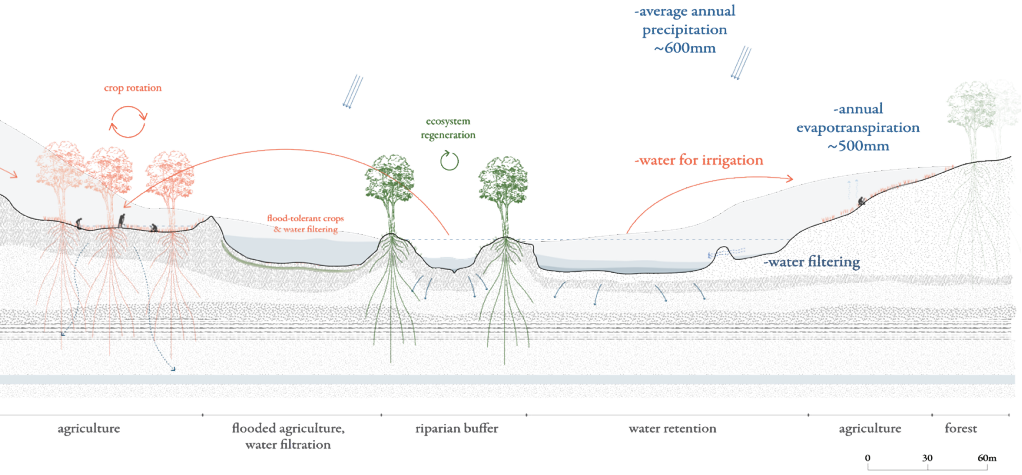


Phasing interventions

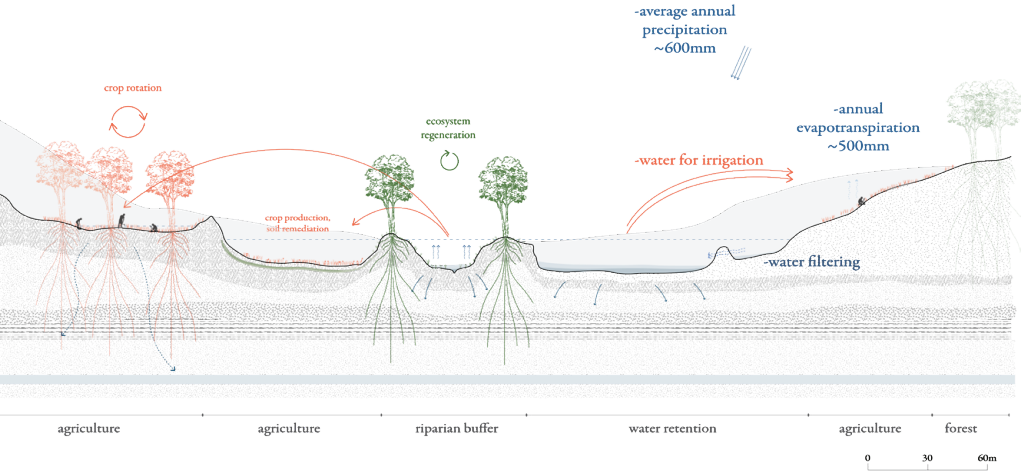



-Diversified Crop Rotation
-Crop Selection based on
Water Availability
-Cover Crops
-Agroforestry Systems
-Soil restoration
crop rotation
-water for irrigation
-winter water level
-summer water level
rhizofiltration
plants
forest
terraced agriculture
water retention

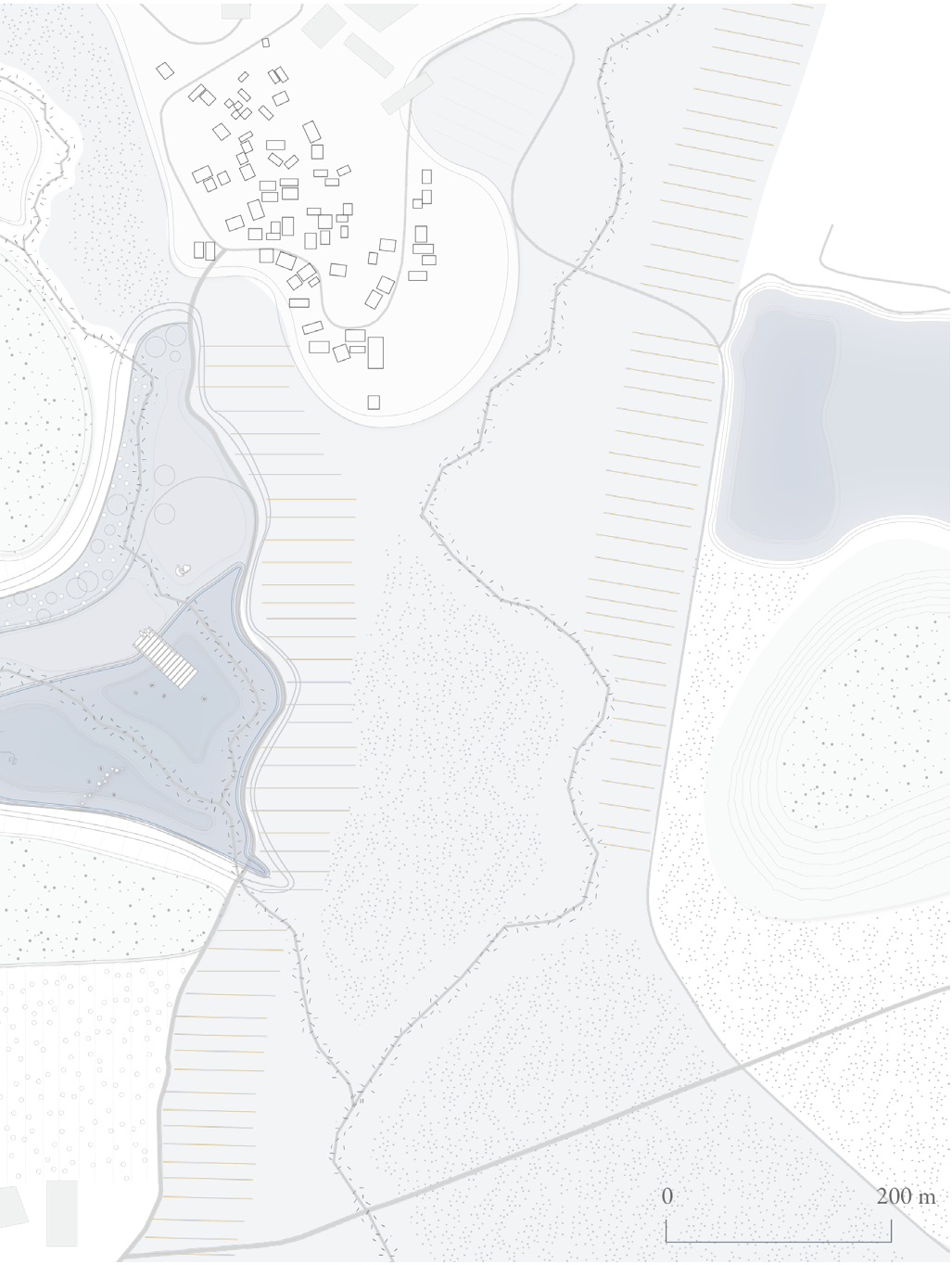

-Diversified Crop Rotation
-Crop Selection based on
Water Availability
-Cover Crops
-Agroforestry Systems
-Soil restoration
crop rotation
-water for irrigation
-winter water level
-summer water level
rhizofiltration
plants
forest
terraced agriculture
water retention

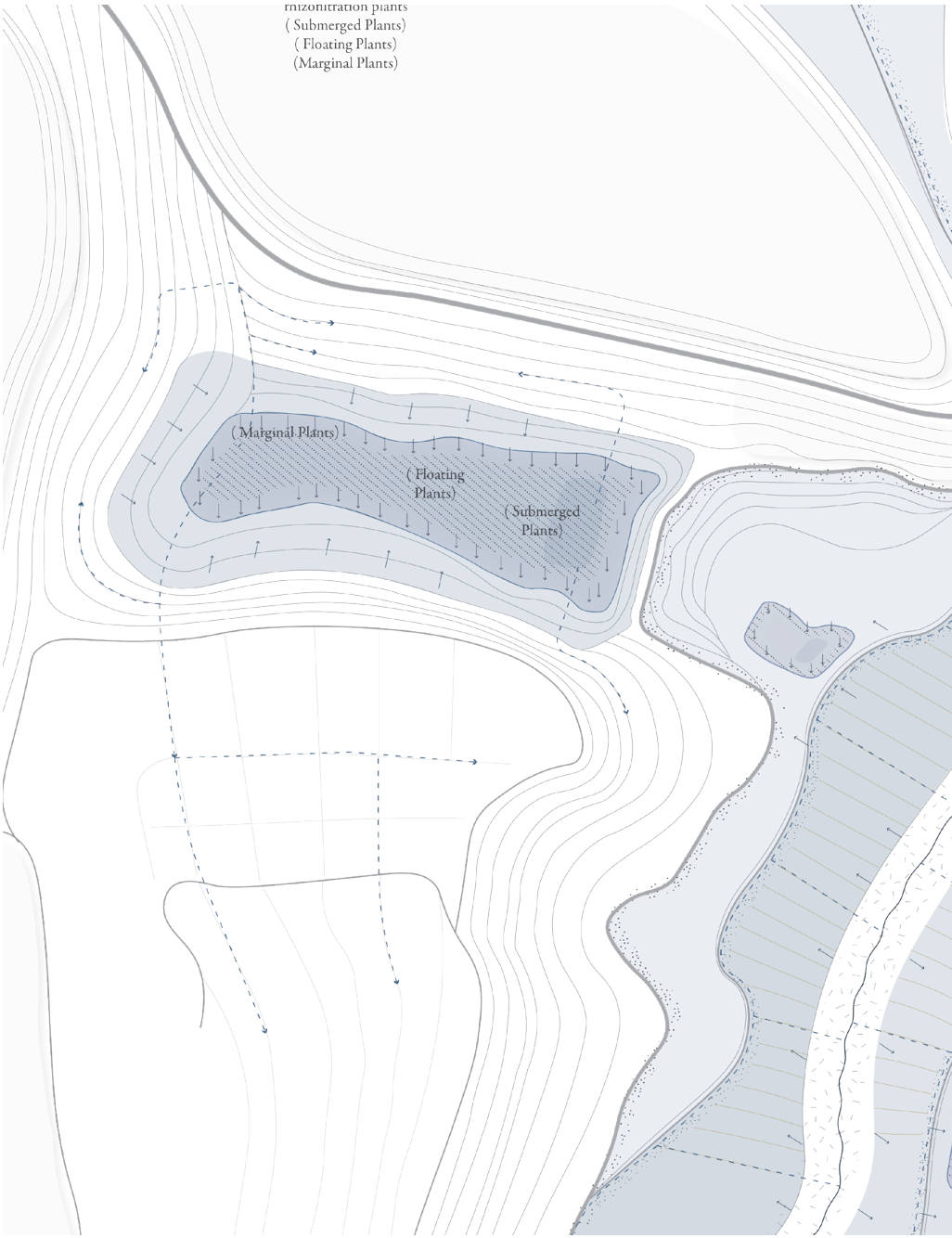


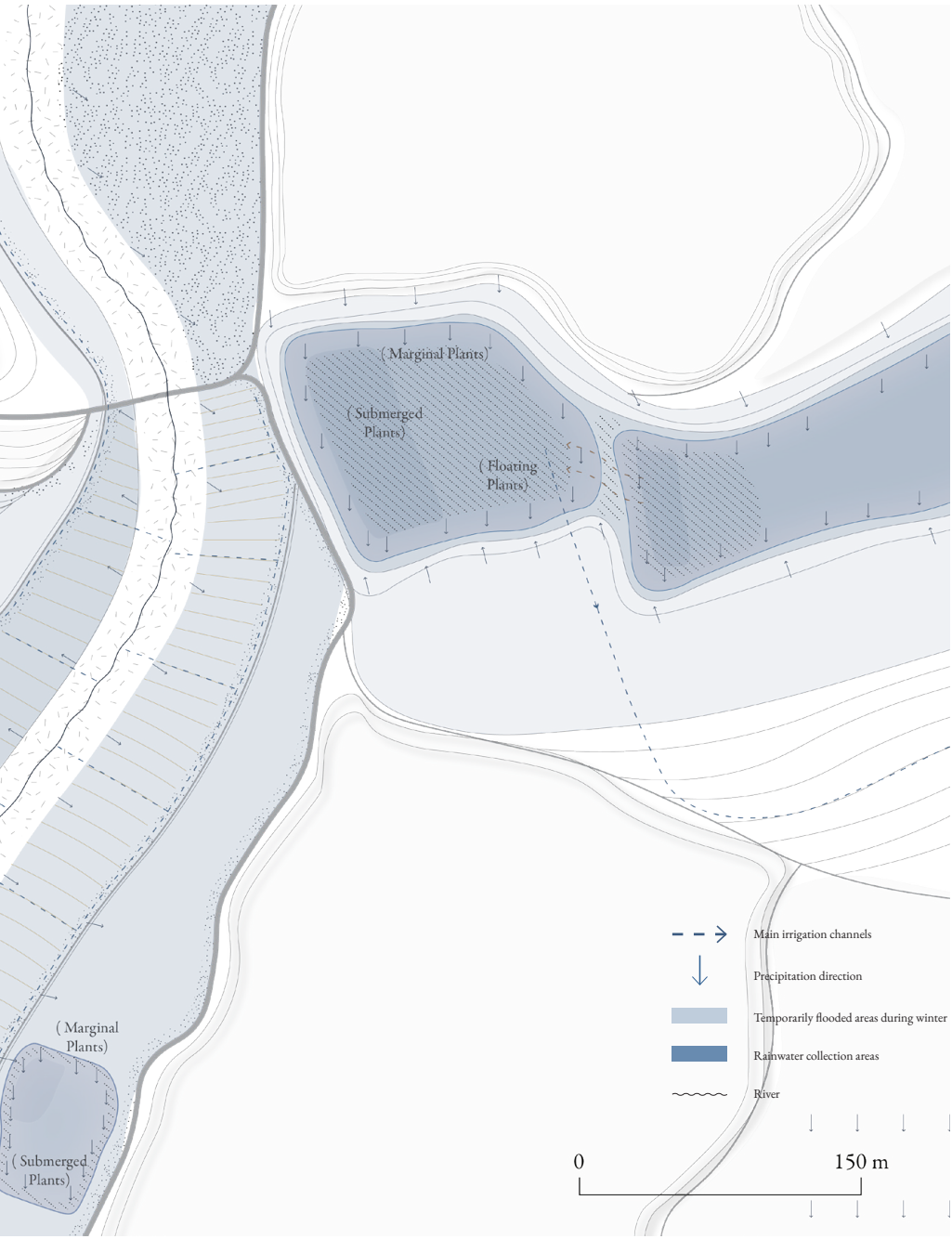
How the terraforming processes form the new climate resilient landscape during winter, designed by author

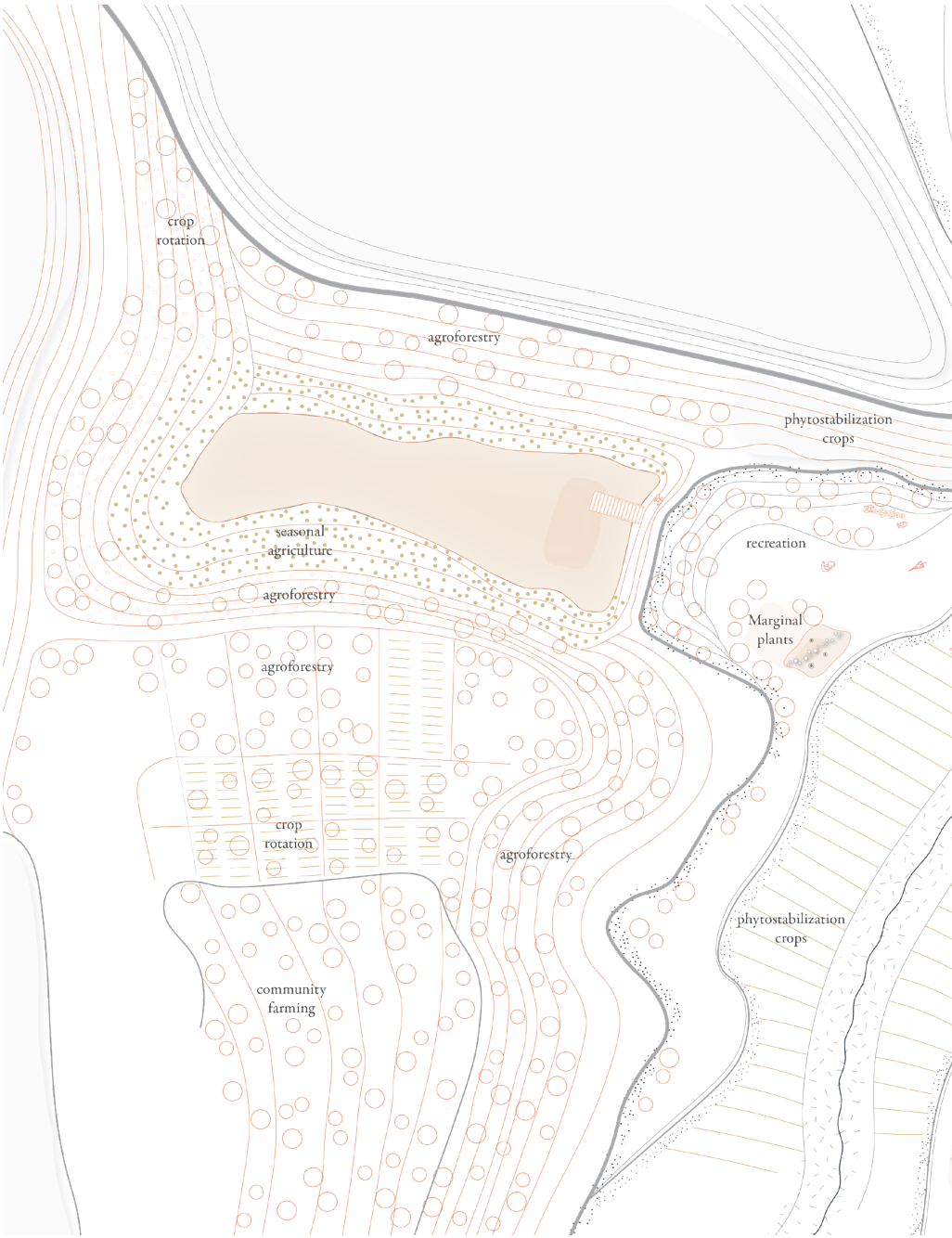


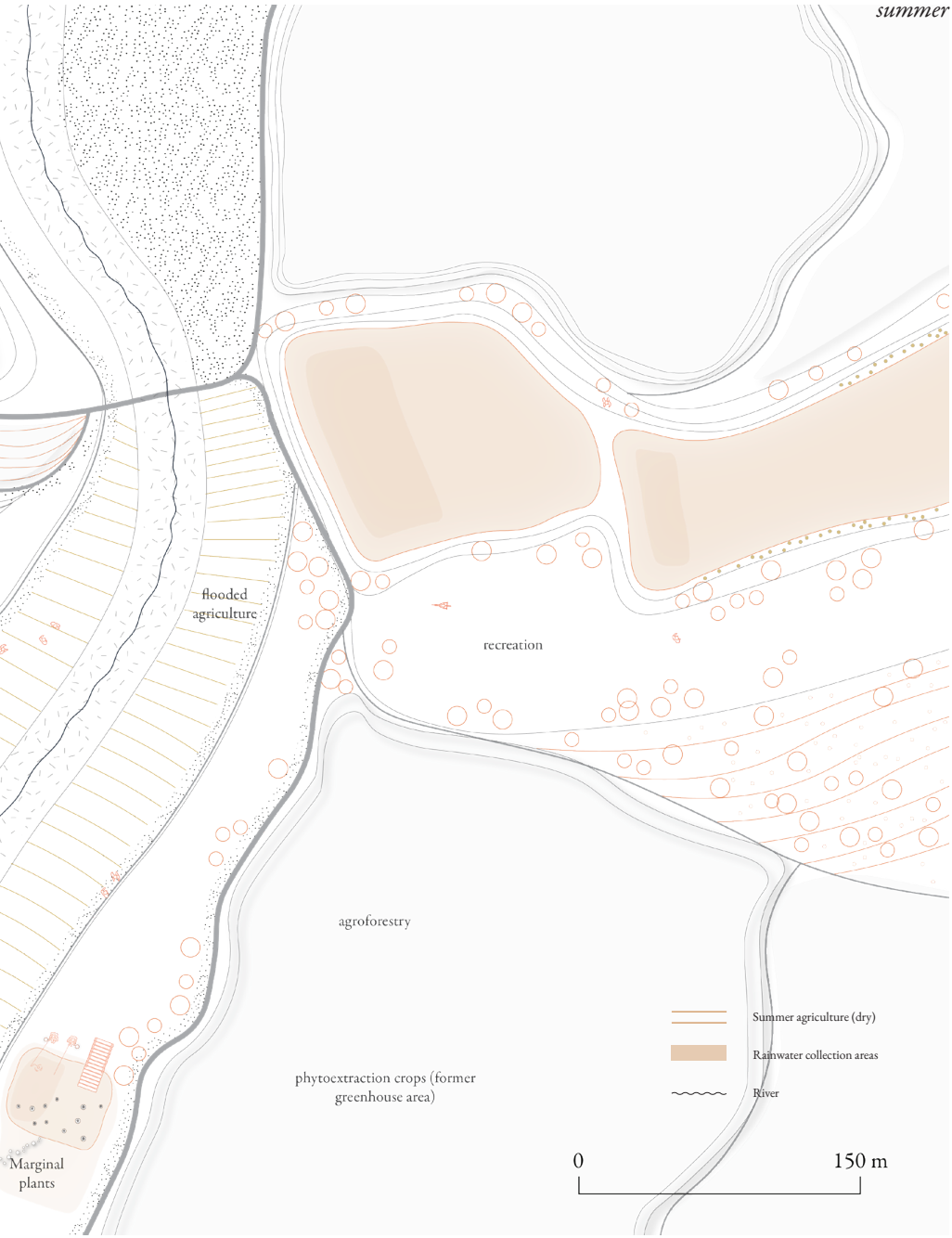
How the terraforming processes form the new climate resilient landscape during summer, designed by author

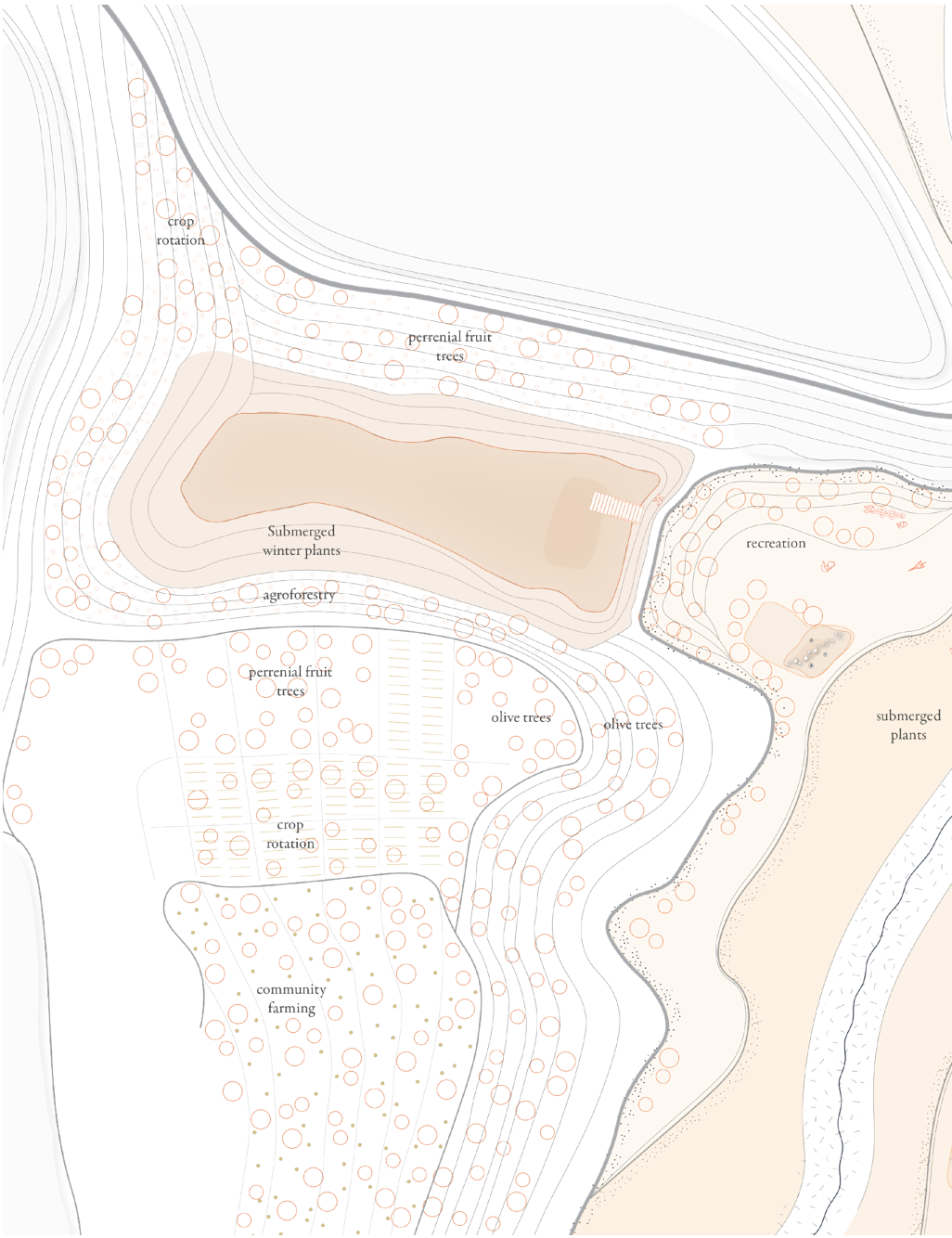

0
200 m

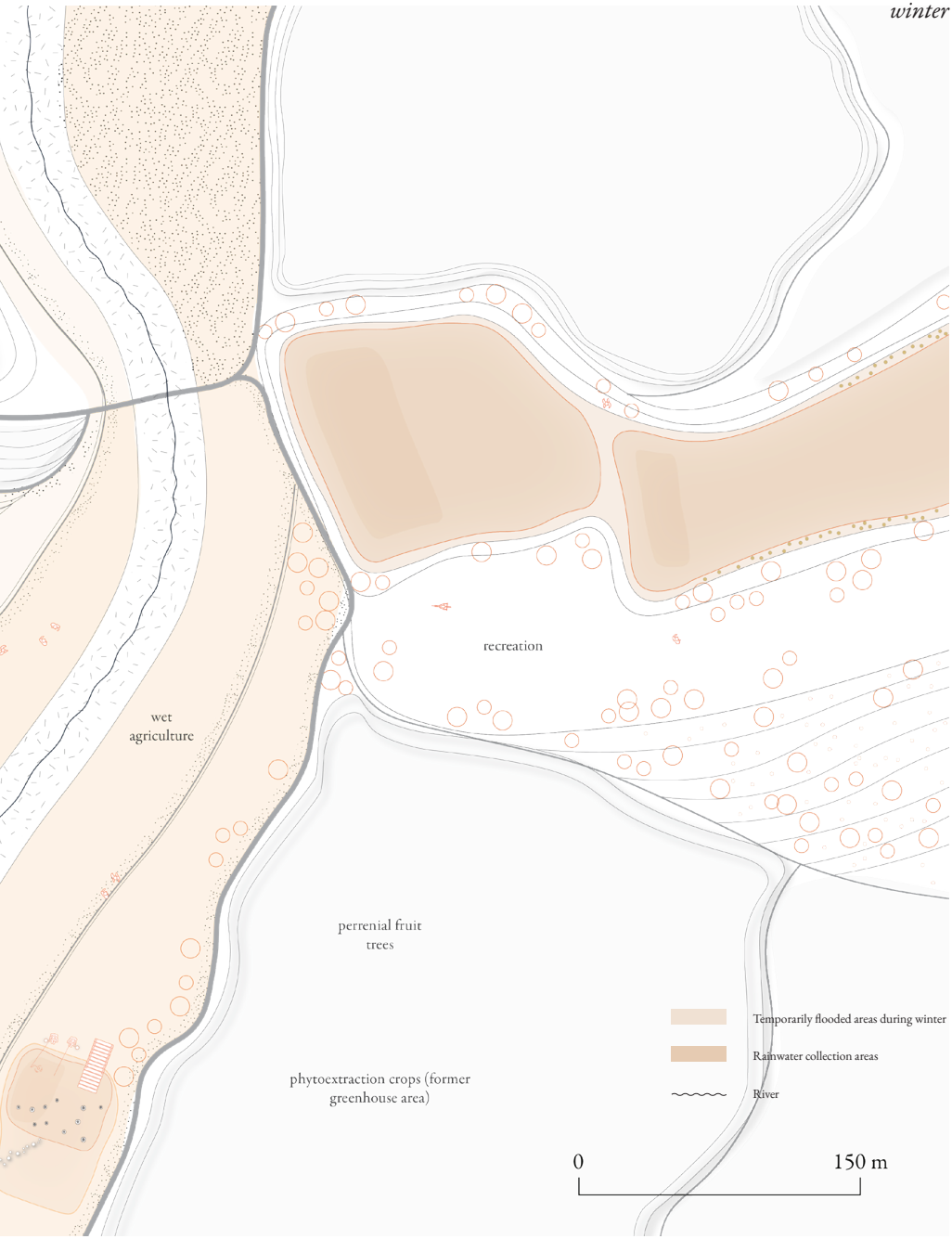

rhizofiltration plants
(Submerged Plants)
(Floating Plants)
(Marginal Plants)
(Marginal Plants)
(Floating
Plants)
(Submerged
Plants)


(Marginal Plants)
(Submerged Plants)
(Floating Plants)
(Marginal Plants)
(Submerged Plants)
Main irrigation channels
Precipitation direction
Temporarily flooded areas during winter
Rainwater collection areas
River
0
150 m

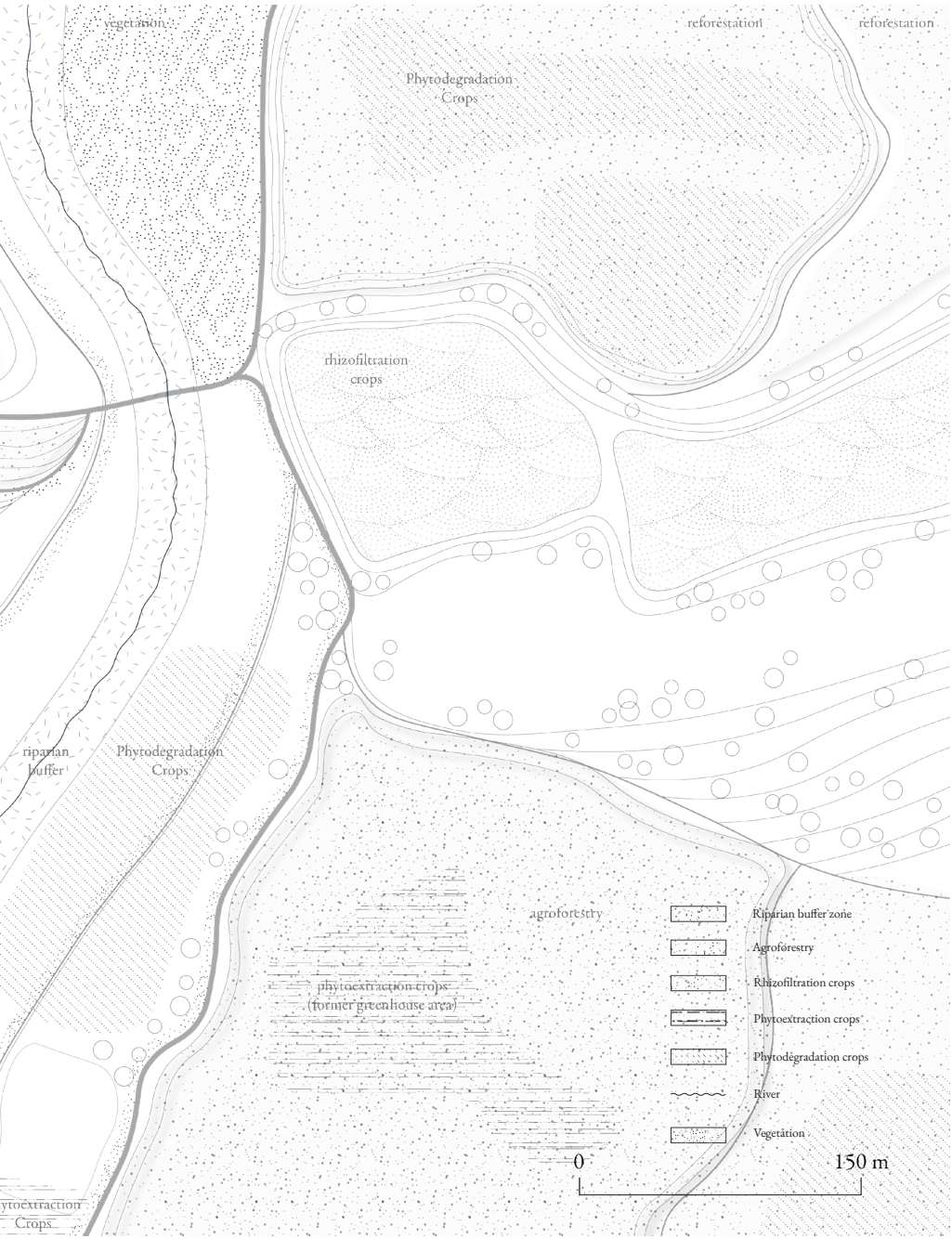

crop
rotation
agroforestry
phytostabilization
crops
seasonal
agriculture
recreation
agroforestry
Marginal
plants
agroforestry
crop
rotation
agroforestry
phytostabilization
crops
community
farming

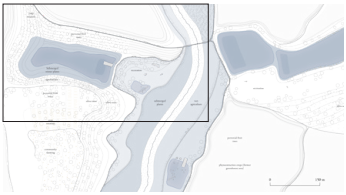

flooded agriculture
recreation
agroforestry
phytoextraction crops (former greenhouse area)
Marginal plants
Summer agriculture (dry)
Rainwater collection areas
River
0
150 m


crop
rotation
perrenial fruit
trees
Submerged
winter plants
agroforestry
recreation
perrenial fruit
trees
olive trees
olive trees
submerged
plants
crop
rotation
community
farming


recreation
wet
agriculture
perrenial fruit
trees
phytoextraction crops (former
greenhouse area)
Temporarily flooded areas during winter
Rainwater collection areas
River
0
150 m

cover
crops
reforestation
soil
remediation
through crop
rotation
phytostabilization
crops
rhizofiltration
crops
agroforestry
agroforestry
crop
rotation
agroforestry
cover
crops
phytostabilization
crops

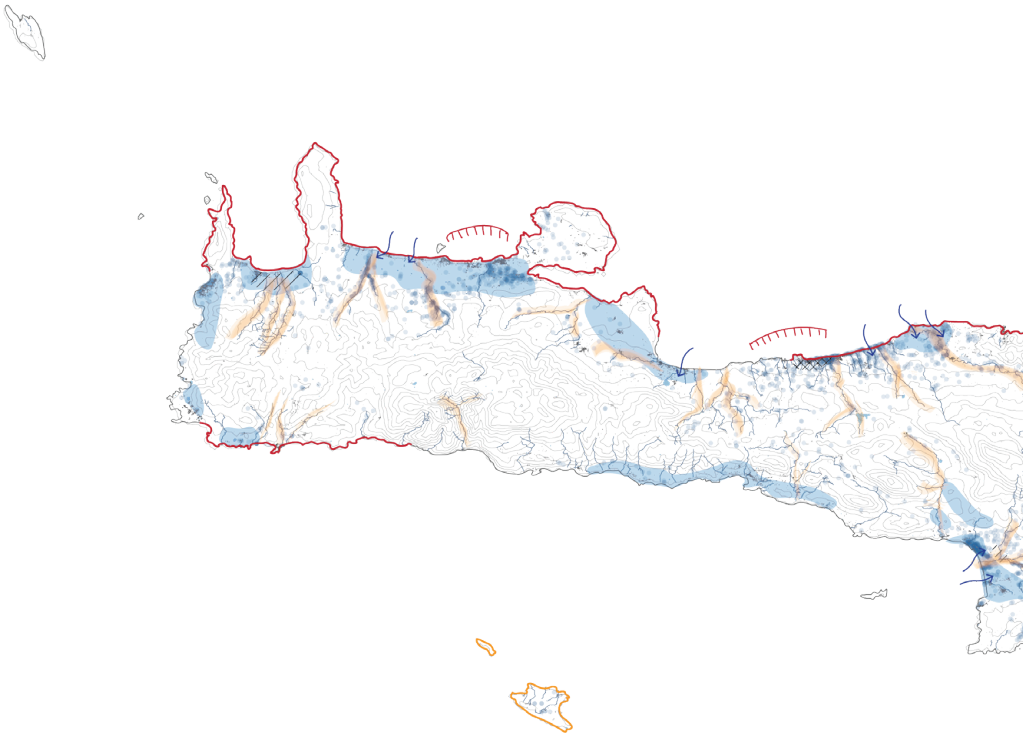

vegetation
reforestation
reforestation
Phytodegradation
Crops
rhizofiltration
crops
riparian
buffer
Phytodegradation
Crops
agroforestry
phytoextraction crops
(former greenhouse area)
ytoextraction
Crops
Riparian buffer zone
Agroforestry
Rhizofiltration crops
Phytoextraction crops
Phytodegradation crops
River
Vegetation
0
150 m



Symbiosis of human and natural ecosystems of the future

View of the water retention landscapes and the community engagement in the recreation areas

View of the water retention landscapes and the community engagement in the regenerative agricultural practices


0
25
50 km

Design Strategy
water risk management

Riparian buffers along rivers, river restoration

Areas that need water retention landscapes (flood risk zones)

Wells

River system

Town

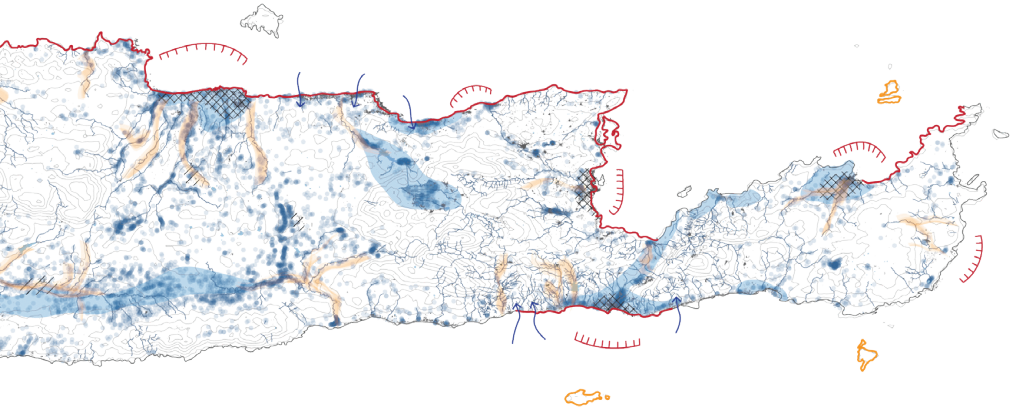
City

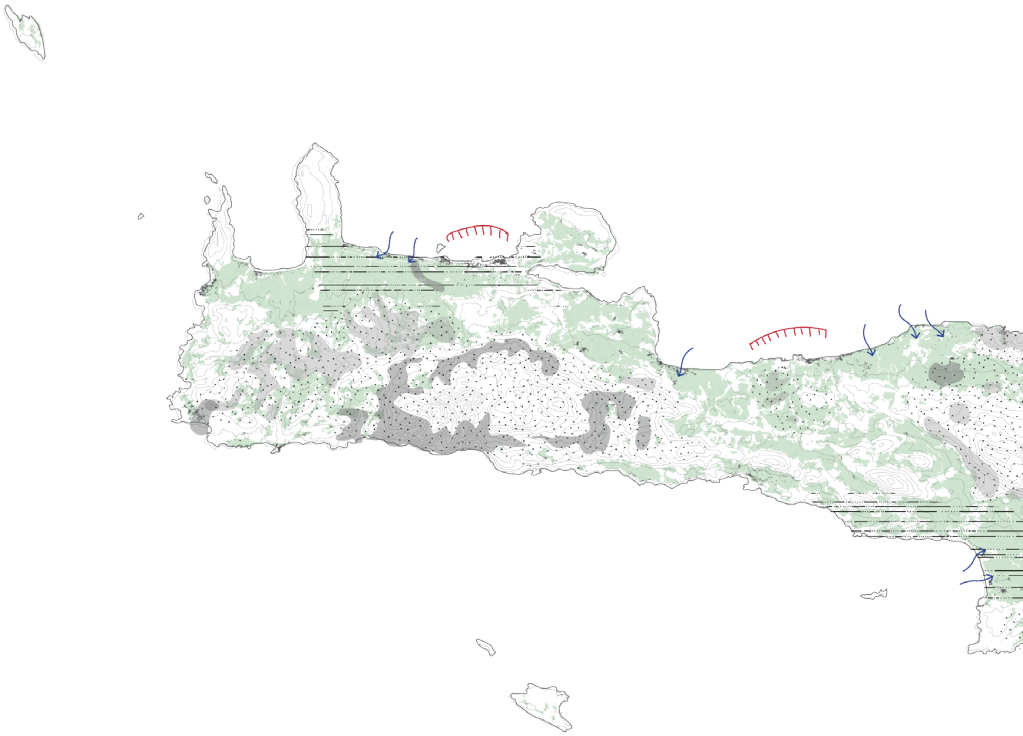
Let the sea come in (buffer zone)

Built environment that needs protection

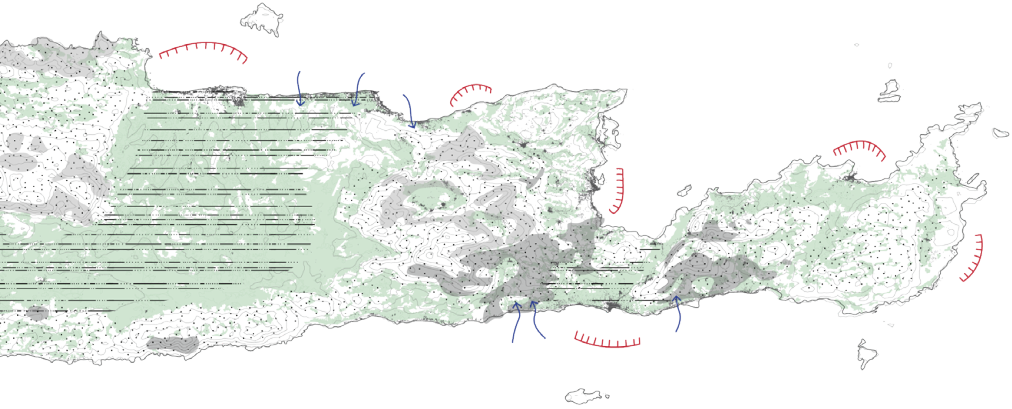
High coastal risk of sea level rise

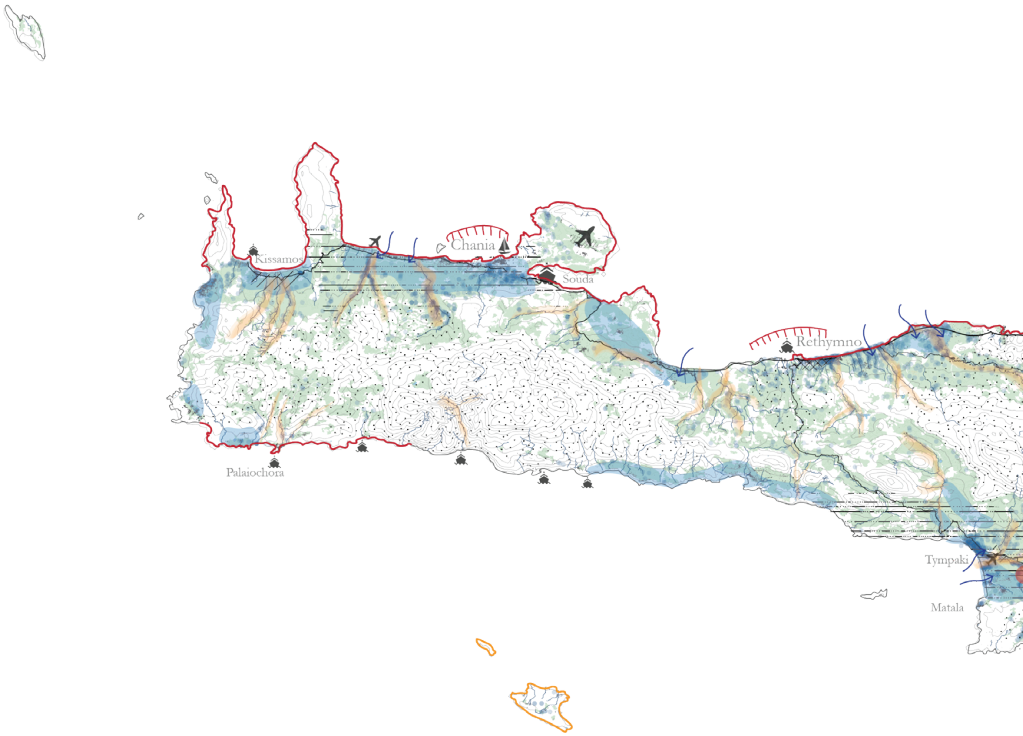
Medium coastal risk of sea level rise




0
25
50 km

Design Strategy
regenerative agriculture and nature restoration





0 25 50 km

Design Strategy
territorial scale of the island

High coastal risk of sea level rise

Medium coastal risk of sea level rise

Soil remediation

Regenerative agricultural practices

Reforestation

Contours per 1000 m

Riparian buffers along rivers, river restoration

Areas that need water retention landscapes (flood risk zones)

Wells

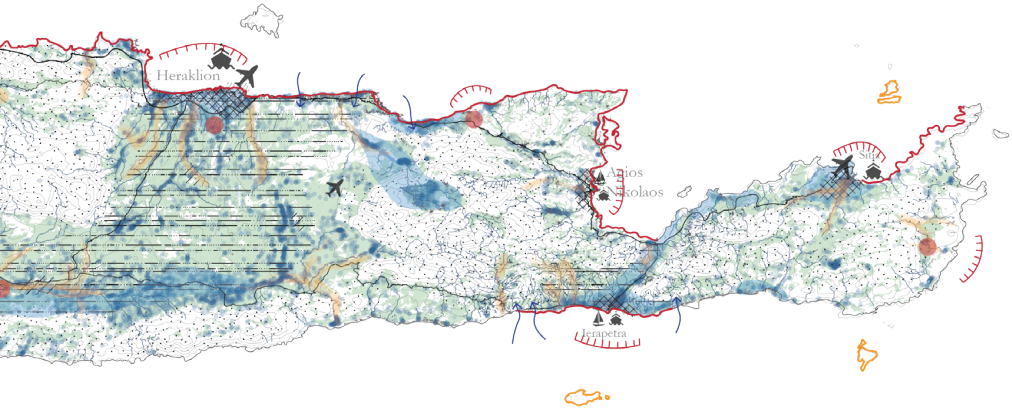
River system

Town

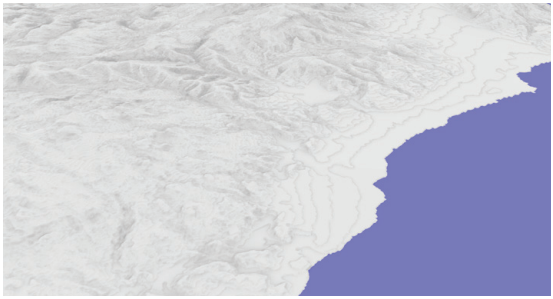
City

Let the sea come in (buffer zone)

Built environment that needs protection

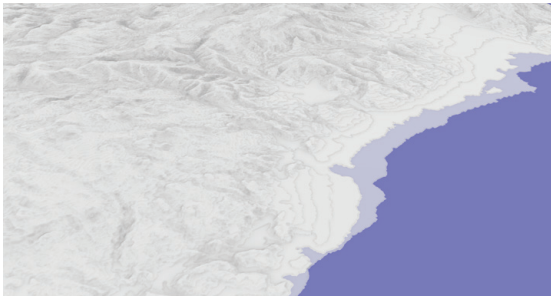


Phasing



Existing Sea Level — 2024

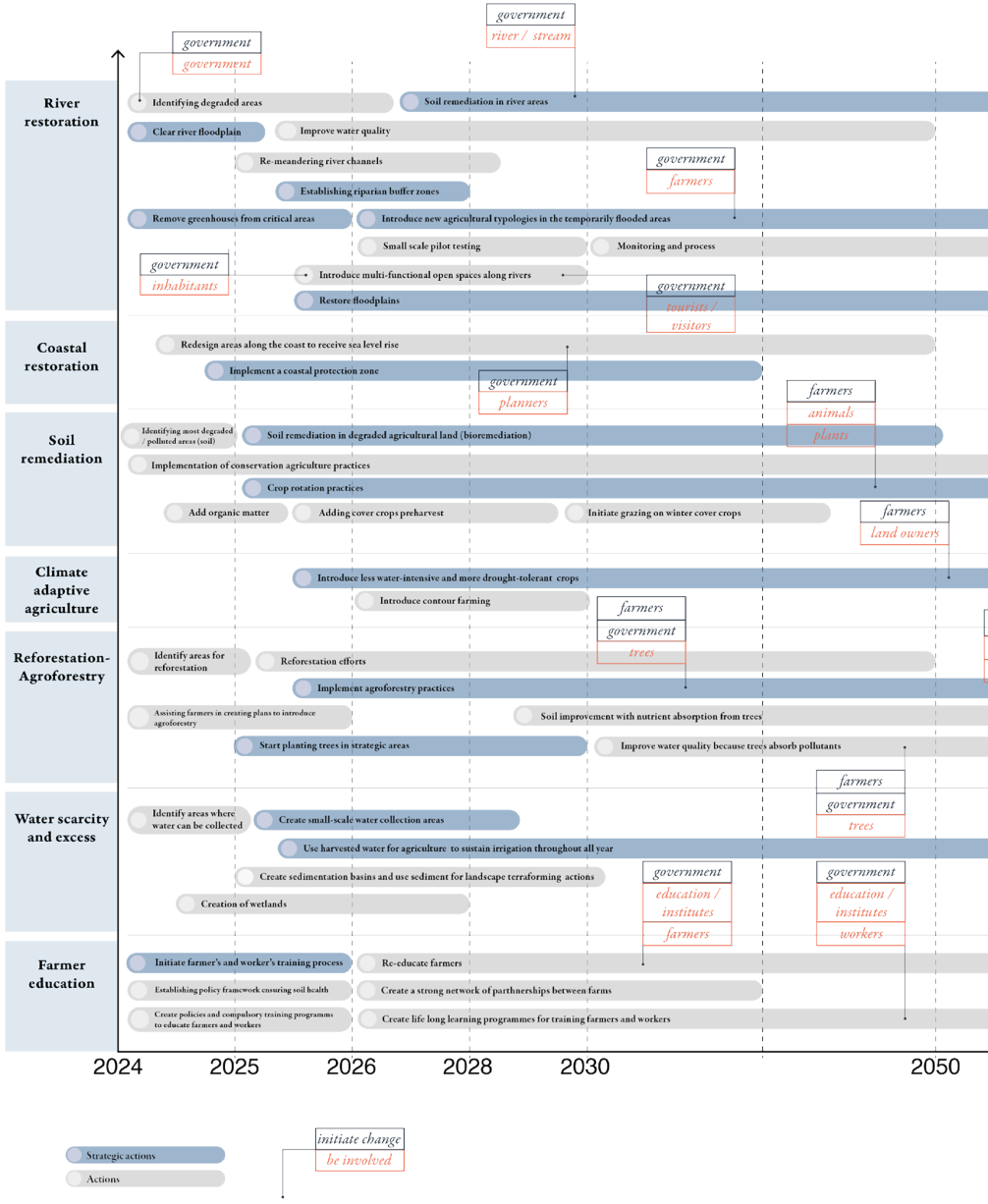
Sea Level Rise 1m — ~2100



Sea Level Rise 2m — ~2150

The Sea Level Rise research is part of the process of decomposition of the diverse challenges and threats that the island is facing, however does not constitute the only or major threat. (fresh water scarcity, floodings, salinity intrusion to aquifer, droughts, soil degradation etc.)

Sea Level Rise Simulation according to climate scenario adopted by the thesis, designed by author


River restoration
Coastal restoration
Soil remediation
Climate adaptive agriculture
Reforestation-Agroforestry
Water scarcity and excess
Farmer education
government
government
government
river / stream
Identifying degraded areas
Soil remediation in river areas
Clear river floodplain
Improve water quality
Re-meandering river channels
government
farmers
Establishing riparian buffer zones
Remove greenhouses from critical areas
Introduce new agricultural typologies in the temporarily flooded areas
Small scale pilot testing
Monitoring and process
government
inhabitants
Introduce multi-functional open spaces along rivers
Restore floodplains
government
tourists / visitors
Redesign areas along the coast to receive sea level rise
Implement a coastal protection zone
government
planners
farmers
animals
plants
Identifying most degraded / polluted areas (soil)
Soil remediation in degraded agricultural land (bioremediation)
Implementation of conservation agriculture practices
Crop rotation practices
Add organic matter
Adding cover crops preharvest
Initiate grazing on winter cover crops
farmers
land owners
Introduce less water-intensive and more drought-tolerant crops
Introduce contour farming
farmers
government
trees
Identify areas for reforestation
Reforestation efforts
Implement agroforestry practices
Assisting farmers in creating plans to introduce agroforestry
Soil improvement with nutrient absorption from trees
Start planting trees in strategic areas
Improve water quality because trees absorb pollutants
farmers
government
trees
Identify areas where water can be collected
Create small-scale water collection areas
Use harvested water for agriculture to sustain irrigation throughout all year
Create sedimentation basins and use sediment for landscape terraforming actions
government
education / institutes
farmers
government
education / institutes
workers
Creation of wetlands
Initiate farmer's and worker's training process
Re-educate farmers
Establishing policy framework ensuring soil health
Create a strong network of parthnerships between farms
Create policies and compulsory training programms to educate farmers and workers
Create life long learning programmes for training farmers and workers
2024
2025
2026
2028
2030
2050
Strategic actions
Actions
initiate change
be involved

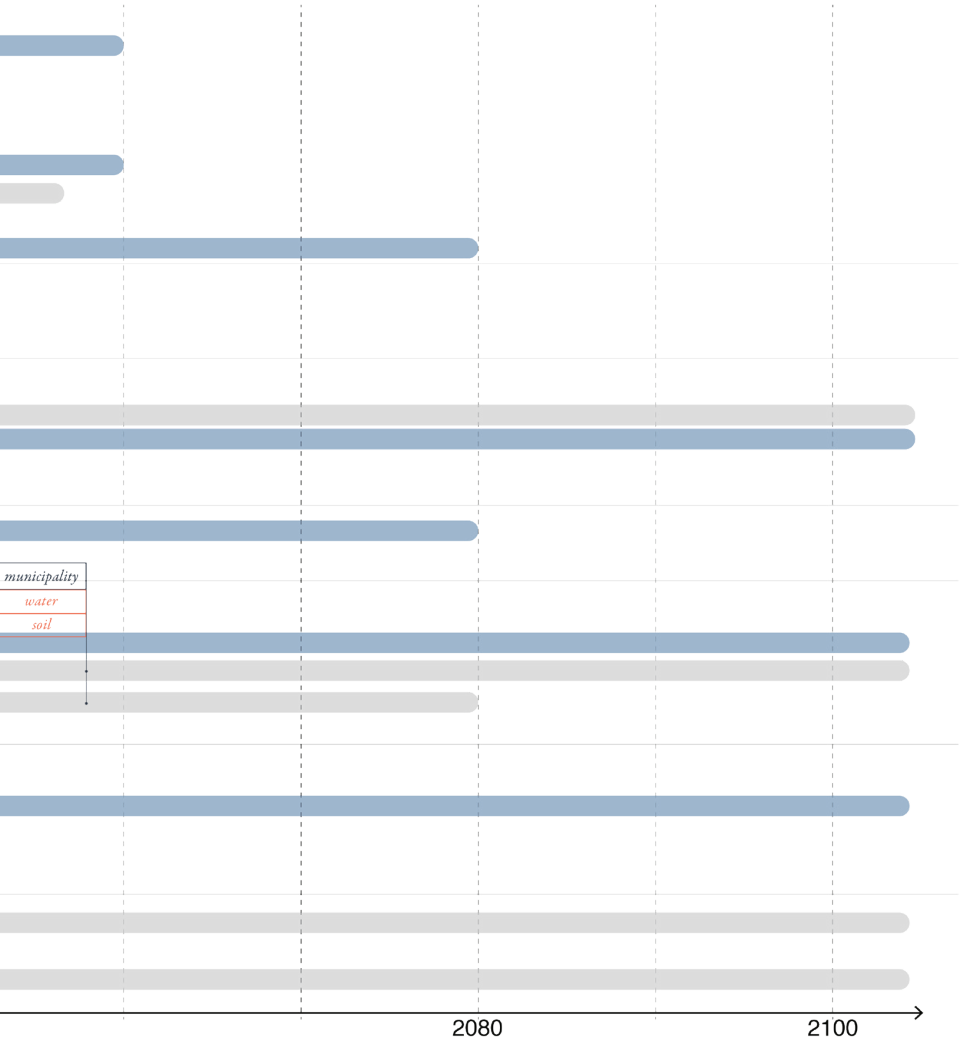


Figure 109: Project phasing in time, designed by author

Conclusion

"One can only hope that the expected extremes of the Anthropocene will not lead to conditions that cross the threshold to glaciation."

Frank Sirocko, paleoclimatologist

In conclusion, the island of Crete stands in a critical position, exposed to the challenges of climate change and alteration from human activities such as flooding, drought, and desertification. The region's distinctive seasonality influences essential biophysical and human activities, leading to a complex, interconnected system of natural and human elements. This project characterizes the island as an altered nature, impacted by natural and human processes with different spatio-temporal dimensions. (Houseman, L., 2013) Particularly in the region of the Isthmus of Ierapetra, water scarcity and excess are intensified due to diverse topography, climate, and human alterations. The uneven distribution of precipitation and the increasing water demands from intensive agriculture, tourism, and urban development, exacerbates water imbalances, overexploitation, and pollution. Climate change further intensifies these issues, with rising temperatures, changing precipitation patterns, extreme weather events, and sea level rise posing threats to settlements, infrastructure, and ecosystems. Consequently, Crete's water and soil resources are under severe pressure, necessitating integrated, sustainable water and soil management strategies to ensure resilience for ecosystems and communities.

Recommendations for researchers

The restricted timeframe of this thesis imposed constraints on the depth of research conducted. Given the extensive research required and the complexity of translating findings into spatial outcomes, it is essential to develop more accurate scientific analyses of hydrology, soil, and crops through collaboration with scientists from various fields and expertise. Interdisciplinary cooperation is needed to conduct comparative studies on hydrology, ecology, climate change, and the socio-economic impacts of water management practices in the area. There is a need for the assessment of local soil and water system conditions, current land degradation status a with respect to their particular context and environment and extensive mapping of the natural and human systems of the area and the island in general, including river and riparian vegetation systems, to map in depth the impact of agricultural activities both in soil and water and project future land and soil degradation risk.

Moreover, it is fundamental to reconsider current agricultural practices and the extensive land they cover. There is an urgent need to study and adopt regenerative agricultural practices that minimize their environmental impacts and restore soil and natural systems through soil conservation measures across scales.

Future research should also focus on further spatially translating these findings into general planning guidelines and proposing effective policies for stakeholders. Current policies should be influenced by local-scale design interventions, an example of which is this thesis design proposal that respects the dynamic environmental elements such as water and soil, acknowledging their interdependencies with human activities.

This thesis calls for more researchers and designers to study the island from a spatial perspective, advocating for a shift from the inflexible and superficial current planning and design methods. Through diverse cartographies and research that informs the design proposal, this project critiques the rigidity of existing planning and design instruments in Greece and Crete. It emphasizes the importance of considering the temporal dimension of the island's processes and the dynamic character of fundamental elements such as water, soil, geology, and climate.

Recommendations for policymakers, planners, designers

Understanding the historical dynamics of water management, along with the cultural values associated with water on the island, is essential for informing strategies for adaptation and resilience in the face of current and future challenges. This includes restoring rivers and their alluvial plains, and designing integraded local water retention and infiltration system to temporarily store rainwater to meet future human needs, while also forming Water Safety and Emergency Plans, considering the island's hydrology, changing climate, and socioeconomic dynamics (Tzanakakis et al., 2020). Protecting and restoring natural ecosystems, such as forests, wetlands, and riparian buffer zones, should be prioritized in planning and design to enhance water retention, secure freshwater, and mitigate the impacts of climate change.

Policymakers and regional and local government agencies responsible for regulatory resource management should collaborate across scales to address water-related challenges and opportunities. Water scarcity phenomena are expected to become more frequent in the Mediterranean in the near future and must be seriously considered by decision-makers and within water and soil management frameworks. This includes changing traditional land-use planning practices to more flexible ones and prioritize new factors such as flood risk, soil quality and climate-resilient agricultural practices. This approach addresses water scarcity and excess in the face of climate change and uncontrollable human pressures and investigates the interrelations and interdependencies of various systems, including hydrogeology-river systems, agricultural production, soil, and climate. These issues must be addressed on a local scale with small-scale interventions that secure fresh water and soil health in the region and protect against flooding and erosion.

To achieve this, there is a need to create an integrated water system to collect water for the dry season and distribute it in case of emergencies such as flash floods, river and dam overflows. Among the many pressures and opportunities for water management on the island, one key feature that stands out is the need to take advantage of the topography and areas where water is stored naturally, creating water retention and infiltration landscapes that can store and filter water to meet the demands of the dry seasons. The project proposes new design typologies and directions for planning regulations aimed at nature and river restoration, such as temporarily flooded zones along the rivers and the establishment of riparian buffer zones. The most vulnerable areas along rivers should be identified and cleared of buildings to restore alluvial plains and natural habitats.

These spatial design interventions will slow down water flow, especially during intense rain events, recharge the aquifers, prevent complete runoff to the sea, and avoid flooding incidents. At the same time, flood mitigation strategies should be included in the island's preparedness plan, incorporating water retention and infiltration landscapes and enhancing groundwater recharge. Adaptive measures, including coastal protection buffer zones, flexible land-use planning, and structure relocation strategies, aim to mitigate the impacts of sea-level rise and protect coastal communities and infrastructure.

By addressing these challenges through a holistic, integrated, and sensitive planning and design approach across different scales, we can foster a more resilient and sustainable future for the island.

Recommendations for local communities

Local communities on the island of Crete must recognize the significant impact of their actions on the environment and take proactive steps to improve it. Prioritizing awareness and education initiatives will help community members understand the importance of sustainable practices of care and the vital role that water and soil play in their lives and activities.

For that reason, there is a need for inhabitants to implement small-scale water conservation techniques, such as rainwater harvesting and drip irrigation, aiming to reduce water waste. Additionally, adopting regenerative agricultural practices, such as crop rotation and reduced tillage, and minimizing the use of chemical fertilizers and pesticides, opting instead for natural alternatives, will enhance soil and water health and biodiversity. By engaging in soil restoration projects and implementing erosion control measures, communities can improve soil fertility and prevent further degradation. Community involvement and collaboration, such as planting native vegetation and restoring degraded land, are essential in preventing soil erosion and enhancing local biodiversity. Participation in agriculture-based community-engagement initiatives, such as reforestation efforts and the development of community forests and rural libraries (seed libraries, community gardens, and farmers' markets), will further enhance ecological health and promote a shared sense of responsibility. (Singh, V., Mehra, B., & Sikes, E. S., 2022).

Collaboration with local authorities, policymakers, and designers can ensure that water management strategies address both local needs and sustains ecological balance. Setting up community workshops and educational programs to raise awareness about sustainable practices and the benefits of ecological restoration can empower residents to make informed decisions. By taking these practical steps, local communities can significantly contribute to the sustainable management of Crete's natural resources and strengthen their resilience to climate change.

Transferability

The thesis selects the case of Crete as a representative example, a paradigm that exemplyfies the challenges that a Mediterranean island is facing both from climate changes and human activities. The thesis showcases that the lessons learned from studying Crete's transformation and resilience potential could be applied to other islands globally by tailor resilient strategies and actions, proposed by this thesis, to local climate risks and conditions of the region, such as seasonal variability. It is also important to acknowledge and incorporate indigenous and traditional knowledge to enhance the relevance and effectiveness of interventions. It is fundamental to adapt the methodology to align with local agricultural, geological, and water management systems.

Key strategies include implementing water conservation techniques and reforestation projects to address desertification and enhance water security. Green infrastructure should be utilized to manage stormwater and reduce flooding, while large-scale land manipulations, such as reforestation, wetland creation, and river restoration can enhance ecological resilience. Additionally, designing landscapes that allow for natural water infiltration and movement will reduce runoff and promote groundwater recharge. By emphasizing these elements and adapting them to local contexts, the proposed methodology can effectively address climate-related challenges, fostering climate-resilient communities.

It is essential to tailor resilient strategies and actions to local climate risks and conditions of the region, such as seasonal variability. Finally, fundamental is to adapt the methodology to align with local agricultural, architectural, and water management practices.

Reflection

THE PROJECT

As part of the Transitional Territories studio and intensive courses, it was made clear how urgent and important is to understand and explore the different forms and alterations of the Cretan landscape emphasizing in the topography, water and earth systems through the lens of water scarcity and excess. The project is driven by the urgency of addressing the island's vulnerability to the present and future catastrophic effects of climate change that can threaten Crete's sensitive ecosystems, while at the same time stressing the preservation of her historical and cultural heritage and the sustaining of her socioeconomic systems. The project's investigation delves into several critical processes that provide the framework to understand the island's dynamics, resilience, and the interplay between natural and human systems. It attempts to critically research and interrelate notions such as the island's geological formation and materiality along with the Earth and human systems by creating solid research that informs the design proposal of an alternative design and planning method along with a design strategy proposal for enhancing the preparedness of the island.

"We have learned that landscapes cannot be understood as objects when we see them react violently to human activities. We are instead led towards the need for a different understanding of territories and landscapes in order more fully to understand their complexity, to understand all the issues that are entangled with a river, the climate or a forest."

Arenes, A. (2022). Design at the time of the Anthropocene reporting from the Critical Zone

METHOD AND APPROACH

While attempting to answer the pressing question of how the island will transition and transform in the future impacted by climate changes and destructive human activities, critical and research cartography technics were introduced, that encompass critical thinking and manipulate space and time. Furthermore, the overall philosophy of the studio, together with the literature suggested by the mentors assisted in developing and expanding the theoretical and conceptual knowledge and thinking and pushing the ambitions and project goals forward. Finally, the project has evolved significantly following unexpected paths creating a new methodology and critical design approach aiming to design by setting new priorities and considering a different perspective, where earth and water elements play a vital role in understanding transitions and designing spatial transformations.

Through the Transitional Theories Studio and Geographical Urbanism and particularly the narrative exercises and the inspiring presentations, a coherent narrative was critically synthesized highlighting the urgencies while reflecting on the past events that influenced the materiality and the complex systems and processes of the island. More particularly on how urbanisation forms and patterns and the diverse landscapes (waterscapes, geological formations, materiality) were, are and will be impacted by climate changes. This informed the theoretical understanding to scientifically and logically support the work methodology providing an evidence-driven project. Over the course of the studio, the importance of research and analysis through critical cartography of the complex systems and cycles was highlighted. They proved to be extremely valuable and at the core of the project, including surface and subsurface elements particularly water and soil and processes (and the interdependency among them) to, in the end, re-compose a new spatial reality and strategy for the island.

The project takes advantage of the agency of design through a critical research by design approach comprised of a literature/data review and the observations from the field trip supporting the cartographical analysis and providing sufficient knowledge and data about the different domains of expertise necessary to understand the island's complex systems and conduct more in-depth research. These acts of cartography and capturing landscapes and systems highlight the agency of research and design for creating possible futures, supported by diverse projects across scales, based on decisions informed by the cartographies.

The spatiotemporal dimension of the project is being manipulated through the agency of design with time, which put forward and situates the challenges and imbalances between design, socio-economic, and environmental conditions in time through the lens of water scarcity and excess, flooding and desertification, acknowledging the long or short time that each process requires.
All of those steps form a design thinking process, which allows the creation of different "poetics of change", and future projections during its analysis process, forming a non-linear path forward.

LIMITATIONS AND FURTHER RESEARCH

The current research project, while providing valuable insights, is not without limitations. Firstly, the restricted timeframe of one year imposed constraints on the depth of the research conducted. That is because of the enormous amount of research and complexity that needs to be manipulated and translated into spatial outcomes, that could not be completed in one year and from one project. This together with the limited amount of accurate data openly available, limited the extent to which data could be gathered and analysed, potentially leaving some aspects related to the project underexplored and reducing the depth of the research outcomes.
Despite these constraints, the research was conducted diligently, ensuring that the findings were as reliable and comprehensive as possible. To address these limitations, future research endeavours could consider more in-depth analyses in collaboration with different disciplines, conducting comparative studies. A potential next step could be more extensive and in-depth fieldwork in dialogue with other disciplines and experts to understand even more the identity of the case study area and to analyse and assess in depth the natural and human systems present. There is a need and urgency for extensive mapping of the natural and human systems of the area and the island in general, including river and riparian vegetation systems, to map in depth the impact of agricultural activities both in soil and water. Moreover, extremely important is the assessment of local soil and water system conditions with respect to their particular context and environment. Finally, a useful next step that this thesis attempted to explore, but remained unfinished would be to create digital simulations of flooding events and their impacts on the case study area to strengthen the understanding of the urgency of positioning water, soil and the relation of human and natural systems to the core of the design and planning methods. These directions for further research aim to enhance the agency of the project and provide a more clear understanding of the island of Crete and the challenges that faces while confronting decision-makers to take responsibility and change the way and methods of planning and design.

SIGNIFICANCE

The island of Crete serves as an analogue for understanding the challenges related to climate instability in the Mediterranean region, resulting in less frequent precipitation and seasonality shifts that could affect water resources with catastrophic consequences for local communities and ecosystems. (Koutroulis et al., 2010, 2011; Tsanis et al., 2011; Tapoglou, Vozinaki, Tsanis, 2019).
In the last 30 years, the overwhelming development of Crete has unleashed strong pressures on natural resources and has altered the landscape significantly. Along with the intense human activities (urbanization and the growth of the agriculture and tourism industry), climate change alters landscape and weather patterns, setting in danger both the natural resources that support the society and the cultural landscape of the island by exponentially increasing water demands. (Tapoglou, Vozinaki, Tsanis, 2019). The first severe consequences have already started during the last decade, with the island of Crete facing increased droughts (Koutroulis et al., 2011). Climate-induced hazards such as landslides, flooding and desertification have become the new reality.
As part of the Transitional Territories studio exploring the topic of 'Altered Nature – Poetics of Change' with a focus on altered nature, resources scarcity and its dynamic relation with the built environment, the project's investigation delves into several critical processes that provide us with the framework to understand the island's dynamics, resilience, and the interplay between natural and human systems attempting to create solid research that informs the current design and planning methods by designing an alternative future for the island. It involves synthesizing and designing with emphasis on themes such as seasonality, porosity, and elasticity attempting to restore the relationship between soil, earth, nature, water and humans.

This project as part of the Urbanism master track involves design, spatial representation of both natural and human processes, land use management and design both above and below ground and embracing climate change impacts in the design. The urban might not be the primary focus territory researched in this project, nevertheless, it is an inseparable part of the system. The project is a spatial analogue that projects a future in which humans live in symbiosis with water and nature, respecting and caring for water, soil and the organisms that live within them. It connects to MSc AUBS as the project acknowledges and relates to the human influence and built environment exploring the spatial perspective and how the built environment and human activities such as agriculture have influenced infrastructure and earth systems including water and soil.

Scientific

The scientific relevance of this graduation work includes the interconnection of various scientific fields with the discipline of urbanism. Throughout the research, a literature review was conducted encompassing a diverse collection of literature, related to notions such as radical adaptation, terraforming, critical zones, hydrogeology and water management, tectonic geomorphology, natural disasters, environmental pollution, and climate change. In addition, the project aims to critique and rethink the current planning instruments used in Greece, highlighting their limitations in capturing the dynamic nature of environmental processes and human activities and advocating for exploring alternative ways of understanding and addressing spatial and environmental challenges with an emphasis on water and earth (soil) systems and their relation with human life. Proposing a case study to demonstrate this alternative approach adds depth and practical relevance to this thesis, allowing for a concrete exploration of how these principles can be applied in space.

Professional & Societal

The project attempts to define a future projection, a different narrative for the island of Crete as a common ground for the human and more-than-human assemblages that need to be prepared and reinforced to withstand serious present and future climatic threats. The case of Crete is selected as a representative example, a paradigm, an island with significant historical and cultural heritage aiming at her transformation and resilience against climate change. The investigation serves as an analogue, providing valuable lessons and findings related to design with the concepts of resiliency, porosity, elasticity and manipulation of space (terraforming) that can become transferable, assisting other communities in confronting similar issues.

Furthermore, the shifting the current (traditional) planning and design methods while confronting decision-makers and providing a case study for urban planners and policymakers can be significantly valuable to the professional community. The methods and tools the project develops can be adapted and implemented in various cultural and geographical contexts.

In addition, this graduation project directly addresses quality of life and survival both for human and natural ecosystems for the whole island, and the limitations of a changing climate, shedding light on spatial vulnerabilities. The importance of the island of Crete for human civilizations is historically validated and societally undeniable. However, the island has been threatened by a significant ecological and cultural crisis, threatening to alter the quality of life and spaces together with the earth's ecosystems.

The project through the notions of extreme, water scarcity and excess (drought-flooding) attempts to reposition and rethink our way of co-habit with nature, soil, topography, water and our way of living.

PERSONAL JOURNEY

This thesis as part of the Transitional Territories Studio, identified, de-constructed and recomposed across spatiotemporal scales narratives of water and soil elements and their significant impact on material elements, ecosystems and human life. Through this process, I investigated the complex interrelation between the earth and human assemblages that influence phenomena such as climate change and water scarcity, extremely relevant to my case. Even since the beginning, I was exposed to how to interpret and represent processes of formation and alteration of land and waterscapes leading to the phenomenon of scarcity, particularly for my project about the island of Crete.

One important thing that I realised through the course of this graduation year is how difficult and overwhelming is to be personally attached and involved in a project, particularly since my origins are from the same island my project focuses on. Having experienced disappointment on multiple occasions in the past due to the actions of individuals crucial to the island's future adds another layer to this complexity and brings forward the feeling of responsibility. After a discussion with my mentor, I realised that it is very important to always believe that you can change things for the better and put all your efforts into achieving your goals. This ascertainment is extremely helpful both for my project and my academic and professional life after.

Later on, the Geographical Urbanism intensive strengthened my theoretical understanding and assisted me in developing the theoretical, methodological and representational means to address the social, ecological and geopolitical complexities and spatiotemporal dimensions of my project. In the end came the presentation moments within the graduation year which were challenging because I had to create and present a clear and coherent narrative of the project. The project's inherent complexity made it particularly difficult to narrow down my focus to just a few key areas since I believe that there are way more elements that are inseparable and drive the island's urban, social and environmental development. Overall, the whole graduation year was an extremely constructive process with beneficial discussions and inspiring presentations within the Transitional Territories studio that made me realise the powerful agency of design.

The past year provided me with incredibly valuable experience and insights for me and my future role as an architect-urbanist, making me capable of dealing with complex projects acknowledging the design across spatiotemporal scales and realities, and exploring urban transformations. During these months, I also strengthened my research capabilities and learned how to transform them into a critical understanding of diverse and complex urgencies through design. This exciting journey / personal struggle to critically define my project to advocate for change, confronting decision-makers with the realities and threats that the island is facing almost reached its end until the next one begins.

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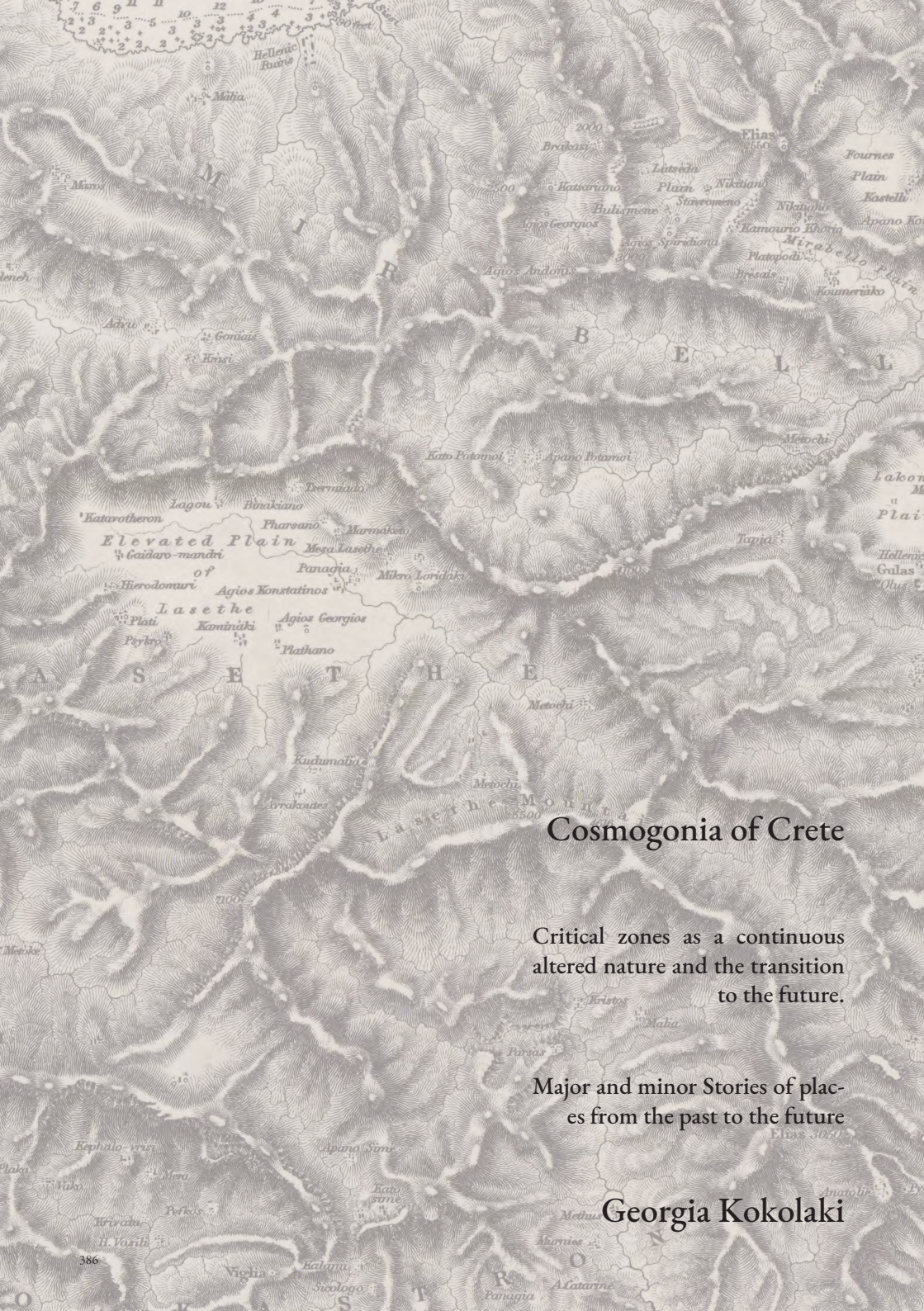

Cosmogonia of Crete

Critical zones as a continuous altered nature and the transition to the future.

Major and minor Stories of places from the past to the future

Georgia Kokolaki

Appendices

Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Georgia Kokolaki
Student number	5853826

Studio		
Name / Theme	Transitional Territories	
Main mentor	Luisa Maria Calabrese	Urbanism (section of Urban Design)
Second mentor	Elena Longhin	Urbanism (section of Urban Design)
Argumentation of choice of the studio	The Transitional Territories Studio focuses on the altered nature, raw resources scarcity and its dynamic relation with the built synthesis, and narratives. This alignes perfectly with my project, which is exploring the different forms of the Cretan landscape that constitute an altered nature with a foundation the interplay between the topography and bathymetry that shape both the terrestrial and marine environments through the lens of water scarcity and water excess and climate changes with impacts on land and on human systems. My investigation delves into several critical processes of formation and alteration of land/waterscapes leading to the state of scarcity highlighting the interelations between biophysical units, urban form, human activities and land use in urban design projects that provide us the framework to understand the island's dynamics, resilience, and the interplay between natural and human systems. The project serves a catalyst for change, aiming to empower the inhabitants of Crete but at the same time to confront decision-makers with the realities and threats that the island is facing. Thus, my project will propose a set of interventions that compose and manipulate a site, at diverse scales, to address some of the critical zones of the island such as the northern coast with the big cities and infrastructure, the fragmented inland, the extensive agriculture zone that overexploits natural resources and the southern coast with the steep topography with gorges and caves.	

Process

Method description

Analytical mapping:
Utilizing advanced mapping techniques, my thesis employs analytical mapping to diagnose, deconstruct and synthesize, providing a significant and innovative understanding of geological, hydrological, and cultural dynamics on Crete that could provide the island with the assets to adress climate threats..

Extensive Research and Study:
This method involves exhaustive literature reviews and in-depth studies, delving into the island's past through research and mapping.

Diachronic mapping and Literature review:
Developing an understanding of the island's past and significant geological, hydrological, cultural and archaeological heritage, relating changes in its physical land with significant phenomena through time. This approach uncovers the island's dynamics and evolution, linking past events with present challenges and potential.

Critical Cartography:
Creating a narrative as a tool for awareness and initiative by reflecting upon the inland and under water and underground topography.Through innovative mapping practices, critical cartography shapes narratives that transcend traditional boundaries.

Experimenting:
In the experimentation phase, I engage in research, scenario making and hands-on exploration and prototyping to test design concepts. This iterative process allows for testing ideas and ensures that proposed interventions align with the island's unique characteristics.

Backcasting :
The anticipation of probable realiţies based on the envisioned change against current trends and the potential tensions in time and in the land.

Scenario Making:
This method involves creating hypothetical climate and planning scenarios through the process of terraforming to explore potential futures for the island of Crete. By mapping out various case scenarios, and using the worse case scenario, the project aims to develop proactive and adaptive strategies and resilience plans for the island's dynamic environment.

Field work:
Field work is an essential method which involves on-site investigation and data collection, allowing for a clear understanding of the island's physical, cultural, and environmental nuances. Through direct observation, photography and extensive research, fieldwork enriches the research process and ensures a grounded and contextually sensitive approach to the thesis project.

Graduation project	
Title of the graduation project	Cosmogonia of Crete: Critical zones as a continuous altered nature and the transition to the future. Major and minor Stories of places from the past to the future.
Goal	
Location:	The project is located in the island of Crete, in Greece.
The posed problem,	Problem statement The Southern part of Greece, exposed to the Mediterranean Sea, has always been at the core of climatic disruptions. The island of Crete is threatened by challenges posed by the recent and future catastrophic impacts of climate changes that can threaten its sensitive ecosystems and environmental diversity, while at the same time stressing the preservation of its historical and cultural heritage, and the sustaining of its socioeconomic systems, and resilience. The recent years the island has been facing a critical challenge with its water resources, intensified by the twin spectres of water scarcity and excess (flooding and desertification), while being exposed to a rapidly changing climate. The island has started facing significant water scarcity, which is becoming even more and more obvious for example from the extremely low water level of the existing dams, or the case of a particular village that was covered with water when the dam was built, but this year the village reappeared, stressing even more the urgency. The project focuses on climatic and geological-related problems such as flooding and desertification but at the same time, it recognizes the causes that are leading in different directions resulting in major conflicts. In the past 20 years, even more extreme and frequent climate changes have affected the island of Crete with devastating impacts for the urban and non-urban areas. Flooding and water scarcity have started threatening worryingly human settlements and natural habitats as the existing water infrastructure struggles to meet the escalating demands imposed by settlements and agricultural practices. Simultaneously, the situation along the coast is being exacerbated by the excessive influx of tourists, particularly in the northern part of the island, where tourism has reached its saturation levels and together with the threat of sea level rise, the coast is facing a disastrous challenge. The coastal and inland areas of Crete are increasingly vulnerable to extreme weather events, storm surges, flooding and desertification. Addressing the risks associated with water excess and scarsity requires a comprehensive strategy that harmonizes with the natural dynamics of the landscape changes the relationship with soil, earth, nature and water. We have reached the point where it is not enough to change our activities, we need to change our way of changing. That is why my project catalyzes change, aiming to educate and empower the inhabitants of Crete but at the same time to confront decision-makers with the realities and threats that the island is facing.

research questions and

Main research question:

"How can critical zones navigate the island through the complex system of enviromental, cultural, and socioeconomic challenges driven by uncertainty, climate changes and human activity, with a focus on its diverse topography and culture, preserving its cultural identity, and empowering its citizens to actively engage and act in shaping a resilient and adaptive future?"

Sub - research question:

Diagnosis, historical heritage and Interventions

- "How do historical and cultural water-use practices shape the hydro-social dynamics in Eastern Crete, and how can this understanding inform contemporary urban design for water resilience?"
- "How can indigenous knowledge and local wisdom related to water management be integrated into urban design strategies to enhance adaptive capacity and foster sustainability in the face of climate change?"
- "How have historical flood events impacted the region, and what lessons can be learned from them?"
- "What are the current and projected climate change impacts on water resources in Eastern Crete, considering factors such as changing precipitation patterns, aquifer depletion, increasing water demand, potential sea-level rise, and temperature increases?" How do these impacts influence the urban fabric and infrastructure of the region?"
- "How can urban design interventions address the challenges of water scarcity and excess in the Eastern Crete region, fostering resilience to climate change by integrating sustainable water management practices?"
- How do temporal dynamics, such as seasonal variations and long-term climate trends, impact water availability on the island, and how can urban design strategies accommodate these fluctuations for resilient water management?
- How do cultural narratives and storytelling shape perceptions of water in Eastern Crete, and how can incorporating these narratives into urban design projects enhance community engagement and resilience?

design assignment in which these result.

The overarching goal is to foster a sustainable and climate-resilient future, that not only addresses the imminent challenges of water scarcity and excess but also becomes a paradigm not only for Crete but for islands facing similar challenges globally.
My investigation delves into several critical processes that provide us the framework to understand the island's dynamics, resilience, and the interplay between natural and human systems attempting to create a solid research that informs the design proposal of alternative futures for the island.
The project will propose a set of interventions that address some of the critical zones of the island such as the fragmented inland with the operationalised agricultural land that coexists with the small settlements, the restrained rivers that flood frequently creating negative impacts on the land. Therefore, starting from the territorial scale of the island and then focusing on particular smaller regions and scales, this research takes advantage of the agency of design to improve the survival and quality of life on the island. The project's approach is characterised by designing with sensitivity to natural habitats, considering the concepts of porosity, elasticity, fluidity, and temporality as important guidelines to create a resilient island in the future. A critical aspect of this project is to fundamentally alter and restore the relationship with the soil, earth, nature, and water, recognizing them as dynamic components crucial to the island's survival.
There are multiple sets of actions that are needed to achieve those goals. This thesis project proposes a series of strategic projects and actions, although it focuses in depth only on the most urgent actions.
(design examples: redesign river alluvial plain, design retention landscapes, reduce land for agriculture, open up parts of the coast to the sea)

[This should be formulated in such a way that the graduation project can answer these questions.
The definition of the problem has to be significant to a clearly defined area of research and design.]

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Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?
2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

The island of Crete serves as an analogue for understanding the challenges associated with climate instability in the Mediterranean region where the climate is likely to alter (it has already started) and have less frequent but more intense precipitation on average and more frequent and severe droughts in some regions (Koutroulis et al., 2010, 2011; Tsanis et al., 2011). Shorter rainy periods and seasonality shifts could seriously affect water resources by a significant reduction of water availability with wide-ranging consequences for local societies and ecosystems. (Tapoglou, Vozinaki, Tsanis, 2019). It is indicative that, during the last decade, the island of Crete has faced an increased number of droughts (Koutroulis et al., 2011).

Nowadays, the rapid development of Crete in the last 30 years has created strong pressure on many natural resources and has altered the landscape significantly. Urbanization and growth of the agriculture and tourism industry have a strong impact on the water resources of the Island by substantially increasing water demand. (Tapoglou, Vozinaki, Tsanis, 2019). Together with the intense human activities, climate change came to alter once and for all the weather patterns, setting in danger both the natural resources that support the society and the cultural landscape of the island. Climate-induced hazards such as landslides, flooding and desertification have become the new reality.

As part of the Transitional Territories studio exploring the topic of 'Altered Nature – Poetics of Change' with a focus on (the state of) altered nature, raw resources scarcity and its dynamic relation with the built environment, my investigation delves into several critical processes that provide us with the framework to understand the island's dynamics, resilience, and the interplay between natural and human systems attempting to create solid research that informs the design proposal of alternative futures for the island. The 'poetics of change' relates to the projective exploration of my project of these transformations in nature and the built environment. It involves synthesizing and designing with the themes of seasonality, porosity, and elasticity attempting to change the relationship between soil, earth, nature and water. More specifically, my project explores the current status of altered water landscapes on the island and their impact on future inhabitation, production, and living.

Furthermore, the leading question that both the studio and my thesis attempt to address is how understanding the altered status of matter, land and water systems helps us to construct alternative forms of life in a future scenario. While attempting to answer the pressing question of how the island will transition and be transformed in the future impacted by climate changes and destructive human activities, I was introduced to critical and research cartography techniques that encompass critical thinking and manipulate space and time. Furthermore, the overall philosophy of the studio, together with the literature the mentors suggested assisted me develop and expand my theoretical and conceptual knowledge and thinking and push my ambitions and project goals forward. Finally, I believe that my project has evolved significantly following new and unexpected paths offering me a methodology and critical design skills to understand and visualise transitions or spatial transformations.

My project is also very well connected to the Urbanism master track as it involves the spatial representation of hydrogeology, the use of land above and below ground, climate change, and design. The urban might not be the primary territory researched in this project; nevertheless, traces of the urbanized world are found everywhere as most land serves the urban. The project is a spatial analogue that projects a future in which humans live in symbiosis with water and nature in general. It connects to MSc AUBS as the project acknowledges and relates to the human and built environment and explores the spatial perspective and how the built environment has influenced inhabitation and earth systems.

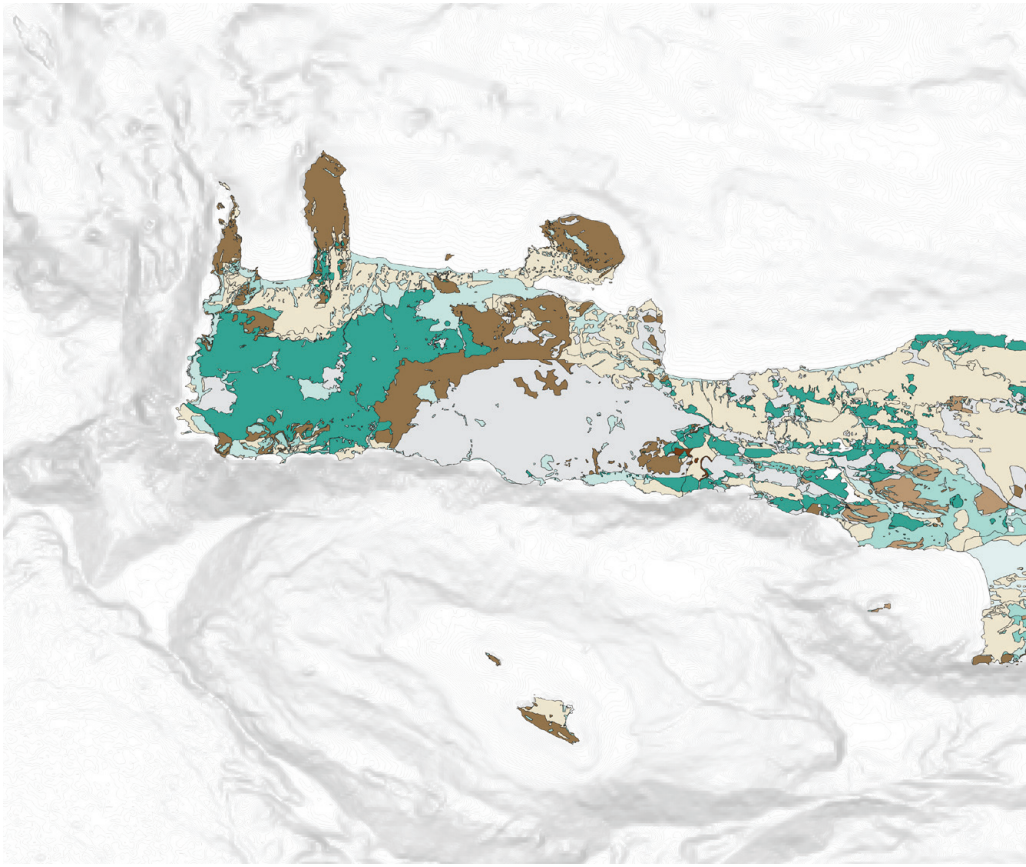
Scientific

The scientific relevance of my graduation work includes the interplay of various scientific fields with the discipline of urbanism. Throughout my research, I conducted a literature review encompassing a diverse collection of diverse literature, related to notions such as critical zones, biodiversity, tectonic geomorphology and fault zones, hydrology and water management, natural disasters, environmental pollution, and climate change.

Professional & Societal

The project attempts to define a future projection, a different narrative of the island of Crete as a common ground for the human and more-than-human assemblages that need to be prepared and reinforced to withstand serious present and future climatic disruptions. The case of Crete is selected as a representative example, a paradigm, of a historically urbanised fabric with an enormous cultural heritage that manifests a variety of implications and restrictions of the transformation and resilience against climate changes. My investigation serves as an analogue, providing valuable lessons for regions facing similar challenges. Findings related to design with the concepts of resiliency, porosity, elasticity and absorption can become transferable, assisting other communities in confronting climate-related issues. Similarly, my focus on decision-maker's empowerment and awareness can empower local populations, while serving as a case study for urban planners and policymakers worldwide. The methods and tools my project develops can be adapted and implemented in various cultural and geographical contexts. In addition, my graduation project directly addresses quality of life and survival both for human and natural ecosystems and the whole island, and the limitations of a changing climate, shedding light on spatial vulnerabilities. The importance of the island of Crete for human civilizations is historically validated and societally undeniable. However, the island has been threatened by a significant ecological and cultural crisis, threatening to alter the quality of life and spaces together with the earth's ecosystems. The project through the notions of extreme, water scarcity and excess (desertification-flooding) attempts to reposition and rethink our way of co-habit with nature, land topography, water and our way of living.

Further research
Cartographies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Tectonic nappe of Tripali zone-Carbonates - T.br
Tectonic nappe of Tripolis zone-Carbonates - K.k
Tectonic nappe of Pindos zone-Carbonates - K.E
Neogene - Mk, Mm.I
Platy limestones - J-E
Ophiolitic Complex of Alien Series - o
Quaternary sediments - Q.al
Phyllites - Schistolithic of Alien Series - f
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Tectonic nappe of Tripolis zone-Flysch ft
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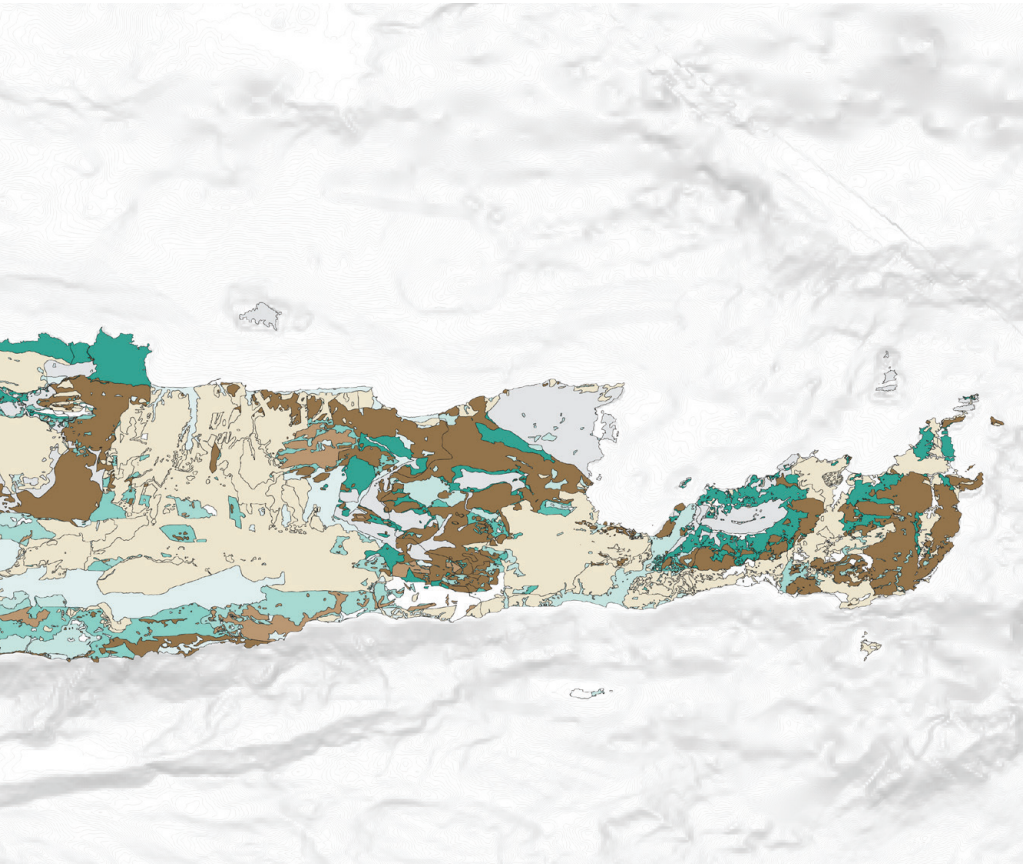

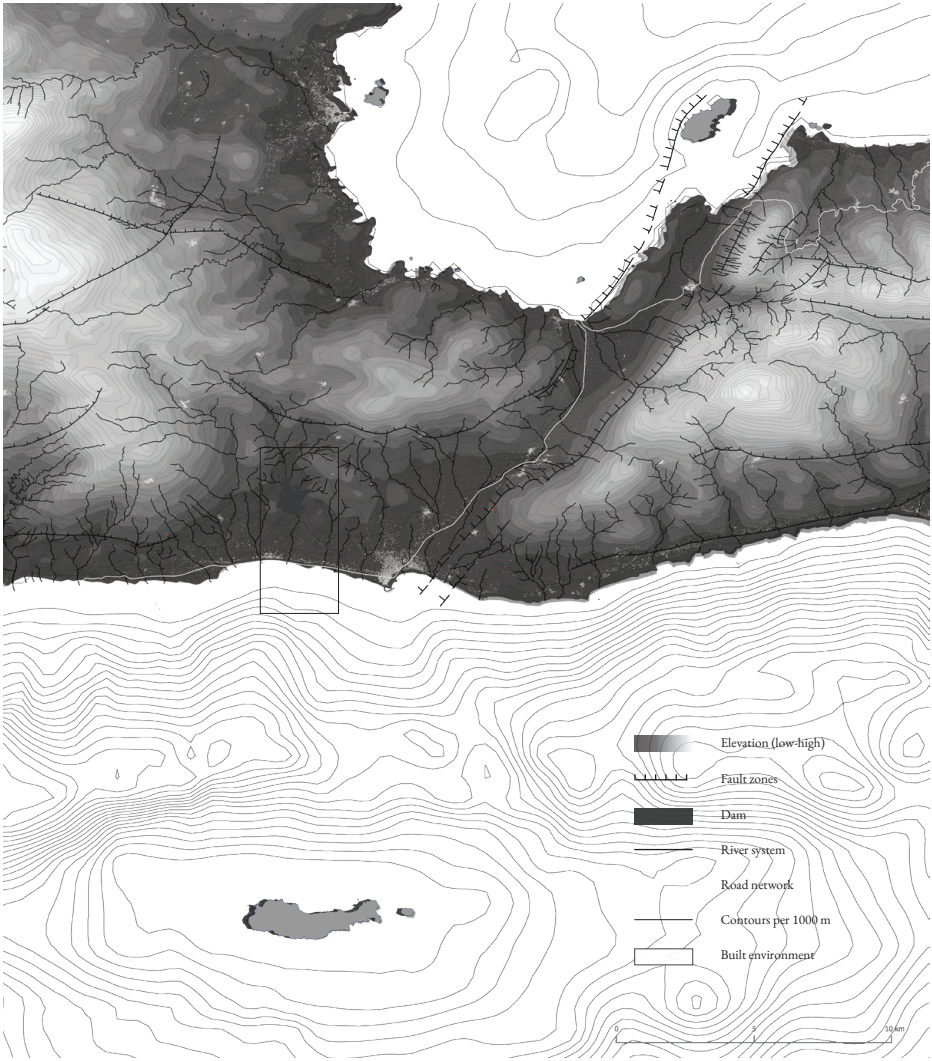
Elevation (low-high)
Fault zones
Dam
River system
Road network
Contours per 1000 m
Built environment
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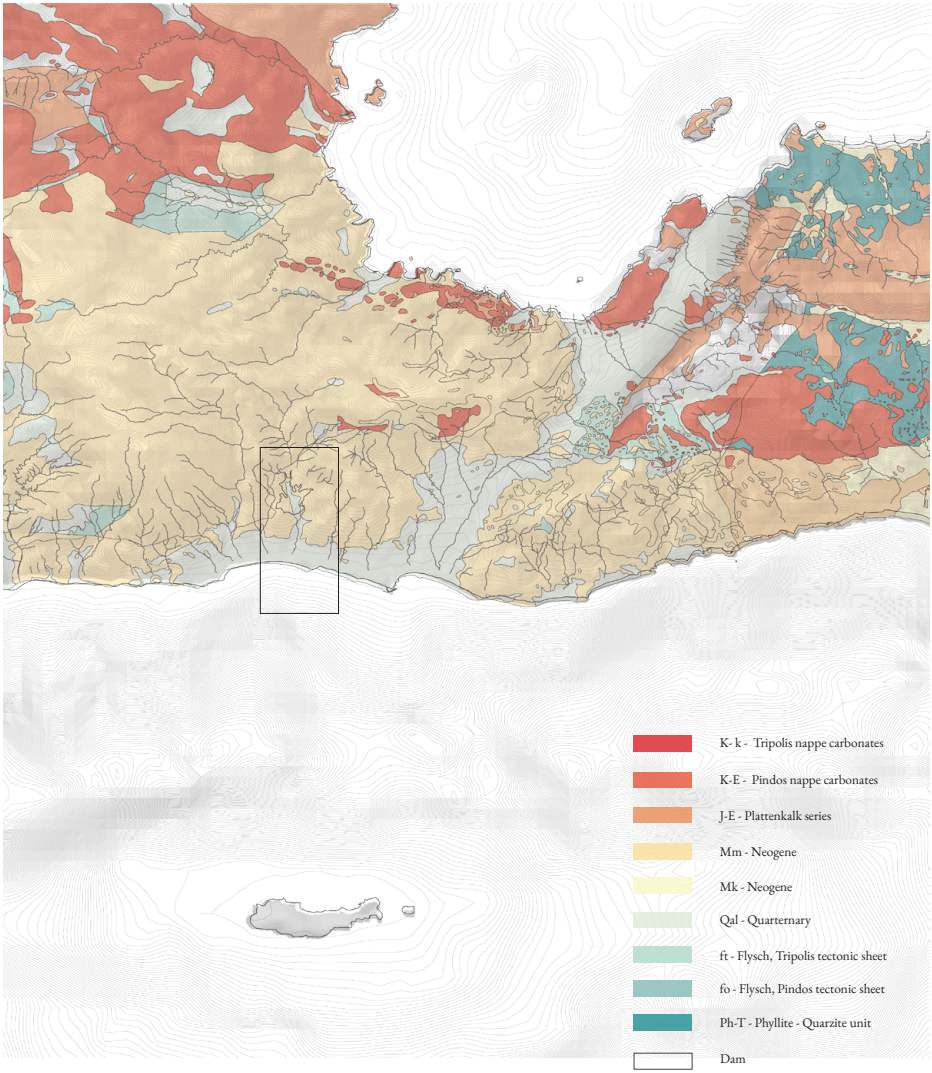
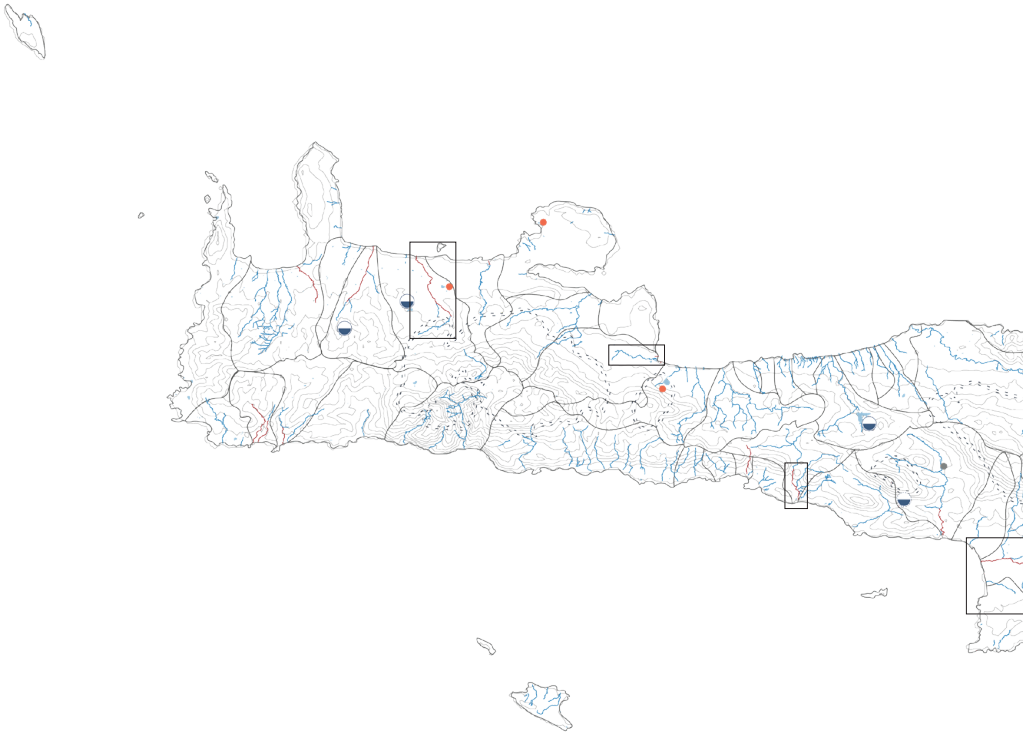

K- k - Tripolis nappe carbonates
K-E - Pindos nappe carbonates
J-E - Plattenkalk series
Mm - Neogene
Mk - Neogene
Qal - Quarternary
ft - Flysch, Tripolis tectonic sheet
fo - Flysch, Pindos tectonic sheet
Ph-T - Phyllite - Quarzite unit
Dam
River system
Contours per 10 m
0
5
10 km

Further research
River typology exploration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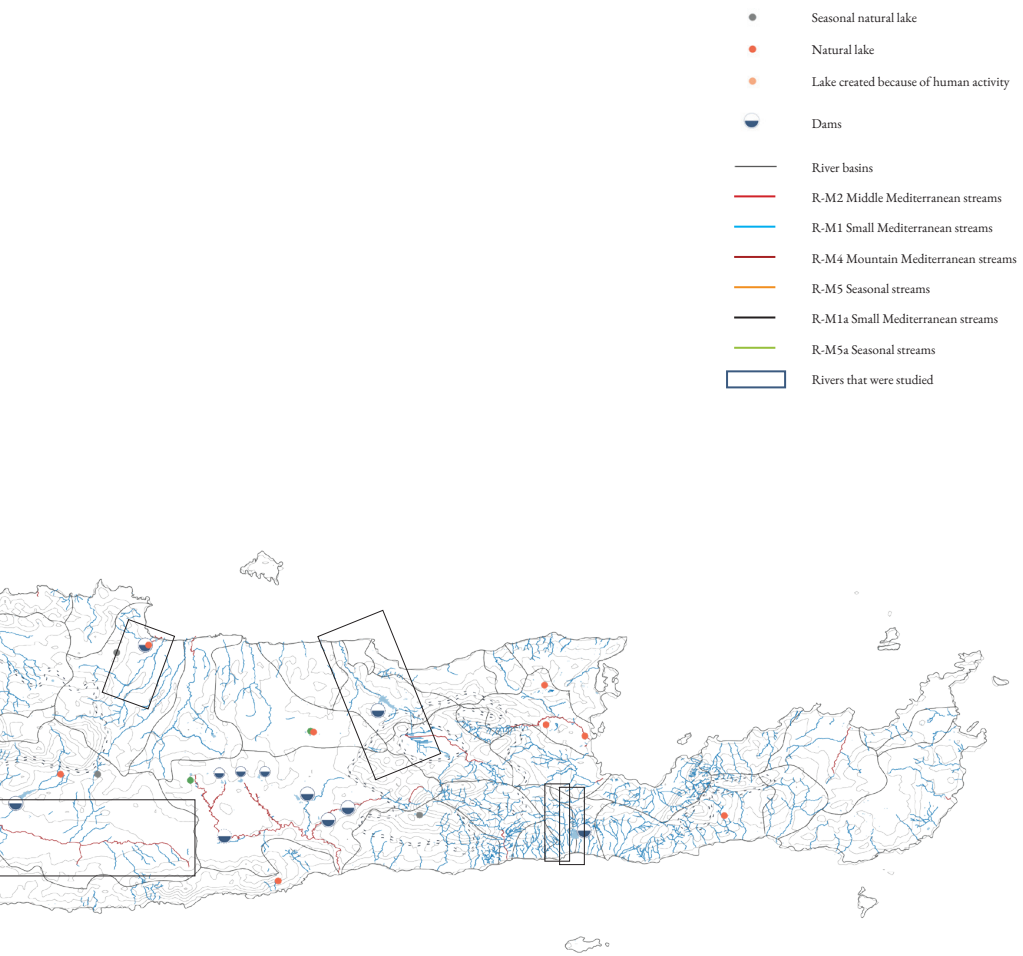
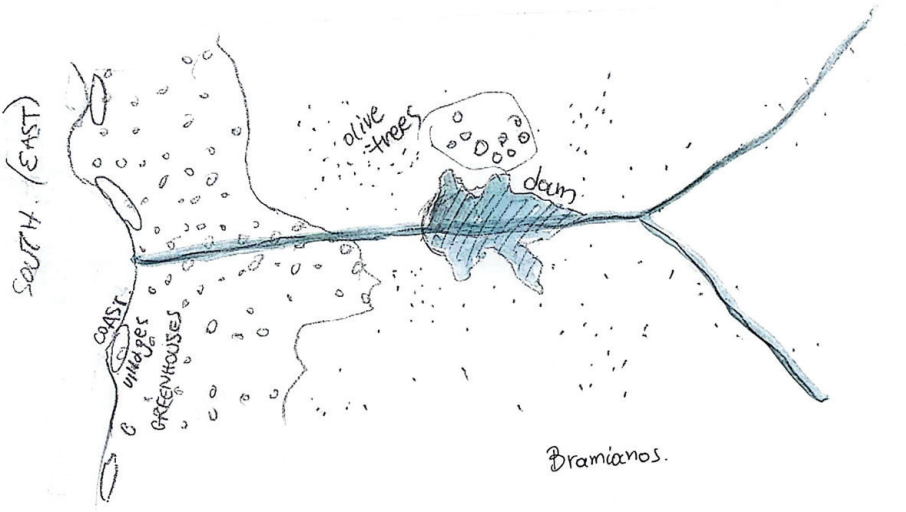
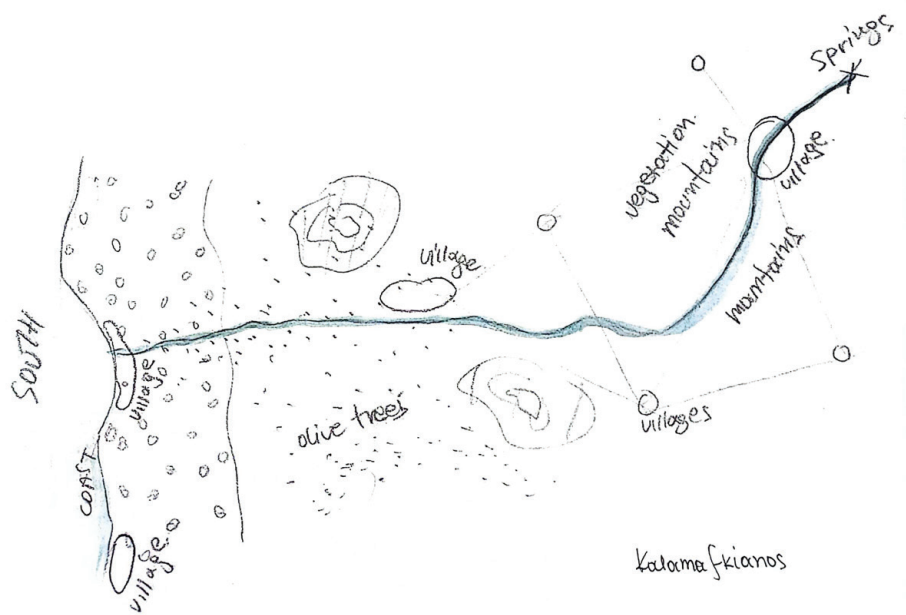
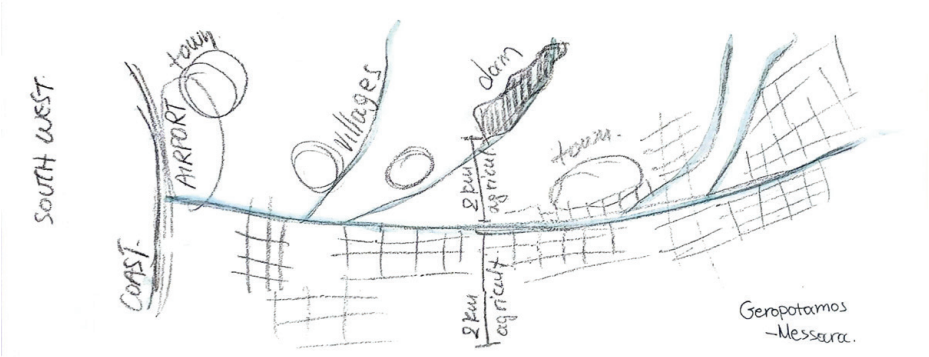
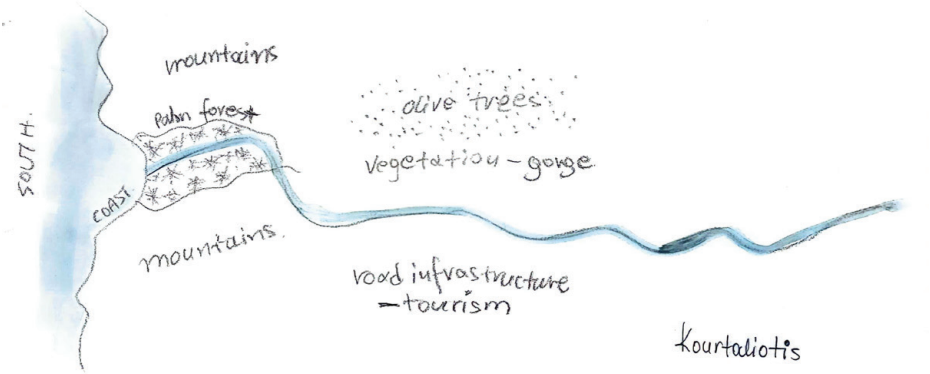
River typology exploration

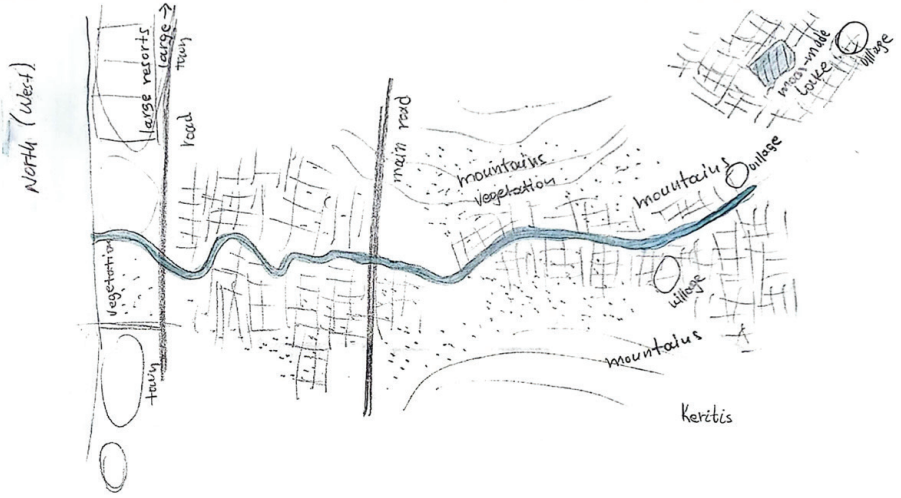


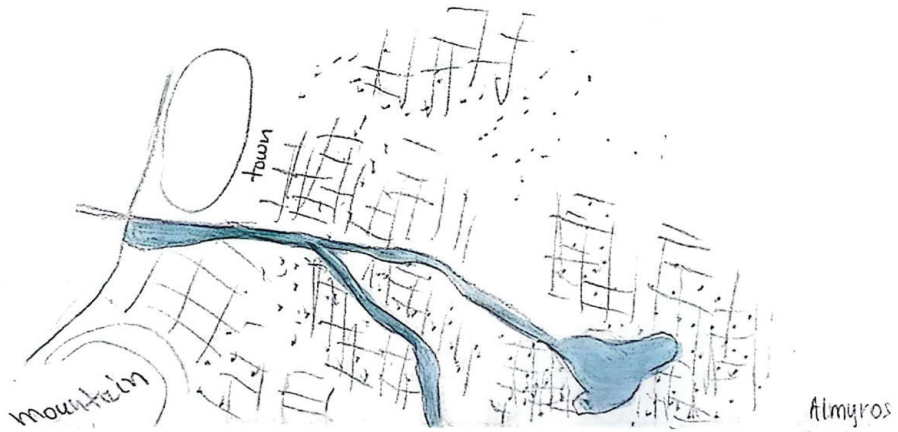

SOUTH. (EAST)
olive trees
dam
COAST
villages
GREENHOUSES
Bramianos.

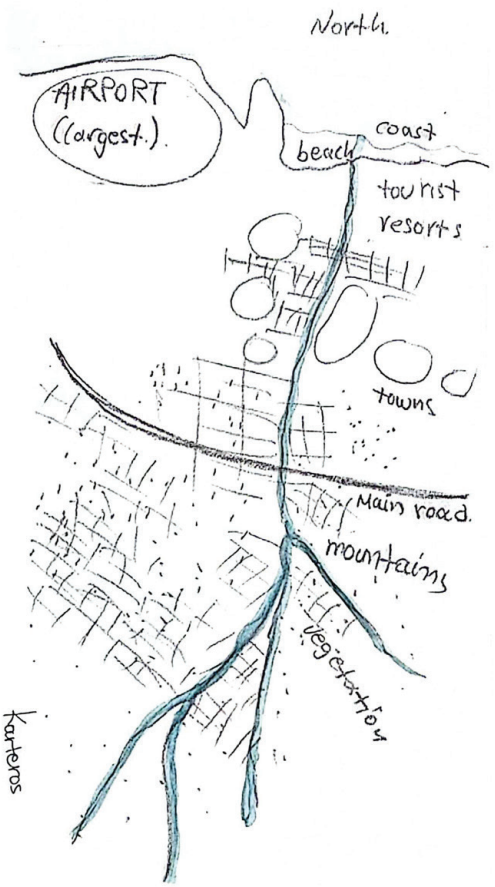

SOUTH
Springs
vegetation
mountains
village
village
mountains
olive trees
villages
COAST
village
village
Kalamafkianos

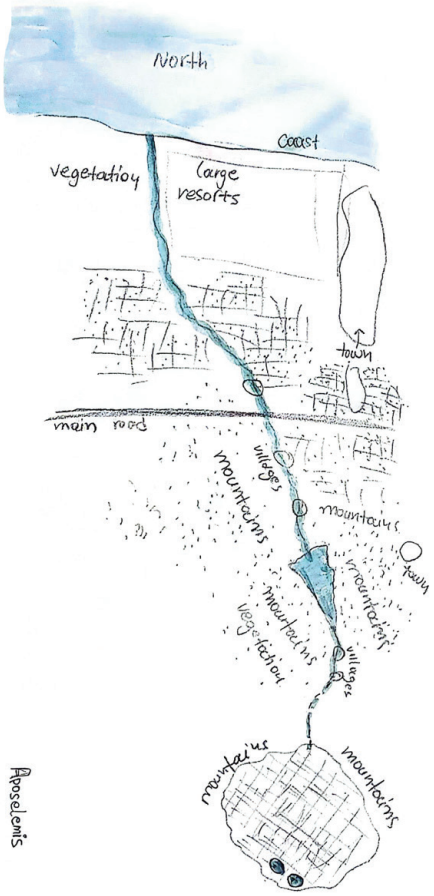

SOUTH WEST
COAST-
AIRPORT
town
Villages
dam
2km agricult
town
2km agricult
Geropotamos
-Messara


SOUTH
COAST
mountains
Palm forest
mountains
olive trees
vegetation - gorge
road infrastructure
-tourism
Kourtaliotis


NORTH (West)
large resorts
large town
road
vegetation
town
main road
mountains
vegetation
mountains
village
village
mountains
mountain
mountain-inside lake
village
Keritis


town
mountain
Almyros


North
AIRPORT
(largest.)
coast
beach
tourist
resorts
towns
Main road.
mountains
vegetation
Kateros


North
coast
vegetation
large
resorts
town
main road
villages
mountains
mountains
town
mountains
vegetation
village
mountains
mountains
mountains
Agioselemis

Most of the island's rivers are considered intermittent and seasonal streams (or ephemeral, temporary rivers) due to their occasional water flow. These terms describe watercourses that experience fluctuations in flow, typically in response to seasonal rainfall or snowmelt. These rivers can remain dry for several years at a time and are common in regions with limited or highly unstable rainfall or specific geologic conditions.

The number of temporary rivers is increasing, as many formerly perennial rivers are becoming temporary due to overexploitation of water, particularly for irrigation. Despite their inconsistent water flow, intermittent rivers are considered significant terraforming agents in arid regions, particularly on the island of Crete, as they are responsible for water and sediment movement and erosion during flood events. The combination of dry, rigid soils and the highly erosive energy of precipitation can cause significant sediment transport to coastal areas, making these rivers some of the most altered aquatic habitats by human activities.

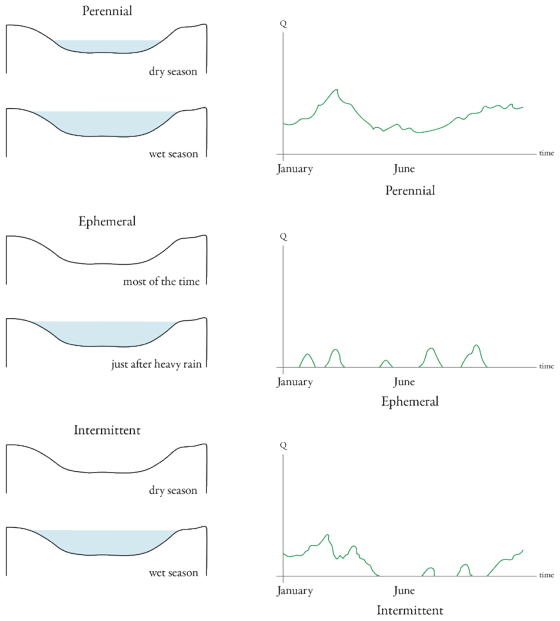


Figure 110: River classification based on water flow, designed by author

The rivers in Crete present a variety of forms, classified based on factors such as local geology, topography, and climate. Local geological features, including the presence of limestone and other sedimentary rocks, along with the island's topography, play crucial roles in shaping these rivers.

Given the Mediterranean climate of Crete, characterized by irregular and seasonally concentrated precipitation, most of the rivers on the island are intermittent or seasonal. These rivers experience flow during periods of increased rainfall and become dry or nearly dry during dry months. Ephemeral (seasonal), which only carry water during rainfall runoff, are typically shallow and lack a defined channel. Intermittent streams, on the other hand, carry water during wet periods of the year and possess defined channels.

River Classifications of channel patterns

According to their channel pattern (straight, meandering, braided, and anastomosing), the streams in Crete predominantly exhibit intermittent or ephemeral characteristics with straight or, less commonly, meandering patterns, in alignment with their seasonal nature. In areas with minimal vegetation and significant human intervention, such as the island of Crete, straight channels are more common. While these channels require less land and can be more stable, as presented in the diagram below, they are characterised by considerable erosion and sedimentation, often lacking essential vegetation to stabilise their banks.

Due to the erosive energy of precipitation events and the dry, rigid soils, streams in eastern Crete often carry a mix of suspended and bed-load sediments. During flood events, significant amounts of sediment are transported, which can lead to sediment deposition in coastal areas. (Schumm, 1981, 1985b). This sediment transport process highlights the active role of these intermittent streams as agents of significant water and sediment movement and erosion during flood events, despite their typically dry state.

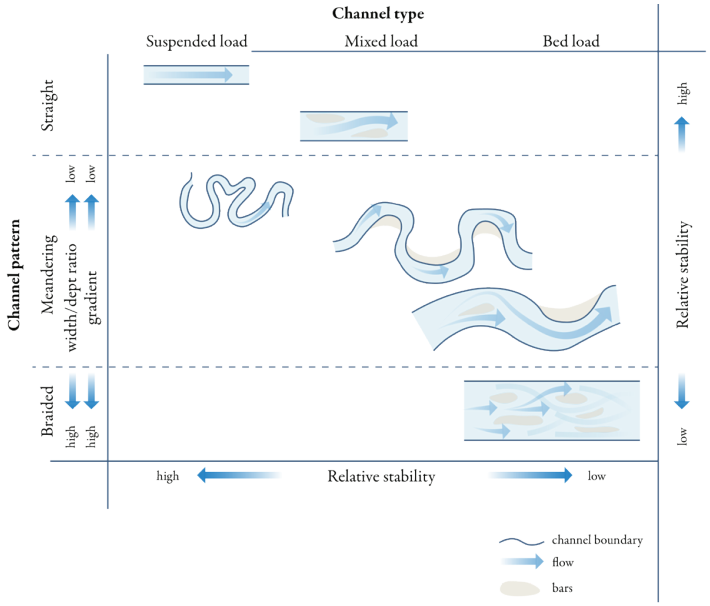
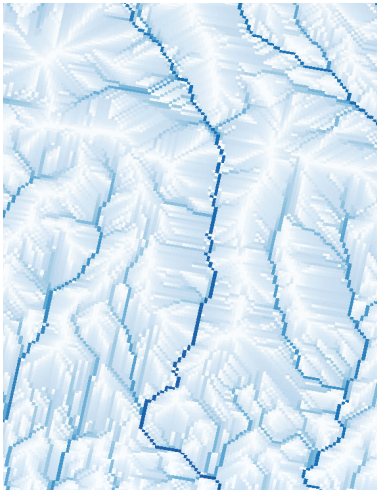


Figure 111: The relationship between pattern, size, stability, and sediment type for alluvial channels, adapted from: *https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/r-wd-06-37.pdf*

The rivers in Crete exhibit dendritic drainage pattern systems, largely influenced by the underlying geological conditions. Drainage patterns describe the connectivity of tributary streams to the main trunk stream. These network patterns result from the region's lithology and structure and are the most common form, developing in areas with homogeneous terrain in which there is no distinctive geologic control (Fryirs, Kirstie & Brierley, Gary., 2012).

Dendritic drainage patterns are typical in regions where the geology is relatively uniform, allowing watercourses to develop naturally without significant interruption from geologic variations. This pattern mimics the branches of a tree, reflecting efficient and natural water flow across the landscape.



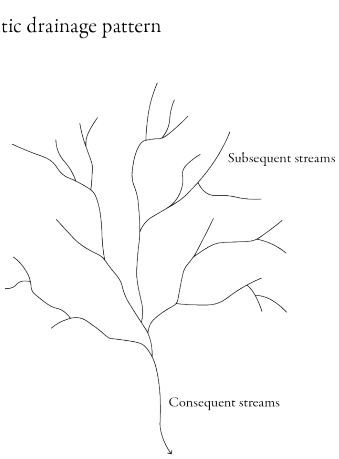


Figure 112: Dendritic drainage patterns in Crete, flow accumulation, designed by author

Stream Dynamics and materiality

All streams have streambanks and streambeds composed of various materials, including bedrock, boulders, cobble, gravel, sand, silt, and clay. The bed material of rivers in eastern Crete can vary depending on factors such as geological composition, sediment transport dynamics, and human activities. For instance, rivers in the Ierapetra region exhibit alluvial characteristics, with sediment deposition occurring along channel banks and floodplains during periods of low flow. In the mountainous regions of Crete, rivers flowing from higher elevations deposit sediment, forming alluvial fans in the plains or lower-lying areas. Alluvial deposits typically consist of a mix of sand, silt, and clay particles, with variations in size and sorting influenced by local hydrogeological conditions.

Other physical characteristics

Other physical characteristics of the streams include pools, riffles, meanders, floodplains, channels, runs, and riparian corridors. Floodplains are flat areas adjacent to stream channels vulnerable to flooding. Pools are deeper sections of the stream with slower-moving water, providing habitat and refuge for aquatic life, while riffles are shallow areas with fast, turbulent flow over a rocky substrate. Runs are smooth, unbroken flow sections of the stream and riparian corridors are vegetated areas along the streambanks that stabilise banks, filter pollutants, provide shade, and support habitats, as illustrated in the following diagrams. These features collectively maintain the ecological balance and hydrological processes of stream ecosystems.

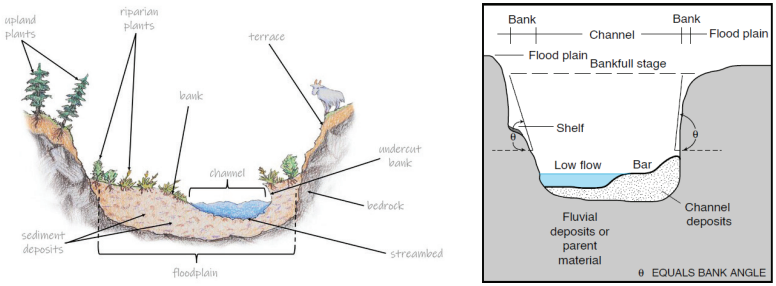


Figure 113: River sections, materiality, Source: *https://wildearthlab.com/portfolio-2/, Fitzpatrick, F., Waite, I., D'Arconte, P., Meador, M., Maupin, M., Gurtz, M., (1998). Revised Methods for Characterizing Stream Habitat in the NATIONAL Water Quality Assessment Program*

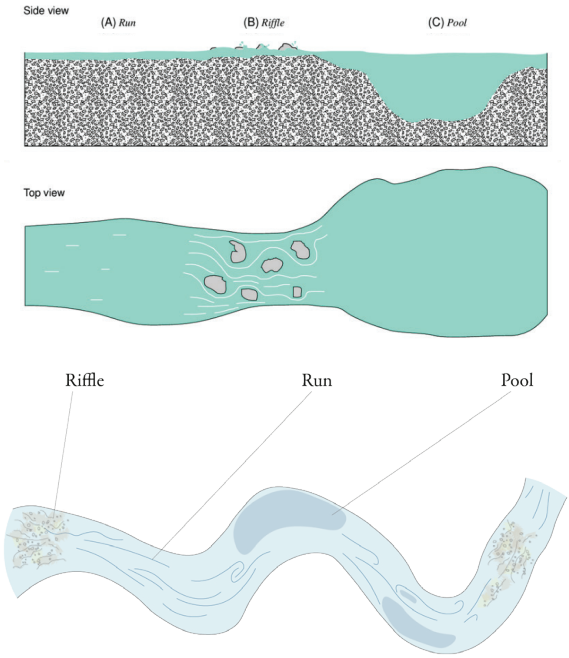


Figure 114: physical characteristics of the streams, adapted from Bisson et al., 1982

Alluvial Channels

Alluvial channels develop within sediment deposits that were previously deposited by river processes. They are characterised by erodible channel boundaries, where sediment is removed and transported further downstream during floods.

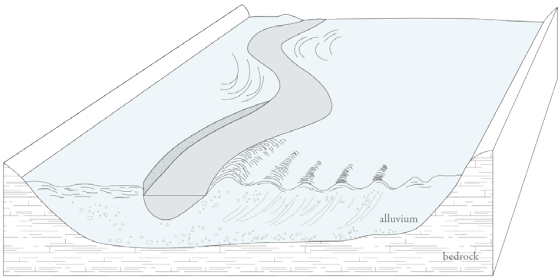


Figure 115: Alluvial channel, materiality, designed by author

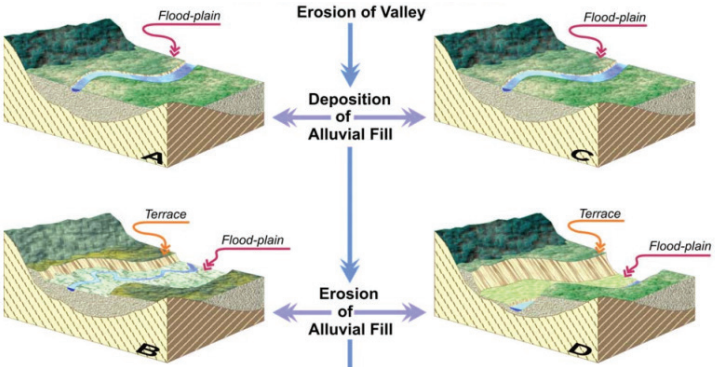


Figure 116: (above) River banks erosion development, (below) River in Ierapetra, materiality, 2023, Source: (above) Leopold et al., 1964, (below) photograph by author

Further research
Population projection

EUROPOP2023, the latest population projections released by Eurostat on 30 March 2023, provides the baseline projections for population changes from 2023 to 2100. (It uses data for population on 1 January 2022). EU population is projected to grow slightly in the first 5 years, followed by a steady decline until the end of the century.

This project embraces the projections for the period of 2023 to 2100 for Greece, which highlight that large declines in the population, at the range of 30 % are projected for Greece where the population size will decrease from 10.459.000,8 to 7.282.000,5. (Eurostat, 2023). Respectively we assume that the population of Crete will follow a similar path of decrease in the timeframe of 2023 to 2100.

This work recognises that these projections are made over a relatively long time horizon, statements about the likely future developments of the EU's population should be treated with caution and interpreted as only one of a range of possible demographic developments. EUROPOP2023 are deterministic projections, or 'what-if' population projections, based on assumptions formulated on a future course of fertility, mortality and migration. (Eurostat, 2023)

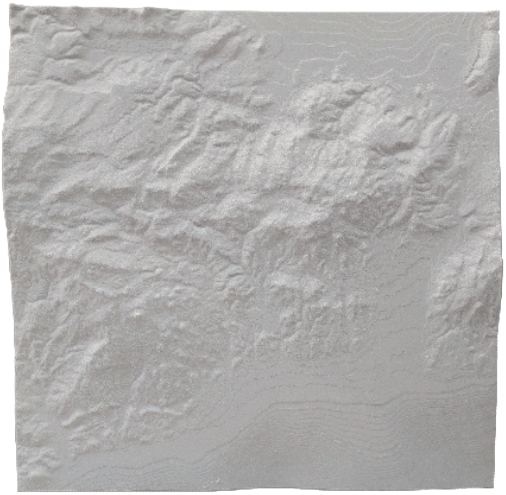
Demographic balances, 1 January 2022-2100
(thousands)

	Population	Cumulative births	Cumulative deaths	Cumulative natural population change	Cumulative net migration	Total population change	Projected population
	1 January 2022			2022-2099			1 January 2100
EU	446 735.3	291 262.3	416 595.9	-125 333.7	98 060.0	-27 273.6	419 461.7
Belgium	11 617.6	8 975.7	10 540.0	-1 564.2	2 502.6	938.4	12 556.1
Bulgaria	6 838.9	3 693.1	6 633.6	-2 940.6	1 173.6	-1 767.0	5 072.1
Czechia	10 516.7	7 808.9	9 885.6	-2 076.7	2 205.7	129.0	10 645.7
Denmark	5 873.4	4 538.3	5 376.5	-838.2	1 090.8	252.6	6 126.1
Germany	83 237.1	58 027.4	78 538.7	-20 511.4	21 391.6	880.2	84 117.3
Estonia	1 331.8	925.2	1 294.8	-369.6	327.1	-42.5	1 289.5
Ireland	5 060.0	4 361.8	4 666.6	-304.8	1 116.2	811.4	5 871.4
Greece	10 459.8	5 017.2	9 246.4	-4 229.1	1 052.0	-3 177.1	7 282.5
Spain	47 432.9	27 417.7	46 032.3	-18 614.6	16 303.2	-2 311.4	45 121.4
France	67 871.9	52 842.6	60 065.6	-7 223.0	7 393.9	170.9	68 042.8
Croatia	3 862.3	1 949.4	3 606.7	-1 657.4	617.7	-1 039.7	2 822.7
Italy	59 030.1	29 905.1	57 526.3	-27 621.2	18 785.6	-8 835.6	50 194.5
Cyprus	904.7	695.6	774.7	-79.1	182.2	103.1	1 007.7
Latvia	1 875.8	903.1	1 654.6	-751.4	41.6	-709.8	1 165.8
Lithuania	2 806.0	1 279.1	2 664.6	-1 385.5	355.2	-1 030.3	1 775.7
Luxembourg	645.4	627.1	675.1	-48.0	399.8	351.8	997.3
Hungary	9 689.0	6 600.5	9 212.5	-2 612.0	1 977.1	-634.9	9 054.1
Malta	521.0	422.4	618.3	-195.9	434.0	238.1	759.1
Netherlands	17 590.7	13 277.2	16 226.6	-2 949.4	3 669.1	719.7	18 310.4
Austria	8 978.9	6 289.3	8 485.6	-2 196.2	2 794.0	597.8	9 576.6
Poland	37 654.2	21 008.5	34 373.8	-13 365.4	5 227.1	-8 138.2	29 516.0
Portugal	10 352.0	5 753.5	9 818.2	-4 064.7	2 693.8	-1 371.0	8 981.1
Romania	19 042.5	11 428.2	16 999.9	-5 571.7	1 138.8	-4 432.9	14 609.5
Slovenia	2 107.2	1 335.1	1 977.0	-641.9	485.5	-156.4	1 950.8
Slovakia	5 434.7	3 397.2	4 922.5	-1 525.3	643.0	-882.2	4 552.4
Finland	5 548.2	3 268.8	5 137.9	-1 869.1	1 105.6	-763.5	4 784.9
Sweden	10 452.3	9 514.2	9 641.4	-127.2	2 953.1	2 825.9	13 278.2
Iceland	376.2	422.6	389.5	33.1	215.4	248.6	624.5
Norway	5 425.3	4 328.7	5 059.0	-730.3	2 036.6	1 306.2	6 731.6
Switzerland	8 738.8	6 609.4	8 097.5	-1 488.1	2 853.6	1 365.5	10 104.3

Figure 119: Demographic balances, 2022-2100, Source: Eurostat, *https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=497115*

Further research
model

Terraforming processes, water retention and infiltration landscapes, model made by author



Isthmus of Ierapetra topography, model made by author

Terraforming processes, water retention and infiltration landscapes, model made by author

Further research
Fieldwork

Figure 120: Significantly lowered water level in the Aposelemis dam 2023, photograph by author

Figure 121: Significantly lowered water level in the Aposelemis dam 2023, photograph by author

Figure 122: Significantly lowered water level in the Aposelemis dam 2023, photograph by author

Figure 123: Channelized water imput of the Aposelemis dam 2023, photograph by author

Figure 124: Sfentili abandoned village inside the Aposelemis dam 2016, photograph by author

Figure 125: Sfentili abandoned village emerged, inside the Aposelemis dam 2023, photograph by author

Figure 126: Sfentili abandoned village emerged, inside the Aposelemis dam 2023, photograph by author

Figure 127: Aposelemis river 2023, photograph by author

Figure 128: Aposelemis river estuary, sustained by underground spring, 2023, photograph by author

Figure 129: Where the river water merges with the sea, Almyros river, sustained by underground spring, 2023, photograph by author

Figure 130: Soil materiality, photograph by author

Figure 131: Aposelemis river 2023, photograph by author

Figure 132: Isthmus of Ierapetra panorama, on the left the northen coast of the island, on the right, the southern, 2023, photograph by author

Figure 133: Mountain rainges in Crete, photograph by author

Figure 134: View of the northern coast of the eastern part of the island, 2023, photograph by author

Figure 135: Mountain rainges in Crete, photograph by author

Figure 136: Mountain tops with snow and clouds in Crete, photograph by author

Figure 137: Church with snowy mountain view in Crete, 2019, photograph by author

Figure 138: Archaeological site of Gournia, excavated in the early 20th century featuring Minoan houses, roads and a cemetery, Pachia Ammos, photograph by author

Figure 139: Northeastern coast of Crete, 2023, photograph by author

Figure 140: Katharo mountain's wild natural environment, 2023, photograph by author

Figure 141: Katharo mountain's wild natural environment coexisting with water infrastructure, 2023, photograph by author

Figure 142: Kefalovrisiou, Kalamafkas springs, 2023, photograph by author

Figure 143: Kefalovrisiou, Kalamafkas springs, 2023, photograph by author

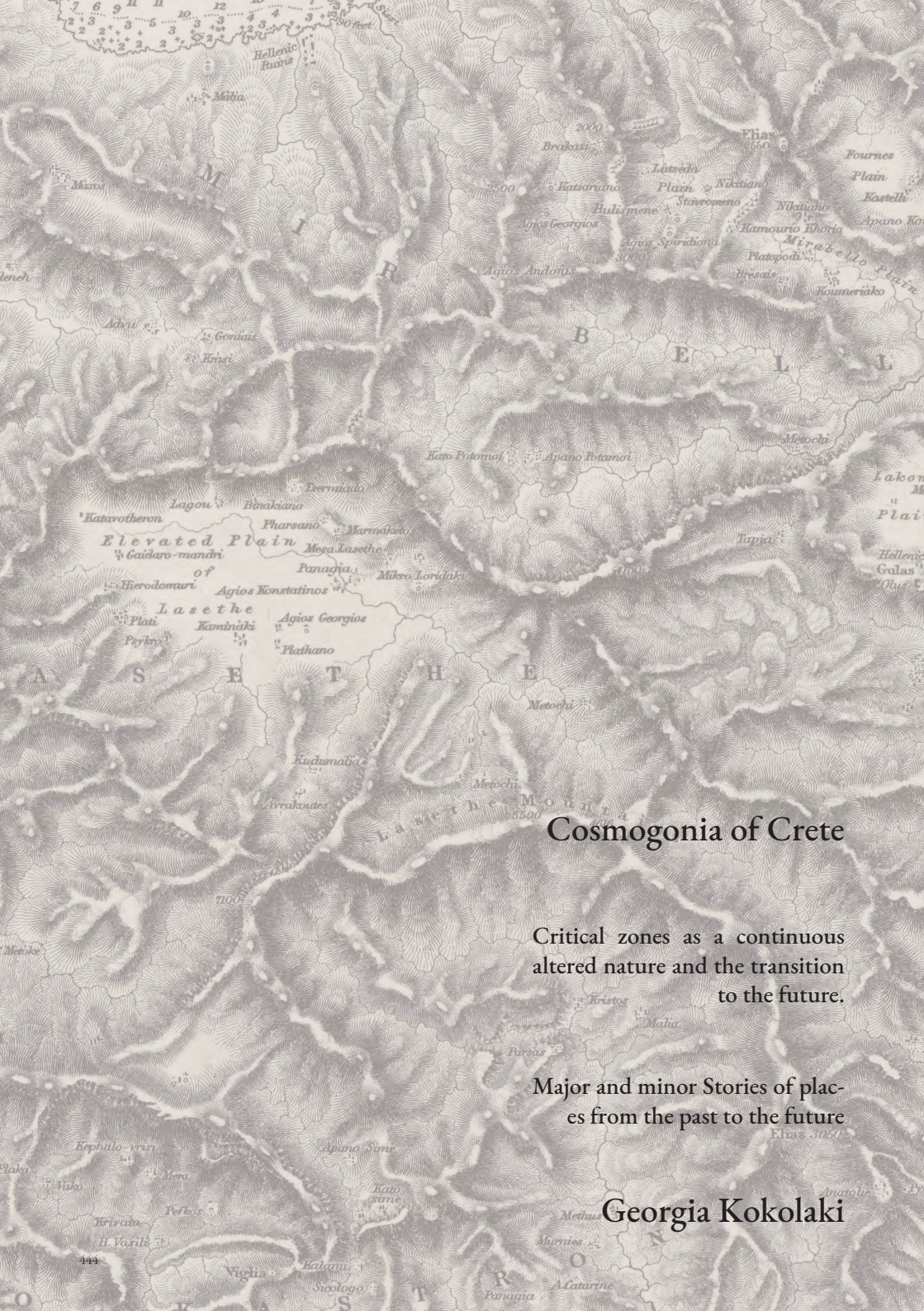
Figure 144: Water infrastructure, bridge over a stream, Eastern Crete, 2023, photograph by author

Figure 145: Water infrastructure, bridge over a stream, Eastern Crete, 2023, photograph by author

Figure 146: Soil materiality, alluvial sediment, photograph by author

Figure 147: Lasithi plateau with cultivations and water reservoir, 2023, photograph by author

Figure 148: Road that crosses a river at Lasithi (known as an Irish bridge), stays dry when the flow is low, but is designed to get submerged under high-flow conditions such as floods, photograph by author



Cosmogonia of Crete

Critical zones as a continuous altered nature and the transition to the future.

Major and minor Stories of places from the past to the future

Georgia Kokolaki