Venice and the Lagoon. Two *New* Visions

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During our first week in Venice our supervisors organized some interesting guest lectures from different speakers that we would like to thank. First Luca Velo (Iuav University) gave us insight into the history of the lagoon and its ecosystemic aspects. Andrea Bortolotti gave us a presentation via Zoom on the Veneto region and the future challenges related to sea level rise. Sjoerd Groeskamp (Nioz) shared his work on the NEED project (Delta Futures Lab) which was very useful to conceptualize our project in Venice. Marta De Marchi – researcher in Urbanism at Iuav University – gave us feedback on the midterm presentations. Ludovico Centis who also is a researcher from the Iuav University presented micro-stories about the lagoon and Stefano Tornieri (architect and researcher) attended the final presentation. All these (local) insights really helped us to understand the problems and the challenges of the Venice lagoon.

Lastly we would like to thank Fondazione Querini Stampalia. During our stay in Venice, they provided us with a beautiful study room where we have been able to work on the project for seven weeks. We received a warm welcome and enjoyed working there.

SUMMARY

What long ago started as a small fishing village, seeking refuge from the Romans, slowly evolved into the city of Venice that we know today. With its unique location came unique problems, most of which were related to the interplay between Venice and its lagoon. By severe measures in the past it has continued to withstand the test of time.

In the decades to come, Venice, once again, has found itself in a difficult situation. Like has been done in the past, drastic measures are required to deal with the current and upcoming difficulties threatening the survival of Venice. These difficulties range from over-tourism to sea level rise and the subsiding of the city. Like the Magistrato alle Acque acted in the past, extreme visions were laid out as possible solutions to these threats.

To investigate alternative futures for Venice this research is done by an multidisciplinary team of TU students and tutors. The basis of the interdisciplinary design was laid in an intensive workshop week with focus on integrating knowledge and ideas that led to two visions which are presented in this report. With the aim of answering the main research question 'how do flood defense systems influence the spatial aspects of the territory in the context of a high dynamic landscape in the Anthropocene?'

The plan for the Perfect Lagoon is focused on tackling all of the current and upcoming problems where the emphasis lies on preserving and perfecting the lagoon using the building with nature philosophy, while also saving the city from drowning. Preservation is done by solving the sediment budget problems. Due to the constantly eroding system, salt marshes and land is slowly disappearing.

In the plan several actions are proposed to counteract the constant erosion as well as the effect that sea level rise will have on this unique estuary. Drastic measures like redirecting rivers and re-purposing the MOSE contribute towards this goal. After preservation comes restoration as one of the goals is to restore and increase ecological value, restoration of salt marshes and removal of negative influences like pollution.

As a second vision, the plan of the Symbiotic System deals with the same problems but here the emphasis lies on interconnectedness of the Veneto region in a sustainable way. More attention is paid to mass tourism. The plan aims to turn Venice into a modern interconnected metropolitan area. The city and the lagoon will be treated as two separated ecosystems. The focus lies completely on making the city of Venice modern, the lagoon will be left to its own natural devices in order to find a new, still unknown, equilibrium.

These visions are then further worked out and explained, and for both visions, technical designs are made to, step-by-step, bring these visions closer to reality. From these visions along with their technical design we can conclude that flood defense systems have a major influence in the spatial aspects of the territory. Not only in its primary function, but more importantly in the secondary functions. Both primary and secondary functions can be used to create a paradigm shift for the territory. Using the multidisciplinary approach, an integral design can be made for the flood defense, in which the opportunities for the territory can be first explored and then designed together with hydraulic infrastructures.

CONTENTS

1. INTRODUCTION & PROBLEM STATEMENT

Venice was established in the year A.D. 697 by Roman people fleeing from Germanic infiltration. By seeking refuge in the lagoon, the people were safe, for the lagoon was hard to reach and easy to defend. Centuries later, Venice became a dominant trade route in the Mediterranean sea leading to rich merchants settling in Venice [28]. The wealthy past of Venice can still be seen today. However, the water which once brought protection and prosperity to the city, has now become a major threat to the city.

Due to the effects of climate change, the sea level has begun rising more and more [29]. Combined with the effect of the steady subsidence of the city of Venice, the city now floods more frequently than in the past. As a measure, the Venetian people started on a storm surge barrier project in 1984, the MOSE. This project took very long to work out and was operational in late 2020 [30]. The MOSE barrier was designed for 60cm of sea level rise (as projected in 1984). It seems that Venice has just a couple of decades (about 30 years, Allan et al. [29]) to deal with the upcoming sea level rise.

The lagoon surrounding Venice was legally fixed by markers (cippi) about two centuries ago [31]. This is an area of about 550km2, of which 420km2 are covered by water, 90km2 by fish farms and 40km2 by embankments, coastal barriers, islands and land. The lagoon is connected to the Adriatic Sea by three constructed inlets: Chioggia, Malamocco and Lido [32]. A representation of the lagoon can be seen in Figure 1.1, as depicted by Ferguson [1].

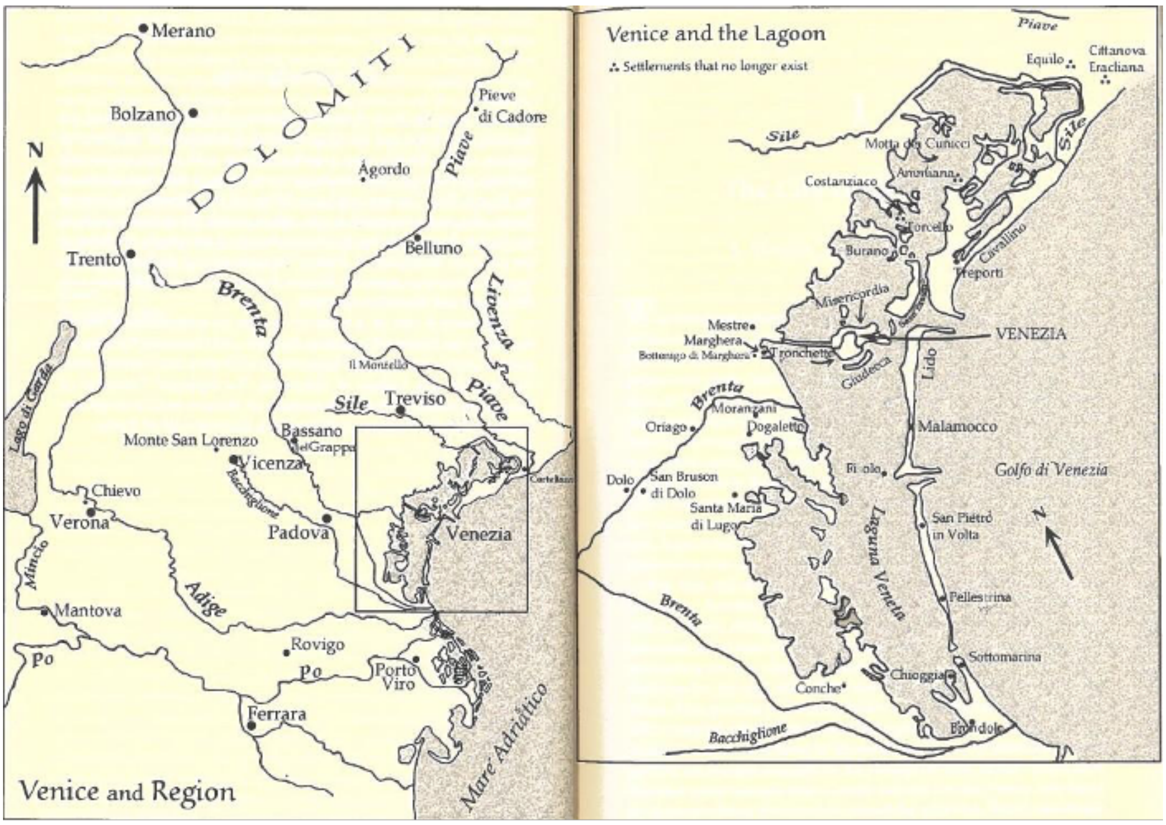


Figure 1.1: The Venice lagoon area represented by Ferguson [1].

1.1 PROBLEM STATEMENT

In the workshop, by reading Ferguson [1] and listening to presentations of Luca Velo, Andrea Bortolotti, Sjoerd Groeskamp, Marta De Marchi, Ludovico Centis and Stefano Tornieri a clear grasp of the context was obtained. With this, the problems in the area also became clear, these are outlined in Table 1.1.

Table 1.1: The problems of Venice and the lagoon.

Sediment Budget	The lagoon has been eroding over the last decades. Due to recent activities, this has become more and more severe. These activities have caused the salt marshes to degrade as well.
Salinity Problems	When the Brenta was diverted from the lagoon to the south of the lagoon in the 16th century, the brackish water started becoming more and more salty. This has negative consequences for the current ecological system.
Sea Level Rise	Due also to human impact on the planet, the sea level is rising, which is slowly drowning the lagoon as well as the city of Venice.
Subsidence	The city of Venice is subsiding. This accelerates the problem of sea level rise as these two factors work in opposite directions.
Canal and channel system	The canals which lead to the port were dredged for large vessels to enter the lagoon. This dredging had led to massive erosion, as well as impacts on the environment by means of a more turbid water column.
Pollution	Porto Marghera as well as the industry taking place in the area create a lot of polluted sediment. At this moment, this contaminated sediment is stored in designed islands in and around the lagoon. This contaminated sediment (rich in metals like Cu, Hg, Pb and more) impacts ecology and public health.
Loss of ecology	By combination of all above mentioned factors, the habitat of the ecology is degrading, which in turn degrades the ecology itself. Local ecology is slowly dying, and exotic species infiltrate and take over the area.
Heritage	The heritage in Venice is very strong. This is something worth protecting but it also conflicts with many other interests.
Venetian inhabitants	Boat traffic, creates waves which erode the salt marshes.
Tourism	Over-tourism creates many issues in Venice. The establishments of many tourist facilities exacerbate housing related problems for residents.
Acqua alta	Storm surges already form a major threat to the city of Venice, flooding lower lying parts of the city and causing damage to historical buildings and people's housing. While the MOSE forms a protection for the coming years, it only closes at very high tides.

More elaborate information on the current situation of Venice and its lagoon can be found in Section 3.1.

REPORT OUTLINE

This project is part of an overarching research, of which the aim is to answer the research question:

*How do flood defense systems (A) interpret the spatial aspects of the territory (B) as part of the probability approach [Risk = Probability * Consequences] (C)?*

Using specific design methods, two visions were created in order to solve the current and upcoming threats to the city of Venice and the lagoon.
First the project approach and methodology will be discussed in Chapter 2.
The current situation and scope are explained in Chapter 3 along with the stakeholder analysis. The two visions resulting from the methodology are explained in Chapter 4 followed by their interpretation and design Chapter 5.
Lastly, we come to the discussion in Chapter 6 and the conclusion in Chapter 7.

2. PROJECT APPROACH AND METHODOLOGY

This project is organized within the scope of the Delta Futures Lab [33] with the aim to perform interdisciplinary research and design within the context of practice and international research. The interdisciplinary goal within the University of Technology of Delft, is not only about the connection between the faculties of Technology, Policy & Management (TPM), Civil Engineering & Geosciences (CEG) and Architecture and the Building Environment (A+BE) but also to establish cooperation within these faculties among the different master tracks and specializations. Furthermore, the combination of the specific disciplinary research methods adds each discipline's knowledge to the interdisciplinary approach.

The approach and methodologies of this project aim to create two different visions for the Venice Lagoon. These visions are worked out into two distinctive designs, each containing distinguishing elements. The interdisciplinary nature of this project challenges master students from TPM, CEG and A+BE to focus on the development of an appropriate understanding of interdisciplinary design and the means to establish it. This chapter elaborates on the project approach and the methods used in order to showcase the process of the development of the interdisciplinary designs.

2.1 PROJECT APPROACH

This project is the result of a collaboration between a group of students from different masters, with the aim of an interdisciplinary approach. This is done by combining the Multidisciplinary Project Course (at the faculty of Civil Engineering and Geoscience) and the Honors Program (faculty of Architecture and the Built Environment). In total, eight students contribute to this project of which three coastal engineering students, one river engineering student, one hydraulic structures student, one construction management and engineering student, an architect student and a landscape architect student.

This research is situated in the context of the All Risk Program - Project A3 - Spatial adaptation in coastal environments (www.all-risk-program.nl). The research aims to find new synergies between disciplines in order to implement measures of water protection systems to achieve the recently updated standards of safety. The All Risk project pursues new measures and strategies which not only consist of dike reinforcement, but can also include spatial planning improvements or other risk-reducing measures. [34] [35]

Guiding the research, the following main question was leading:

How do flood defense systems influence the spatial aspects of the territory in the context of a high dynamic landscape in the Anthropocene?

The following sub questions were addressed by the particular disciplines.

Coastal Engineering

"How does the alteration of the flood defense system impact the local natural systems?"

"How does the future expansion of the existing flood defense systems influence the spatial aspects of the territory?"

River Engineering

"How does the river system morphologically impact the spatial aspects of an urbanized territory?"

Hydraulic Structures

"How can a primary flood defense line reduce the risk of flood and, at the same time, increase the spatial value of the landscape?"

Construction Management and Engineering

"What is the risk of a changing flood defense strategy when considering stakeholders in the territory?"

Architecture

"How do dams and dikes impact the natural habitat and spatial qualities for humans?"
*"How does this affect the water chain and waste management in the Venice lagoon, especially when changing the accent in the probability approach R=P*C on the Consequences?"*

Landscape Architecture

"How can flood defense zones function as a shared territory for humans and flora and fauna alike?"

2.2 PROJECT STRUCTURE

This section first goes into the scoping of each discipline and after that into the structure of the project itself.

2.2.1 SCOPING

Hydraulic Engineering (Hydraulic Structures, River Engineering and Coastal Engineering) aims at protecting people and ecology against water related hazards, such as coastal floods, river floods, erosion and sedimentation. Hydraulic Structures focuses on the design of the hydraulic structures itself, such as flood defenses, storm surge barriers, tunnels and locks. River Engineering is concerned with the prediction of short-term and long-term response of the river system to changes and the design of measures that help serve the various river functions such as flood safety, navigation, freshwater supply, ecosystem services, and recreation. Coastal Engineering strives to resolve various conflicting interests between the coastal environment and the human use of the coastal area. Dunes, barriers, estuaries, lagoons and deltas are coastal systems which receive the focus from Coastal Engineering. Hydraulic Engineering is thus a discipline which is necessary in order to successfully solve water related challenges. For the project context, the hydraulic engineers will be responsible for the lagoon itself, and the interface between water and land.

Construction Management & Engineering keeps an eye on the overall project and its processes that are involved. By analyzing actors, parties and policies, project and construction challenges ahead can be identified. The great number of actors, the complex ecosystem and the cultural importance of Venice and its lagoon, results in a complex project environment. Steering and controlling of these crucial project aspects will contribute to a successful project outcome.

Architecture encourages the project group to take a look at the greater picture over a long period of time and to initiate a change. Extensive analyses of the project area leads to both short and long term challenges that will be addressed by concepts developed by Architecture students. The built, materialized and long term nature of these concepts makes them distinctive from other concepts and essential for the project.

Landscape Architecture focuses on the project area and the larger context in which it is present. It incorporates context into its concepts and designs, and searches for opportunities to anticipate on. Landscape Architecture proves to be useful in the context of the Venice lagoon which is known to be a challenging environment with important cultural, economical and ecological characteristics.

Scope interfaces Where scopes meet is a critical area where information exchange is necessary in order to have a successful Interdisciplinary Project. In Figure 2.1 these interchanges areas are displayed.

	River	Hydraulic Structures	Architecture	Landscape Architecture	CME
Coastal	Inflow of river into lagoon	Dam and hydrodynamic (lagoon) interaction	Spatial influence of coastal solutions	New dike influences lagoon behavior and hydrodynamics influence new dike	Policies and stakeholders in lagoon
River		–	Spatial influence of river solutions	Landscape change influences river course and vice versa	Policies and stakeholders regarding river
Hydraulic Structures			Building on the dam influences structure and vice versa	–	Policies and stakeholders regarding the dam
Architecture				Integrating and connecting the spatial design solutions on the wide range of scales	Policies and stakeholders regarding architecture
Landscape Architecture					Policies and stakeholders regarding landscape

Figure 2.1: Interactions between scopes.

2.2.2 STRUCTURE

The project was divided into two main phases. The first phase took place in the form of a workshop, in the first week of the project. In this workshop, the architecture students, engineering students as well as the supervisors took part. The product of the first phase was an analysis and synthesis of the context, and finally, two visions, differing radically. In this phase, as it was a workshop, there was continuous communication between both groups, which led to immediate iteration.
For phase two the engineering students and the architecture students split up due to logistical reasons. Also, the engineering students worked full-time from this point in phase 2, and the architecture students worked a four-hour week, which introduced a difference in project advancement. For the engineers the product of this phase was to create a design, and preliminary calculations which go along with this. For the architects, the product of this phase was the design itself, due to the nature and scopes of these disciplines. This combination of factors ensures that communication for iteration becomes more important but also more difficult. After the divergent first phase, a more convergent phase began in which the focus was on working out the concepts which resulted directly from the workshop. During a second workshop week, another divergent step is made after which the final phase of the process (for this project) begins, which is finalizing the concepts. This process of convergence and divergence is detailed in figure Figure 2.2.

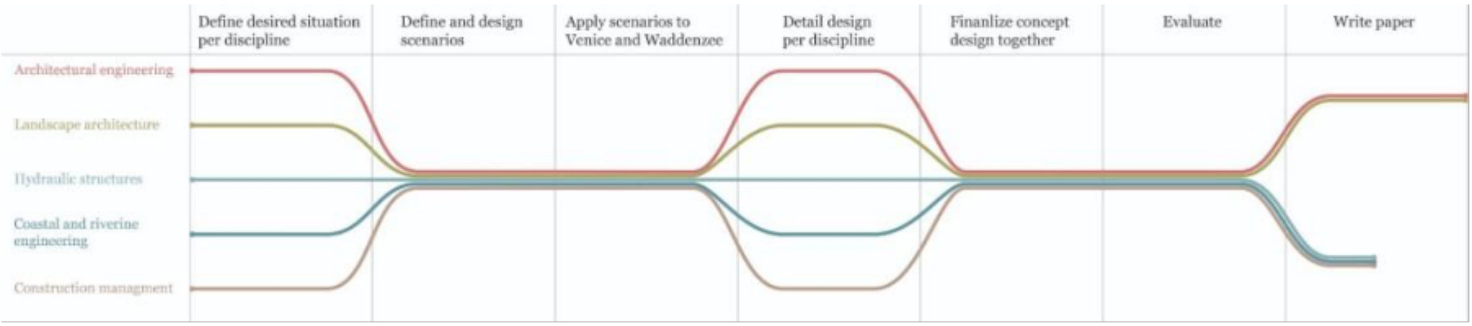


Figure 2.2: Phasing of project.

2.3 METHODOLOGY

Research under the Delta Futures Lab follows the set of interdisciplinary methods for the studies. Different methods are used in each phase of the project.

- Charrettes
- Scoping 'Tohoku' method
- Research by design

Charrettes

The Charrette is about creating involvement by organizing a discussion in successive rounds in which the data is discussed and step by step, or round by round, integration of information that can be used for synthesis and design becomes group knowledge [36]. In the Charrette method, possible solutions to problems within their own discipline are discussed with others from said discipline. Afterwards, the different disciplines are brought together one by one, for example coastal engineering and landscape architecture, and these possible solutions found by one discipline are then explored within the confines of the other discipline. From these meetings, solutions become more and more realistic as they are discussed with more and more people with different backgrounds, an example figure can be found in Figure 2.3. This forms the basis of the interdisciplinary approach on which the rest of the projects build upon.

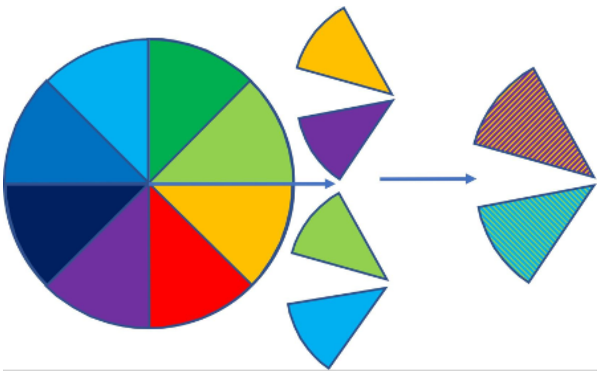


Figure 2.3: Figure depicting the workings of the Charrettes method.
Final two 'triangles' show how in new rounds of the method, two different disciplines meet with the new knowledge obtained from the combination of the previous two disciplines.

Scoping 'Tohoku' method

The integration of information and ideas will be done using, again, the Charrette methodology. With the scoping method, the first condition is met by creating a common understanding of the problem and context of the case. Each group, within their created body of knowledge, orders the chosen measures or concepts by using scopes on the base of the 4P tetrahedron theory (Van Dorst and Duijvenstein, 2004 [2]).

In spatial planning and design, the very general sustainability aspects of the 'triple bottom line' consisting of the three P's: people, planet and prosperity (UN, 2002 [37]) are translated into territorial interventions seeking balance and synergy.

- People: prosperity, health, freedom (of choice), social cohesion, participation, safety;
- Planet: world, flows, energy, water, material, mobility, purity;
- Prosperity: profit, affordability, fairness.

This crucial strategic activity is captured by a fourth P in the 4P tetrahedron theory by van Dorst and Duijvestein [2]. The fourth P represents both project and process. 'Project' stands for the physical results of the balance between the triple P and represents spatial quality, relations through scales, (bio)diversity, robustness and aesthetics. 'Process' regards the interaction between stakeholders, their skills and the institutional context in realizing a balanced design [2]. Below the 4P tetrahedron by van Dorst and Duijvestein [2]

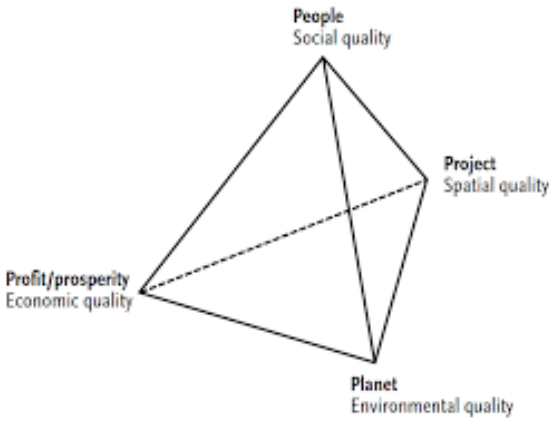


Figure 2.4: The tetrahedron of sustainable construction (van Dorst and Duijvestein, 2004) [2].

Each group weighs their chosen measures or concepts using the following four scopes:

- **People** organization (bottom-up to top-down).
- **Planet** engineering impact (nature-based solutions to hardcore engineering, see also Appendix B) or sustainability goals.
- **Prosperity** financial (expensive to in-expensive) or non-monetary value impact. On the base of these three they balance out their decisions and formulate the last scope.
- **Project** the impact of spatial interventions on the quality of life and created opportunities.

The making of the scopes gives the disciplinary better insight and understanding of the set of measures or concepts they formulated and also allows them to have a foundation to connect their proposals to the proposals of the other disciplines that used the same scopes. Then the chosen measures and concepts can also be weighed in relation to measures and concepts of the other disciplines and true interaction of making decisions between the disciplines takes place.

- **Research by design** - Creating the framework of understanding with the scoping method leads to the question *what if?* Different scenarios can be designed on the basis of this. This is research by design, delivering insight in the context and options for new futures.
- **Tools** - A workshop was held in the first week of the project where visualizations were held, as well as brainstorming sessions. Furthermore, consistent gathering sessions were used to keep the boundaries between the scopes precise. These tools formed a basis for the project on which the work is based.
- **Plan** - The “plan” is used to investigate the horizontal relations between the coastal protection systems and settlements, water bodies and water defense, water bodies and land. It allows for broader analysis on a larger scale and is crucial for the critical cartography method.
- **Sections** - In the aim to understand how technological solutions impact space, the “section” is used as the main investigating tool. Sections are used to see the coastal protection projects only as the final part of a complex system. Specifically, the focus will be done on different spatial scales. Territorial sections – across the coast – are able to observe how all the layers of urbanization change along the coast. Perpendicular sections are also the preferred tool to understand the relationships between the ground line and the movements of water, including subsoil, infrastructures, and occupation.
- **Interdisciplinary design** - Interdisciplinary design is crucial for this project. As each has their own specialty, a good communication regarding scopes and boundaries is necessary in order to create an integrated system.

3. ANALYSIS & SYNTHESIS

This chapter describes the situation of the metropolitan city of Venice, the lagoon, and other relevant surroundings. In the figure below (Figure 3.1), the relevant spaces are numbered, and are explained in the associated sections. With this, the problems in the area are explained, as identified in the workshop.

3.1 ANALYSIS

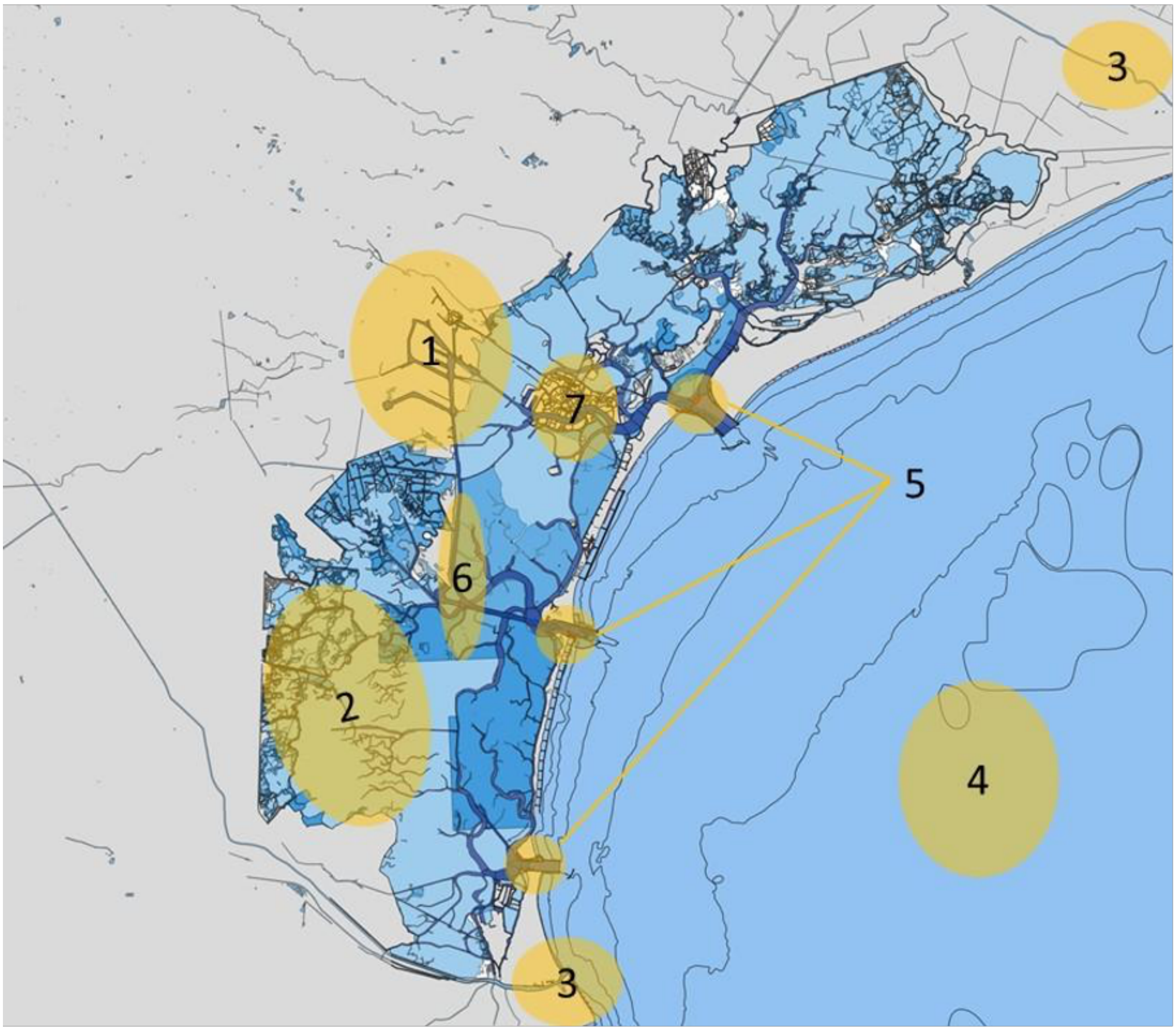


Figure 3.1: The current situation in the lagoon, see text for explanations of the numbers [1].

1: Porto Marghera The Porto Marghera has proven to be a major logistical artery, as it is the seventh largest port in Italy. However this does not come with its downsides, as it brings with it a great amount of nuisance. This is mostly in the form of pollutants, which infiltrate into the sediment. This has proven to have an effect on the ecology of the area, and in the end, public health [38].

2: Salt marshes The southern (and northern) part of the lagoon are covered by salt marshes. A. Sarretta et al. [39] describe the history and the current scenario of these salt marshes. They have degraded over 3 fold in the past century, to the 35km2 they are in the present. This is mostly due to the human interventions in the lagoon over the years. The salt marshes prove to be a great value for biodiversity of the lagoon, as well as protecting the coastline from flooding, and trapping sediment, leading to less erosion of the system [39][40].

3: Rivers Brenta and Piave The rivers Brenta and Piave are two of the twelve main rivers of the lowland watershed in North-Eastern Italy. In the early centuries, the rivers were the largest contributors to freshwater and sediment input into the Venetian lagoon. Slowly over time, this was causing too much silting of the lagoon around Venice, threatening to damage transport links. [14]. A large strategic re-channeling plan was made in the 16th and 17th century in order to deal with these sedimentation problems and others. The Brenta river was canalized southward of the lagoon and merged with the Bacchliglione river, where it eventually debouches into the Adriatic Sea. The tributaries of the Piave river were increasingly laid down by hard preconditions at the north side of the lagoon. Its main branch flows north of the lagoon into the Adriatic Sea. The rivers in their current situation can be seen by the two numbers 3 in Figure 3.1. The annual average discharges of the Brenta and Piave rivers were found to be 100 m^3s^{-1} and 125 m^3s^{-1} respectively. Both rivers suffer from salt intrusion and pollution problems.

4: Adriatic Sea The Adriatic sea provides water level forcing for the lagoon through the three inlets of the lagoon. However, due to sea level rise over the last decades, and in the decades to come, it is 'drowning' the lagoon and its salt marshes, as well as Venice itself, which experiences more high waters than ever before [29].

5: MOSE The MOSE (MOdulo Sperimentale Elettromeccanico - Experimental Electromechanical Module) project is a storm surge barrier built to save Venice from the high tides conditioned by the Adriatic sea. Scientific studies state that it may remain functional for the next 30 years due to sea level rise [30][41][42]. After this period, it will have to be closed continuously, opening questions on which lagoon of the future we may imagine and design.

6: Canal system The canal system in the lagoon has been changing during the centuries concurrently with the expanding port activities . As ships grow over the years, the canal needs to become deeper and deeper. Combined with the fact the sedimentation takes place in these canals, a big volume needs to be dredged annually [39]. This is responsible for a great deal of the sediment related degradation of the lagoon over the years.

7: Metropolitan city of Venice and islands The metropolitan city of Venice lies in the middle of the impaired lagoon. The city itself is subsiding, which reinforces the sea level rise problems in the city. Next to this, Venice is struggling with over-tourism within the historical city center.

3.2 STAKEHOLDER ANALYSIS

The Venice lagoon is a complex environment which consists of many different stakeholders. We are dealing with various different stakeholders such as those that are responsible for the implementation, those that are affected by the implementation, and statutory and regulatory bodies. This results in strongly diverging interests as they all have different backgrounds. Different resources are being used by multiple stakeholders, causing dependencies between these stakeholders. We start by identifying and elaborating on the relevant stakeholders in the Venice lagoon and its surroundings. For both the Perfect Lagoon and the Symbiotic System, a mutual set of stakeholders is being identified, including their problem perceptions about the lagoon. Consequently, a network analysis will be executed as a highly important step for understanding these complex relationships between stakeholders in the process of reaching a consensus on the design of the Venice lagoon. By executing this analysis, we can predict the behavior of the individual actors in the process and their dependencies.

3.2.1 RELEVANT STAKEHOLDERS

At first we define the relevant stakeholders in the project. We divide stakeholders into three main categories: Governmental authorities, businesses, and project-affected communities.

Governmental authorities

Governmental authorities are actors which are part of the international, national, regional or local government. These parties will operate in the interest of the public they are representing. The governmental authorities we distinguish in the Venice lagoon are:

Comune di Chioggia	The municipality of Chioggia, responsible for managing the city of Chioggia.
Comune di Padova	The municipality of Padua, responsible for managing the city of Padua.
Comune di Venezia	The municipality of Venice, responsible for managing the city of Venice.
Città Metropolitana di Venezia	Metropolitan area of Padua, Treviso and Venice, also known as PATREVE. The province of Venice was replaced by this metropolitan in 2015 [43].
Regione del Veneto	Regional government for managing the Veneto region.
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	The Superintendence of Archeology, Fine Arts and Landscape for the City of Venice and Lagoon. Organ of the Italian Ministry of Cultural Heritage and Activities and Tourism whose main action is the protection of goods of historic and architectural interest.
Ministero della transizione ecologica	Ministry of environment, responsible for the development and maintenance of projects/cases connected to water, air, energy, nature and landscape.

Comune di Chioggia	The municipality of Chioggia, responsible for managing the city of Chioggia.
Comune di Padova	The municipality of Padua, responsible for managing the city of Padua.
Ministero delle infrastrutture e della mobilità sostenibili	Ministry of sustainable infrastructures and transport, responsible for planning, financing, implementing and managing the infrastructural networks of Italy [44].
Ministero della cultura	Ministry of culture, responsible for protection and transmiss Italy's cultural heritage, activities and tourism [45].
Italian government	Central Italian government, responsible for managing and leading Italy.

Businesses

Businesses are defined as privately owned companies, aimed at producing products or providing services. Businesses operate in the interest of the owner, executive board or shareholders, with the goal to generate profit in a monetary or humanitarian sense. The businesses present in the Venice lagoon are:

AVM/Actv	Main public transport operator in the urban area of Venice and the suburban areas up to Padua, Treviso and Rovigo.
Cargo ships	Cargo shipping companies making use of the Lagoon and the Porto Marghera.
Cruise ships	Cruise ship operators making use of the Lagoon and the PortoMarghera.
Porto Marghera	Major port which is of large economical significance for the city of Venice and the hinterland.
Giovanni Nicelli Airport	Airport located in the lagoon on the island of Lido, mainly used for private flights.
Marco Polo Airport	Largest airport in the vicinity of Venice that is largely used by commercial airlines to transport tourists in order to visit Venice.
Treviso Airport	Small airport nearby the city of Treviso, also used by commercial airlines to transport tourists in order to visit Venice.

Project-affected communities

Project-affected communities are collected groups of people which have a common interest or goal. The project will have a positive or negative impact on the way of living of these communities, therefore they will be included in the stakeholders. We identify the following project-affected communities:

Farmers	People making their living by working at farms in the lagoon.
Fishermen	People making their living by fishing in the lagoon.
Hunters	People making their living by hunting in the lagoon.
OTS Laguna di Venezia	Association of Sustainable Tourism Operators of the Venice Lagoon, organization for developing and promoting sustainable tourism in the Venice Lagoon.
Residents of Venice	People living and working in the city of Venice.
Tourists	Tourists visiting the historical city of Venice and its lagoon.

Network analysis

The aforementioned actors have their own interests, goals and issues, resulting in a network within this project. By executing a network analysis, we identify and map out the individual interests, goals and issues of each stakeholder. This generates an understanding of the underlying relations between the stakeholders. We start by identifying the interests and goals of each stakeholder, followed by defining the issues and the creation of a stakeholder-issue diagram. Subsequently, a power/interest matrix is being produced, resulting in a power and resource dependency. Ultimately, a stakeholder map will be set up.

INTERESTS AND GOALS

We indicate a general interest and goal for each stakeholder in Table 3.1 below. This particular information of each stakeholder will help us to develop a clearer view of the expected attitudes and possible strategic behavior throughout the project.

Table 3.1: Interests and goals of stakeholders.

Stakeholder	Interest	Goal
Comune di Chioggia	Managing the area within the municipality of Chioggia	Improved prosperity of the municipality of Chioggia
Comune di Padova	Managing the area within the municipality of Padova	Improved prosperity of the municipality of Padova
Comune di Venezia	Managing the area within the municipality of Venezia	Improved prosperity of the municipality of Venezia
Città Metropolitana di Venezia	Improving the prosperity of the metropolitan area of Venice	Improved prosperity of the metropolitan area of Venice
Regione del Veneto	Improving the prosperity of the Veneto region and maintaining cultural and natural heritage sites	Improved prosperity of the Veneto region whilst cultural and natural heritage sites remain healthy

Soprintendenza Archeologia	Promote and preserve the artistic and landscape heritage of particular interes	Protection of goods of historic and architectural interest
Ministero della transizione ecologica	Stimulating ecology	Improved ecology in the Venice Lagoon
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Managing the water, sea and the environment in Italy	Protecting the Italian residents from the water and other environmental impacts
Ministero delle infrastrutture e della mobilità sostenibili	Managing infrastructure and transport related projects in Italy	Constructing sustainable infrastructure connections which contribute to the mobility in Italy
Ministero della cultura	Managing and protecting cultural heritage, activities and stimulating tourism in Italy	Improved protection and sustainable exploitation of cultural heritage
Italian Government	Improving the prosperity of Italy in general and achieving the UN Sustainable Development Goals	Improved prosperity and the achievement of the UN SDG's
AVM/Actv	Generating profits by providing public transport in the Venice region	Increased revenues generated from public transport
Cargo ships	Using the Porto Marghera to deliver cargo	Generating profits from transporting cargo
Cruise ships	Using the Porto Marghera to guide tourists to Venice	Generating profits from providing holiday tours to tourists
Porto Marghera	Generating profits	Increased capacity of the port and improved connection with the hinterland
Nicelli Airport	Generating profits	Increased revenues from flights
Marco Polo Airport	Generating profits	Increased revenues from flights
Treviso Airport	Generating profits	Increased revenues from flights
Farmers	Grounds available for farming	Continuing farming activities in the Venice lagoon and neighboring areas
Fishermen	Waters available for fishing	Continuing fishing activities in the Venice lagoon
Hunters	Grounds available for hunting	Continuing hunting activities
OTS Laguna di Venezia	Stimulating sustainable tourism in the Venice Lagoon	Developing a strategic plan for the development of sustainable tourism in the Venice Lagoon
Residents of Venice	Living in Venice	Living in Venice increasing livability
Tourists	Visiting the historical center of Venice (and the lagoon to a lesser extent)	Enjoying their stay in Venice

Stakeholder-issue diagram

In this subsection we will map out which stakeholders are related to what issues. It is crucial to understand what issue is important to whom and which issues are shared with other stakeholders. Based on the issues the different stakeholders are dealing with, we can predict its role in the process of the project. In Table 3.2 we have listed the primary issue of each individual stakeholder.

Table 3.2: Issues per stakeholder.

Stakeholder	**Issues**
Comune di Chioggia	Adaptions made to the lagoon may encounter resistance
Comune di Padova	Adaptions made to the lagoon may encounter resistance
Comune di Venezia	Protection of the city causes view obstruction
Città Metropolitana di Venezia	Generating finances
Regione del Veneto	Generating finances
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	Generating finances
Ministero della transizione ecologica	Generating finances
Ministero dell'Ambiente e della Tutela del Territorio e delMare	Generating finances
Ministero delle infrastrutture e della mobilità sostenibili	Generating finances
Ministero della cultura	Generating finances
Italian Government	Generating finances
AVM/Actv	Protection of the city and its lagoon may cause limitations for public transport
Cargo ships	New routes to the port and mainland
Cruise ships	New routes to the port and mainland
Porto Marghera	Reduced harbor activities and restricted expansion possibilities
Giovanni Nicelli Airport	Reduced number of flights and restricted expansion possibilities
Marco Polo Airport	Reduced number of flights and restricted expansion possibilities
Treviso Airport	Reduced number of flights and restricted expansion possibilities
Farmers	Reduced or limited exploitation of the lagoon

Fishermen	Reduced or limited exploitation of the lagoon
Hunters	Reduced or limited exploitation of the lagoon
OTS Laguna di Venezia	The current high number of tourists should be decreased in order to successfully develop sustainable tourism
Residents of Venice	Protection of the city causes view obstruction
Tourists	Protection of the city may challenge tourists

The primary issue of each stakeholder is known. However, every stakeholder can face other issues as well. Based on the table above, we are able to assign multiple issues to stakeholders. This resulted in a stakeholder-issue diagram, see Figure 3.2. This diagram provides us with a visual representation of the interrelations between issues and different stakeholders and shows the complexity of the project.

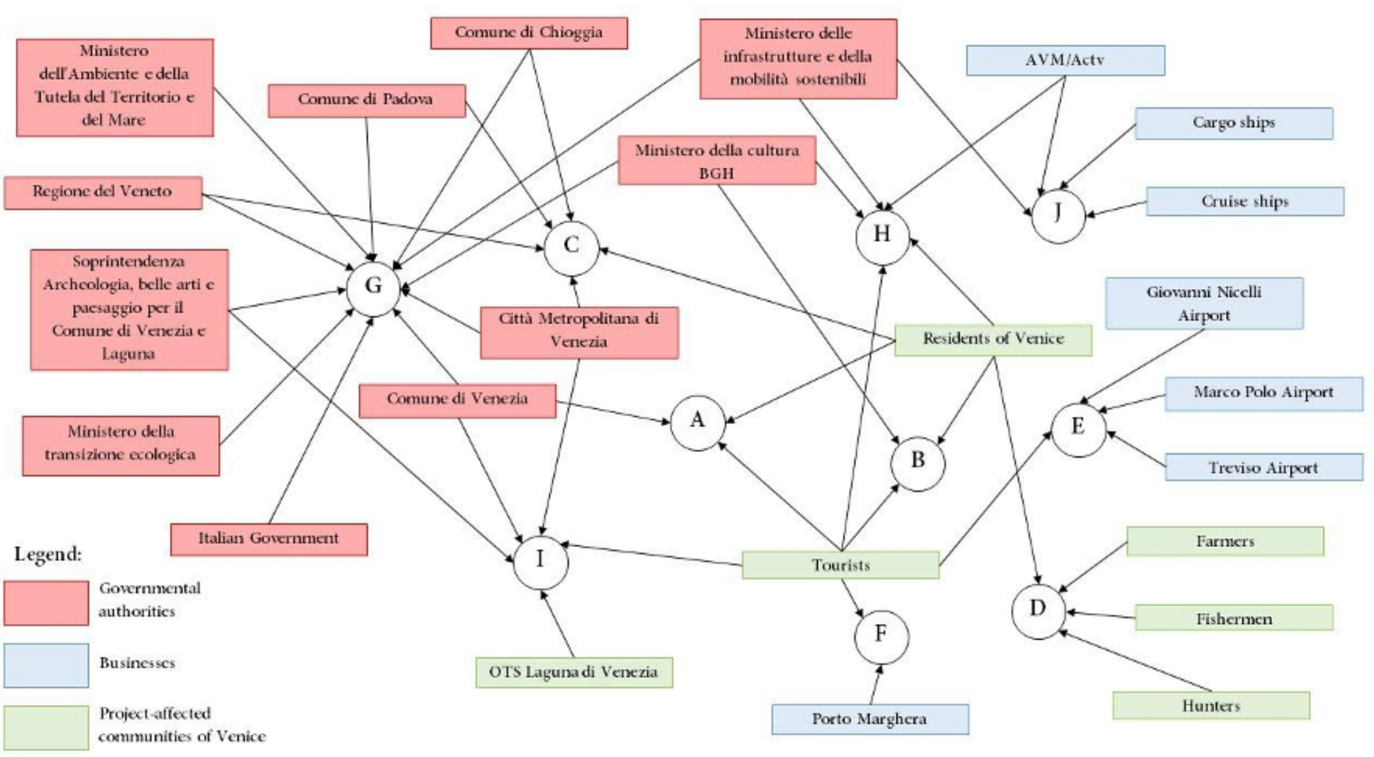


Figure 3.2: Stakeholder-issue diagram.

Table 3.3: Issue definition stakeholder-issue diagram.

Issue	Issue description
A	Protection of the city causes view obstruction
B	Protection of the city may challenge tourists in visiting the city
C	Adaptions made to the lagoon may encounter resistance
D	Reduced or limited exploitation of the lagoon
E	Reduced number of flights and restricted expansion possibilities
F	Reduced harbor activities and restricted expansion possibilities
G	Generating finances (for making adaptations to the lagoon)
H	Protection of the city and its lagoon may cause limitations for public transport
I	The current high number of tourists should be decreased in order to successfully develop sustainable tourism
J	New routes to the port and mainland

3.2.2 POWER-INTEREST MATRIX

To better understand the classification of the different stakeholders, we create a power-interest matrix. Johnson *et al*. [46] developed this power-interest matrix in order to examine the level of interest each stakeholder has in meeting their expectations on decisions about the project, together with the amount of power they can enforce. The stakeholders are divided over four quadrants in the power-interest matrix. The four quadrants in the matrix represent four main classifications of stakeholders. For each classification, a predetermined strategy can be defined and tailored further to smoothen the interaction between the stakeholders in the project. The main types of stakeholders are: Subjects - Players - Crowd - Context setters.

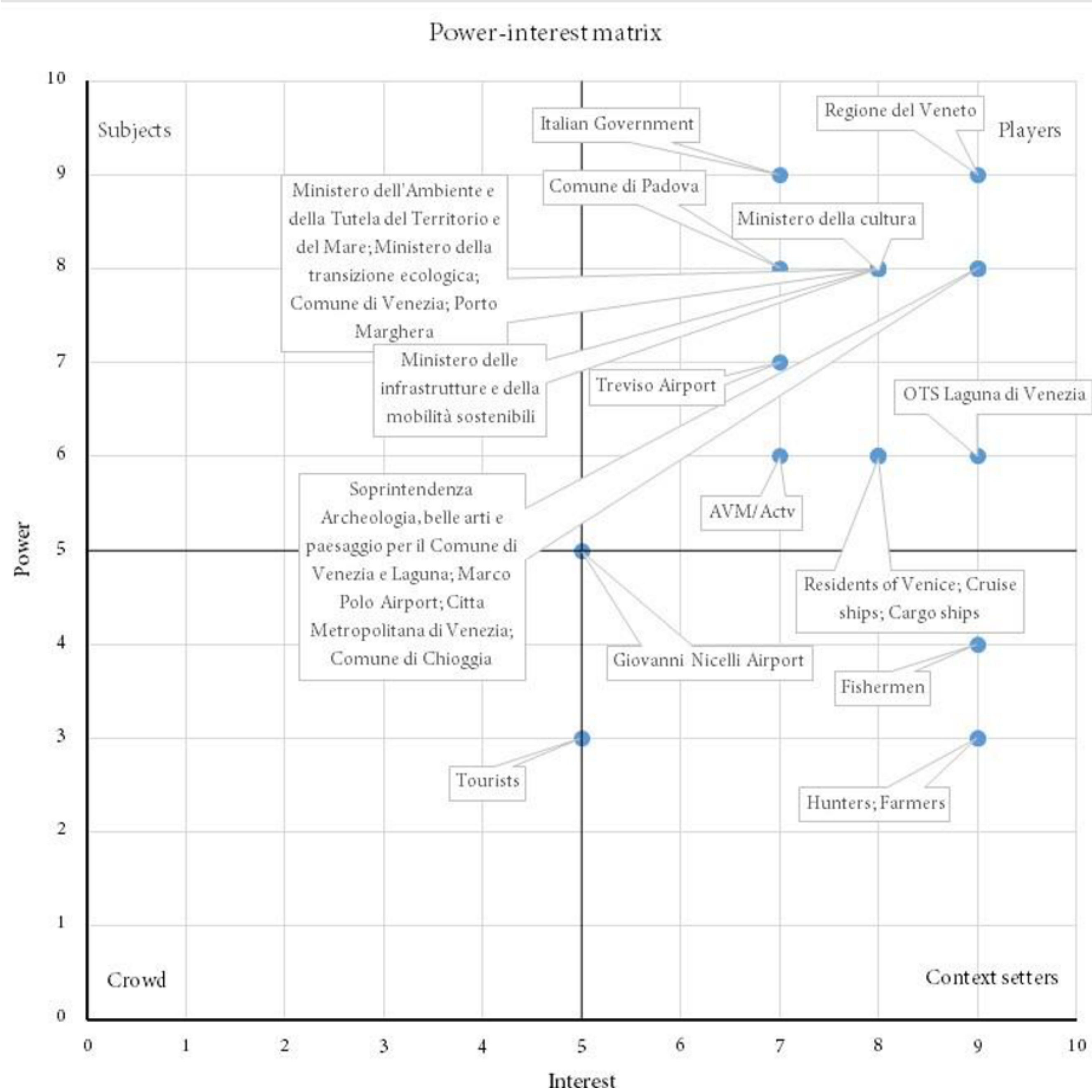


Figure 3.3: Power-interest matrix.

Power and resource dependency

Understanding the interdependencies and defining the powers of the stakeholders is crucial in determining the relations between actors. We determine the power and resource dependency of each stakeholder. For power we distinguish production and blocking power. Production power is the ability to constructively and actively contribute to the process and the project. Blocking power is the opposite of production power and defines the ability to hamper the process in reaching project results. The dependency of each stakeholder defines the dependency of other stakeholders on the owners of the resource.

Table 3.4: Power and resource dependency of stakeholders.

Stakeholder	Power type	Resources	Dependency
Comune di Chioggia	Production	Legislative or statutory	High
Comune di Padova	Production	Legislative or statutory	High
Comune di Venezia	Production	Legislative or statutory	High
Città Metropolitana di Venezia	Production	Legislative or statutory	High
Regione del Veneto	Production	Legislative or statutory	High
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	Production	Legislative or statutory	High
Ministero della transizione ecologica	Production	Legislative or statutory	High
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Production	Legislative or statutory	High
Ministero delle infrastrutture e della mobilità sostenibili	Production	Legislative or statutory	High
Ministero della cultura	Production	Legislative or statutory	High
Italian Government	Production	Legislative or statutory	High
AVM/Actv	Blocking	Public transport	Moderate
Cargo ships	Blocking	Money/Distribution	Moderate
Cruise ships	Blocking	Money	Low
Porto Marghera	Blocking	Money/Distribution	High
Giovanni Nicelli Airport	Blocking	Transport/Money	Low
Marco Polo Airport	Blocking	Transport/Money	High
Treviso Airport	Blocking	Transport/Money	Moderate
Farmers	Blocking	Political support	Moderate
Fishermen	Blocking	Political support	Moderate
Hunters	Blocking	Political support	Moderate
OTS Laguna di Venezia	Blocking	Political support/ Media	Moderate
Residents of Venice	Blocking	Political support	High
Tourists	Blocking	Money	High

Critical stakeholders

The previous subparagraphs provide us with the necessary information to assess and determine the critical stakeholders in the project. Table 3.5 shows the replaceability and dependency of each stakeholder. The replaceability assesses if the stakeholder can easily be replaced by another stakeholder. The dependency evaluates whether other stakeholders are dependent on the resources one produces.

Table 3.5: Critical stakeholders.

Stakeholder	Replaceability (High/low)	Dependency (High/moderate/low)	Critical?
Comune di Chioggia	Low	High	Yes
Comune di Padova	Low	High	Yes
Comune di Venezia	Low	High	Yes
Città Metropolitana di Venezia	Low	High	Yes
Regione del Veneto	Low	High	Yes
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	Low	High	Yes
Ministero della transizione ecologica	Low	High	Yes
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Low	High	Yes
Ministero delle infrastrutture e della mobilità sostenibili	Low	High	Yes
Ministero della cultura	Low	High	Yes
Italian Government	Low	High	Yes
AVM/Actv	High	Moderate	No
Cargo ships	High	Moderate	No
Cruise ships	High	Low	No
Porto Marghera	Low	High	Yes
Giovanni Nicelli Airport	High	Low	No
Marco Polo Airport	Low	High	Yes
Treviso Airport	High	Moderate	No
Farmers	Low	Moderate	No
Fishermen	Low	Moderate	No
Hunters	Low	Moderate	No

OTS Laguna di Venezia	Low	Moderate	Yes
Residents of Venice	Low	High	Yes
Tourists	Low	High	Yes

3.2.3 DEFINING STAKEHOLDER STRATEGY

Based on the stakeholders and their roles in the project, we are able to define a strategy. However, the definitive roles of the stakeholders are dependent on the designs. Stakeholders may have different attitudes towards different designs. Therefore we will further define the roles of the stakeholders for each design in Subsection 5.1.4 and Subsection 5.2.4. The individual stakeholders are identified by using a more advanced typology developed by Murray-Webster and Simon [47]. This is called the three dimensional stakeholder analysis and incorporates eight roles stakeholders can be in the project, see Figure 3.4 The typology provides us with an even more targeted strategy towards the stakeholders.
Knowing per design the type of stakeholders present provides us with the information about expected behavior in the project and process. Combined with the knowledge of the critical stakeholders we can predict problems or opportunities. Ultimately, specific strategy per stakeholder per project can be determined, which enables us to steer the stakeholders in any desirable direction thus ensuring project success.

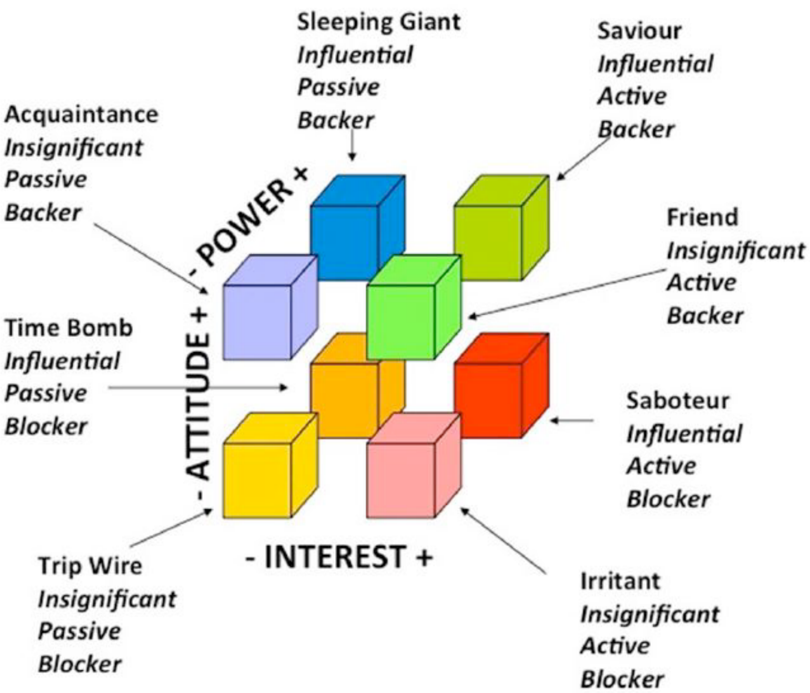


Figure 3.4: 3D stakeholder analysis.

4. VISIONS

How to deal with and intervene in nature in order to cope with anthropogenic changes to the earth, such as climate change, is maybe the greatest challenge that both the profession of architecture and civil engineering have to face in the decades to come. This fundamental question also informs the two proposals regarding the transformation of the Venetian lagoon. With one leaning more towards controlling natural processes and the other more towards enabling them, they both present radical ideas on how to deal with landscape and the urban environment in the future.
An issue within the scope of civil engineering and architectural projects may be the balance between the two disciplines, on the one side the need of maintaining the lagoon as it is today, on the other side letting the the lagoon change in order to cope better with the climate change scenarios which we are going to be facing in the nearby future.
This chapter lays down the visions and accompanying challenges behind these ideas, which were formed by two groups in the workshop.

4.1 VISION 1 – THE PERFECT LAGOON

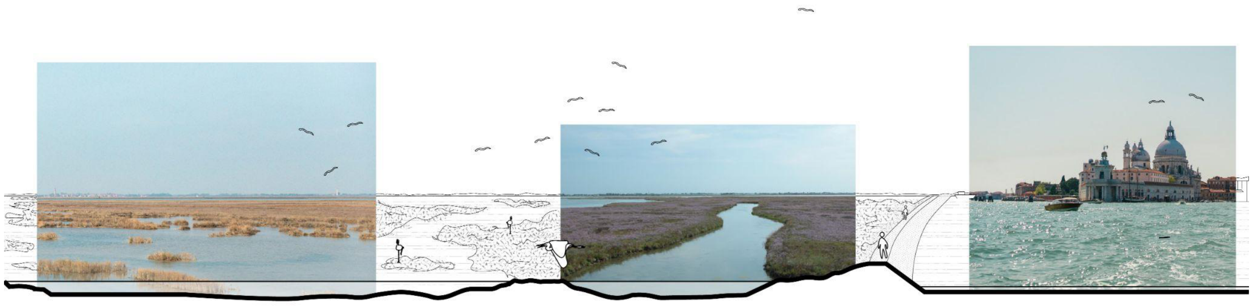


Figure 4.1: Vision diagram The Perfect Lagoon.

Intervening in the lagoon for human benefit has a long standing tradition in Venice. For centuries Venetians have tried to alter the lagoon to their benefit. However, over the last decades the intent and emphasis of this transformation process have shifted. Up until the 19th century Venetians and the state of Venice focussed on actively preserving the lagoon as the shallow waters around them granted them safety and prosperity. In the wake of industrialization however the attributes of the lagoon came to be viewed as an obstacle rather than a benefit to Venice. Economic and infrastructural interests started to tip the scale on the fragile balance of the lagoon knowingly, by for example dredging lagoon inlets to allow for the passing of bigger ships, and unknowingly, by allowing motorboats in the lagoon that destroy both the building fabric of Venice as well as the barene around it or by employing aquifers, which amplify ground subsidence in the lagoon. This resulted in the ongoing destruction of a unique ecosystem in which natural processes were narrowly intertwined with human intervention in order to preserve the transformational state of a landscape into a permanent one. While some efforts have been made to preserve and restore the lagoon, no far-reaching process, neither in planning nor actual projects, has been made as of today.

However in order to not only reverse these local processes, but also tackle global challenges such as sea level rise and biodiversity loss, the state of the lagoon needs to be addressed more urgently than ever. The first vision aims to do that by introducing the concept of the Perfect Lagoon: a return to, but also reinterpretation of the past landscape around Venice, where landscape development takes center stage as a means to adapt to and mitigate the negative impact of anthropogenic development through all scales. This vision embodies a paradigm shift from a world where we constantly fight and work against nature, to one where we live *with* and work *with* nature. Even more so a world where the needs of nature take precedence over human needs, which allows for the reprioritization of human needs over a longer time frame.

This idea is narrowly intertwined with the belief that "Venice is the lagoon and the lagoon is Venice", which is another one of the key principles behind this vision. If we want to save Venice, we must save the lagoon. Only a healthy lagoon can reverse or mitigate the processes that have negatively impacted the city over the past decades such as erosion, ground subsidence and sea level rise.

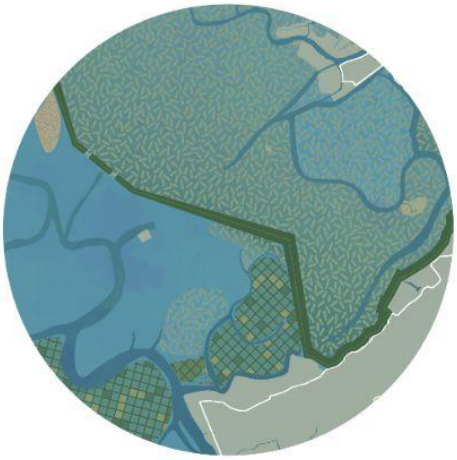
In order to tackle these issues, but also issues that primarily affect the lagoon such as the loss of wildlife that has been greatly diminished in number and diversity, a building-with-nature approach is employed.

However, while the whole philosophy of the Perfect Lagoon and the building-with-nature approach are narrowly interlinked with a past image of the lagoon, the vision is not aimed at faithful recreation of a bygone reality. In line with the idea, *we must change to preserve*, the building-with-nature approach is rather used to understand the inner workings and processes of the past landscape in order to harness their potential in tackling present and future challenges. The goal is to create a lagoon of the 21st century that borrows tactics and images from the past, insofar they are helpful to the future, to creating a resilient, biodiverse, and multi-faceted lagoon. In this way, the lagoon cannot merely redevelop its past form, but it can even eventually exceed it.

With Venice being undoubtedly one of the most famous and iconic cities in the world, we hope this vision will act as an example for other delta regions in the world. *We must change to preserve*. We must redefine what landscape and urban preservation means in the wake of climate change, and we must include political and societal stakeholders in this process in order to gain widespread acceptance of our far-reaching ideas.

Figure 4.2: Impression of The Perfect Lagoon looking over the salt marshes onto the dike and the historic city of Venice.

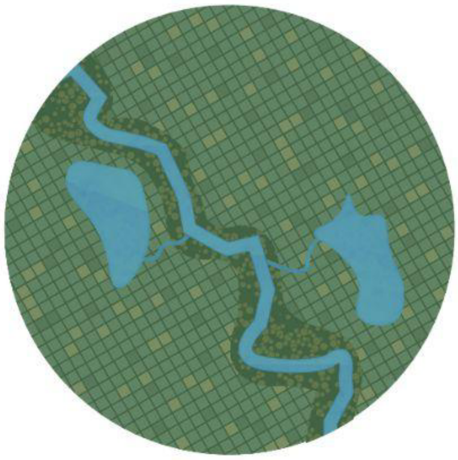
Figure 4.3: Overview map perfect lagoon depicting most important interventions.



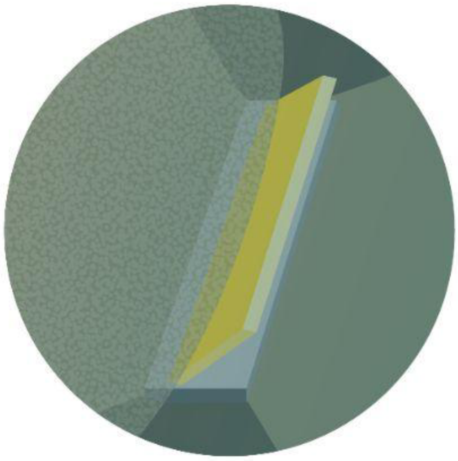
1. Wide green dike enables new saltmarshes to grow

2. New salt marshes in natural lagoon

3. New freshwater supply from rivers and reservoirs



4. Reestablish floodplains and add water reservoirs in the hinterland



5. Mose functions as weir to keep sediment balance in check

6. Industrial areas transformed into agriculture, parks and space for green industry

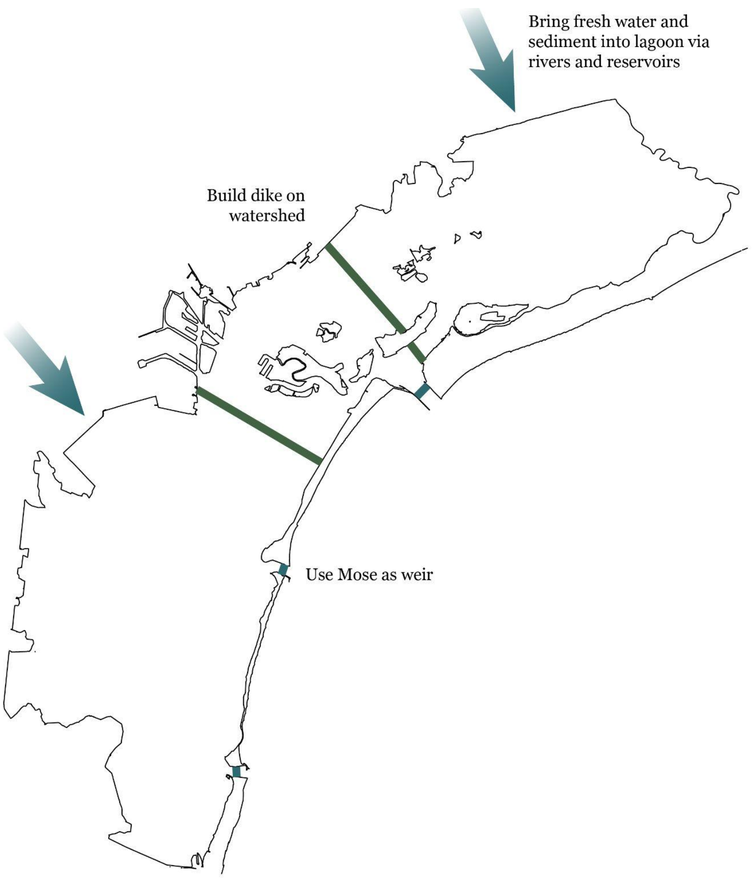
Figure 4.4: Overview map perfect lagoon depicting most important interventions.

4.1.1 THE PERFECT LAGOON

This chapter goes into depth on the spatial and systemic consequences of our vision of the Perfect Lagoon. In our vision the lagoon is divided in three parts by a dike. See Figure 4.5. This is done to protect the central, more urban part of the lagoon from sea level rise, while leaving the more natural Northern and Southern part of the lagoon exposed to the sea. This is necessary to preserve and enhance the characteristic landscape of the lagoon, the *barena* or salt marsh, and harness its potential for flood protection and nature development. The dike that protects the city of Venice aids as a catalysator for this salt marsh development, as well as the central space for recreation and agriculture within the lagoon.

While the overall emphasis of the Perfect Lagoon lays on nature development as a primary goal, the further detailing of the plan also suggests three strategies to allow for human development within this, mostly located in and around the dike: allocate spaces for nature-inclusive farming and fishing *(productive lagoon)*, establish spaces for slow tourism/green recreation and nature education *(livable lagoon)* and create a self sufficient drinking water system as well as swim water quality in the lagoon *(cleansing lagoon)*.

This section will go deeper into how this spatial vision can be achieved and what factors are deemed crucial for the flourishing of The Perfect Lagoon.



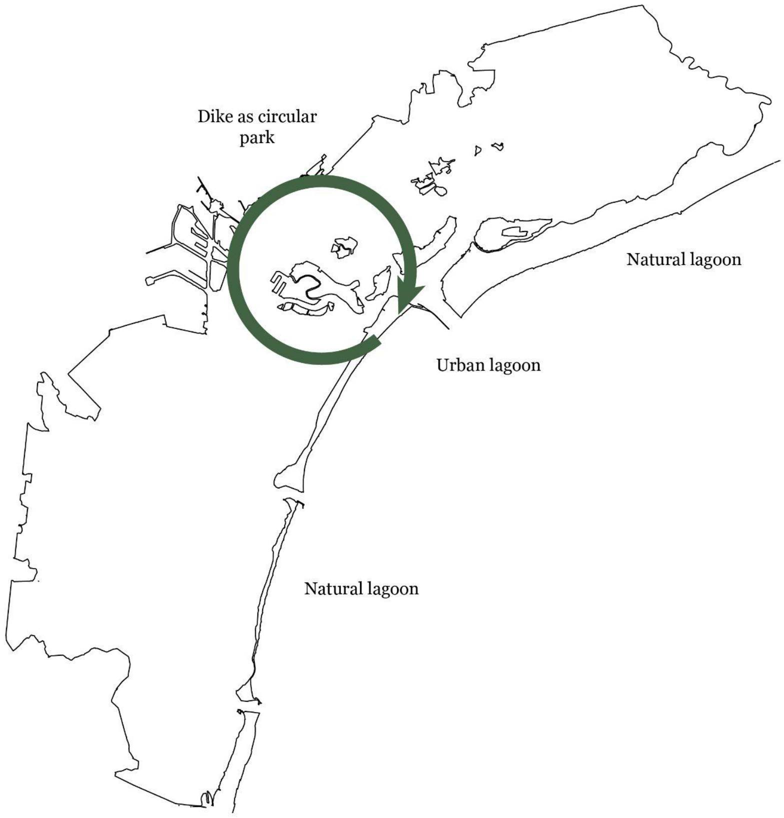


Figure 4.5: Concept water system, concept landscape. Diagram of core concepts of the perfect lagoon focused on sustainable water and landscape systems as well as flood safety.

SALT MARSHES

Figure 4.6: Photo of the salt Marshes near Lio Piccolo part of the Venice lagoon.

A key concept of the Perfect lagoon is the preservation of the current salt marshes and the establishment of new salt marshes in the Northern and Southern part of the lagoon over time. This is made possible by their inherent resilience. Salt marshes consist of a lower zone which is flooded daily by the tides as well as a higher zone that gets flooded regularly. Specific salt-tolerant plants grow on these systems. These plants trap sand (comparable to beach grass on dunes), which essentially means that the barene can grow with sea level rise and restore itself over and over again insofar there is enough sediment in the lagoon. Which in turn enables them to fulfill three main functions within the future lagoon.

The salt marshes in the lagoon are a unique and diverse habitat due to the presence of the brackish water and the unparalleled size of the lagoon. Specifically, waterfowl find their habitat in this specific marshland. By letting the salt marshes grow and excluding humans from them for the most part, they can become biodiverse paradises for animals and plants.

They can further aid in protecting the lagoon from hard waves and flooding due to their morphological qualities and are as such an integral part of the flood defense system. Plants on the salt marshes lastly also aid in cleaning the lagoon by removing toxins from the water.

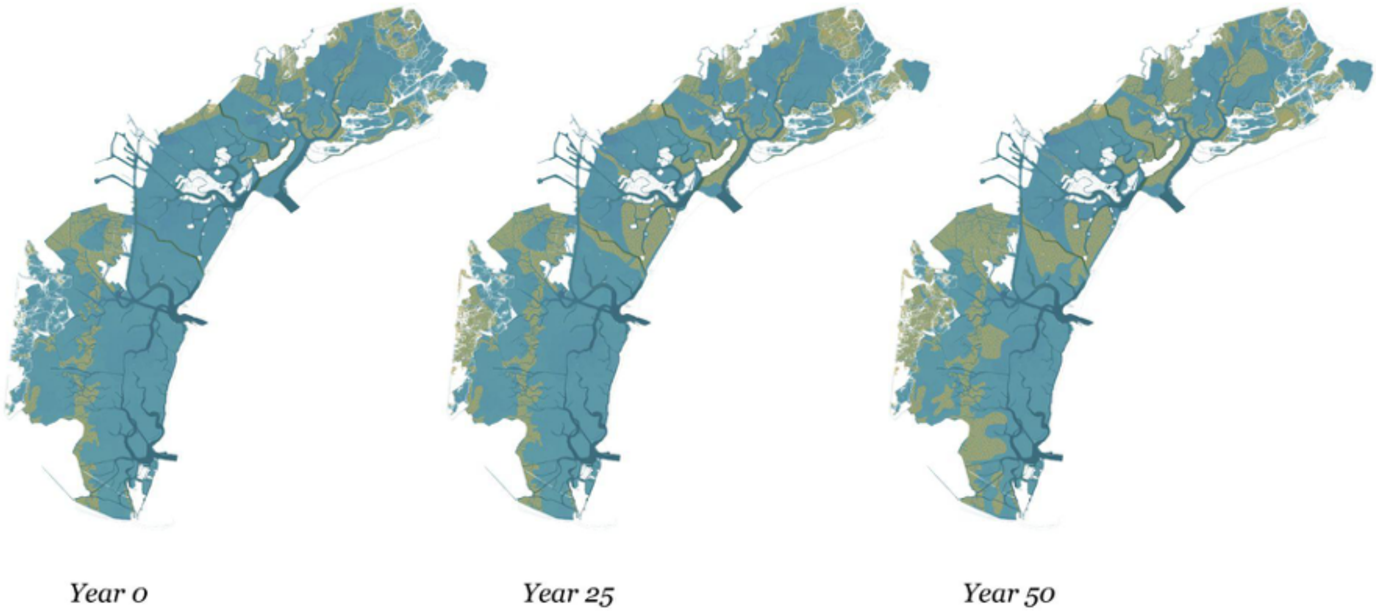


Figure 4.7: Scheme for regeneration of salt marshes over the first 50 years.

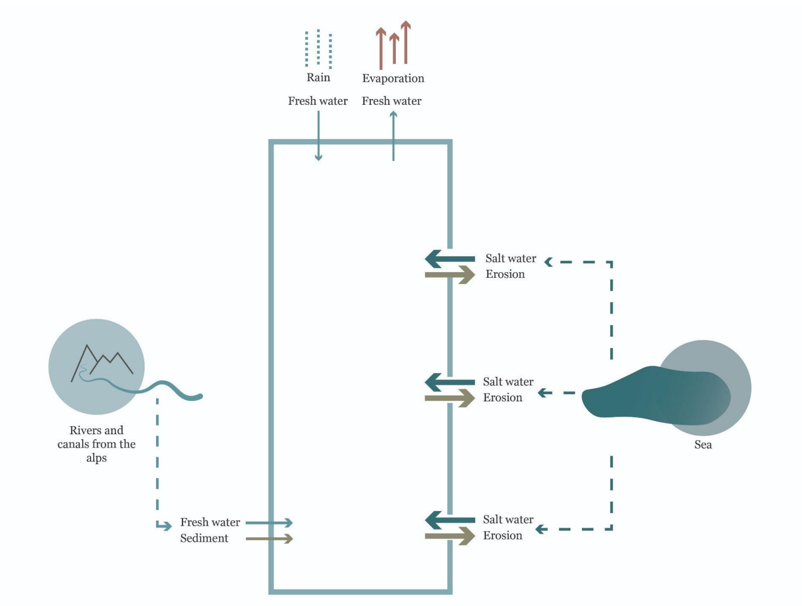
REMOVING THE PORT

Removing Porto Marghera out of the Venetian Lagoon has a lot of benefits for the envisioned Perfect Lagoon. First, the pollution caused by the port and the incoming ships is put to a halt. In addition, the ship produced waves which weather away the salt marshes and slowly destroy the building fabric of Venice. Furthermore, ship noise pollution scares away wildlife. Lastly, a lot of dredging is done to preserve the main channels, which further contributes to the erosion taking place in the lagoon. By removing the port from its current location, this dredging is no longer necessary, reducing erosion in the lagoon.

The trade port will still be of great importance to the city of Venice. A new location for the port will need to be found to, this will be explored in Section 5.1. The old port can at the same time be reused as a center for high-tech food protection in the region, reducing the need to farm in the lagoon.

RESTORING SEDIMENT AND FRESHWATER BALANCE

As explained in Chapter 1, the lagoon faces a freshwater shortage, as well as a sediment shortage. In order to restore a sediment and freshwater balance multiple measures are envisioned: strengthening the connection between the rivers in the hinterland of Veneto with the lagoon, repurposing Mose as a submerged weir, as well supplementing additional fresh water to the lagoon with the help of rain and river fed water storage ponds and by once again harvesting salt in the lagoon. The two most important features, reconnecting the rivers and repurposing MOSE, are explained in greater detail below.



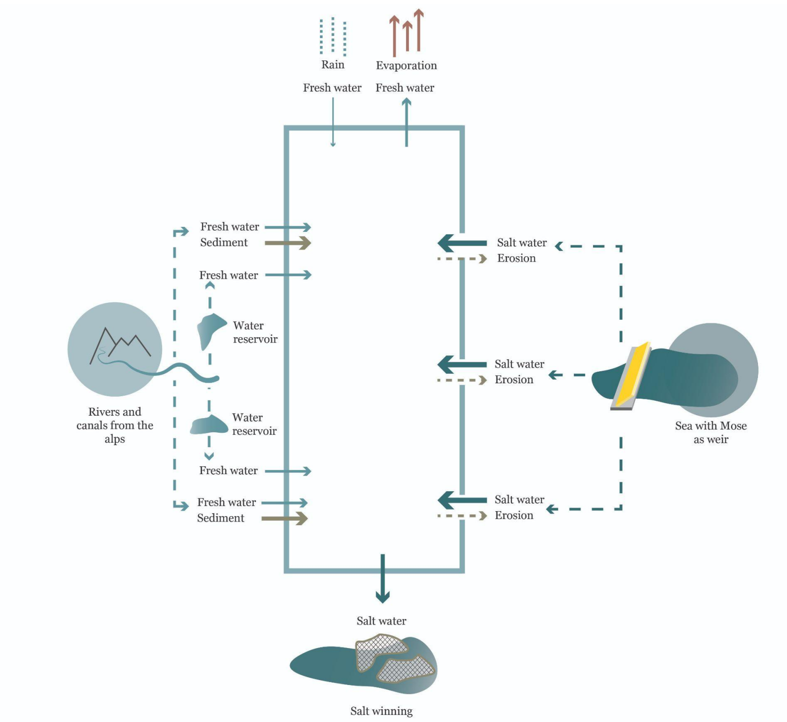


Figure 4.8: Conceptual before and after diagram restoration sediment and freshwater balance.

Reconnecting rivers

Reconnecting the Brenta and Piave rivers into the lagoon will be an essential piece of the puzzle on how to reduce erosion in the lagoon. The additional sediment supplied by the rivers will help balance the current negative sediment budget and by that help in establishing new salt marshes. It is assumed that the sediment plume at the river mouths will be spread further by wind waves and the inner flow. Another important contribution of this concept will be the (extra) supply of freshwater to the lagoon. The combination of fresh, brackish and salt water is essential for the creation of a unique and thriving ecosystem and for the formation of salt marshes.

As described in Section 3.1, the Brenta river was canalized around the southside of the Venetian lagoon during the 16th century. To hold on to the vision of the Perfect Lagoon, a new braided river with natural features is visioned. Its debouching location will be in the Southern part of the lagoon.

The river Piave will also be redirected into the lagoon. The river flow will be diverted near San Donà di Piave and finally debouch into the Northern part of the lagoon. Here it will cross agricultural areas and meet with other channels like the river Sile. See Figure 4.9 for an implementation of the river system of the Perfect Lagoon.

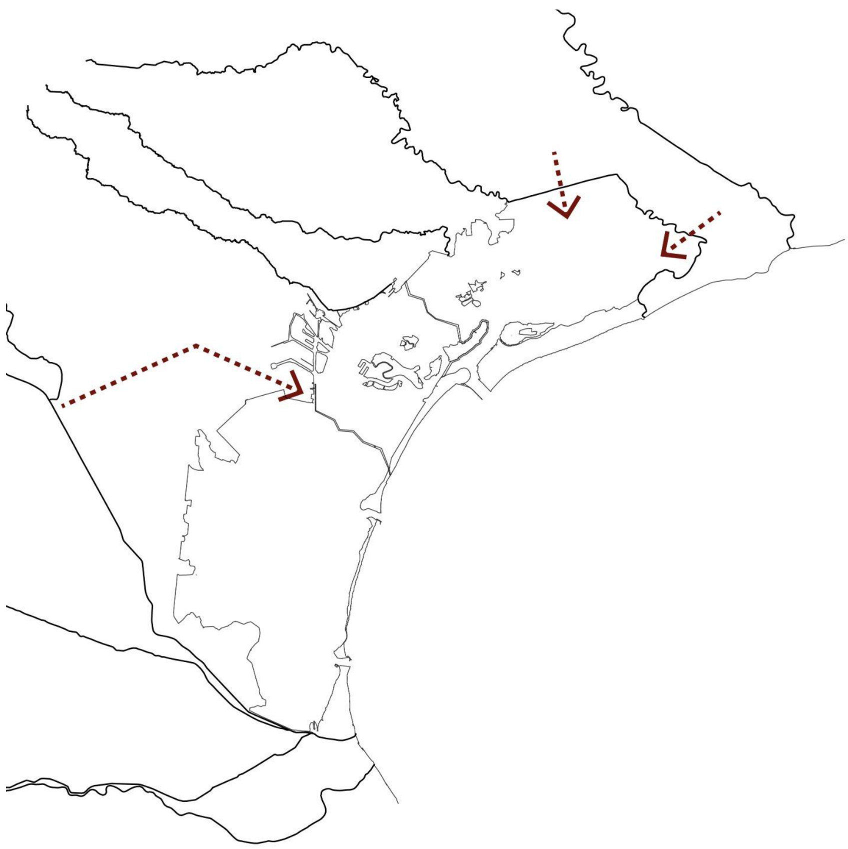


Figure 4.9: Implementation of the new meandering Brenta river and the possible debouching location of the Piave river. The Brenta will flow into the lagoon just below the southern wide green dike where it will develop its own delta. The Piave river can be combined with the Sile river o flow into the northern part of the lagoon.

Mose

In the case of the Perfect Lagoon, the city of Venice will be protected by a dike, and occasional flooding of the lagoon will be allowed. This leaves MOSE without purpose as a storm surge barrier. It will furthermore lose its function as a protection system due to sea level rise [41]. However, MOSE can be repurposed in the Perfect Lagoon and aid in controlling sediment flow as a submerged weir.

DIKE: LOCATION AND FUNCTION

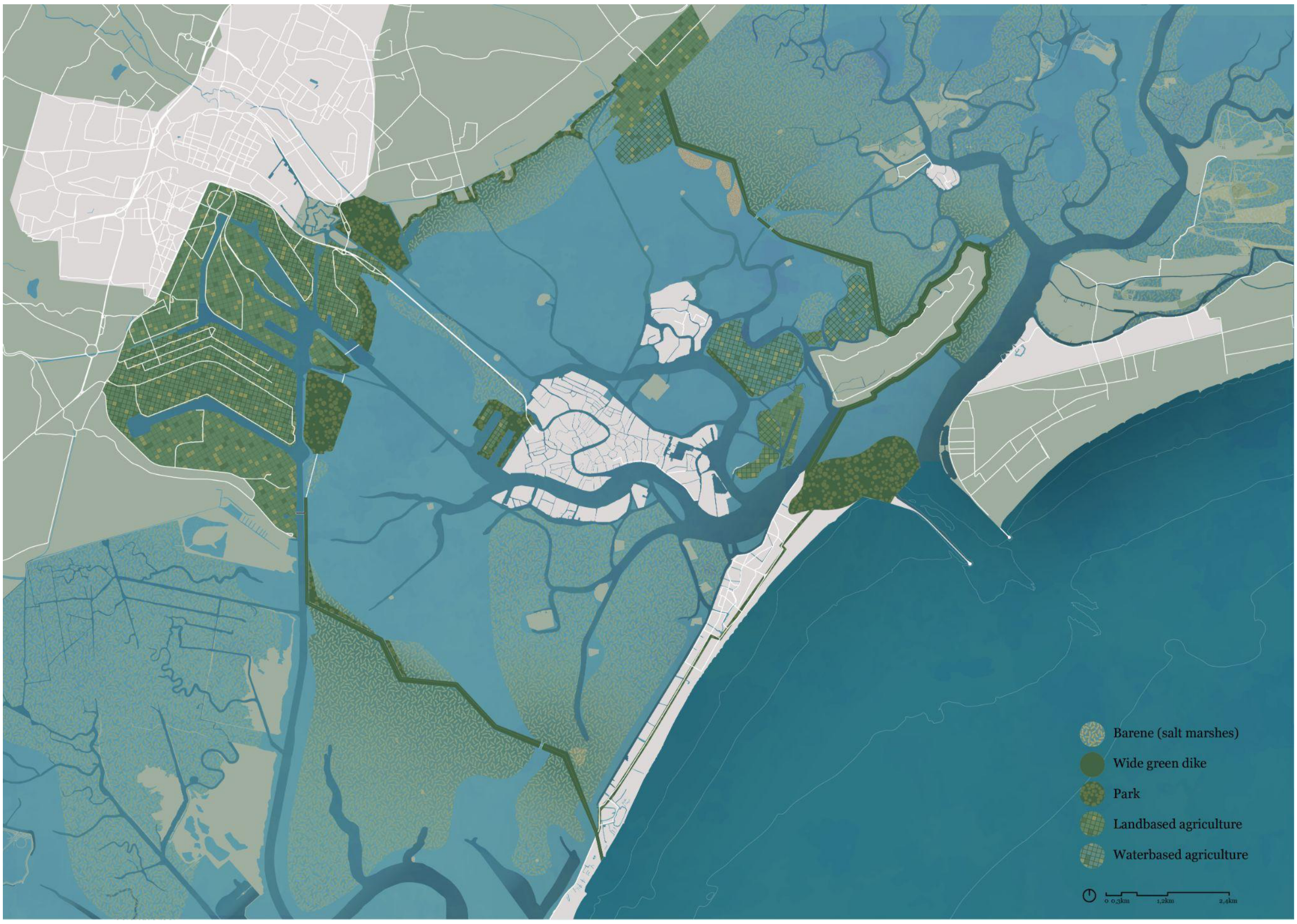


Figure 4.10: Plan drawing depicting position and function of the wide green dike around Venice.

Function

The primary function of the new dike is to protect Venice from sea level rise and flooding. However, the potential of this new infrastructure is far greater than just the establishment of a new water barrier. Since the dike functions as a threshold between the central part of the lagoon and the Northern and Southern part of the lagoon it can react to and facilitate developments and needs in all three parts of the lagoon.

As salt marsh development is considered a key factor in the establishment of the Perfect Lagoon, the aim is to have the outside of the dike act as a catalysator for salt marsh development by essentially becoming a salt marsh itself. In order to achieve that the dike is gently sloped towards the Northern and Southern part of the lagoon and planted with salt resistant plants enabling a sediment trapping mechanism that will enable the growth and development of the barene on the outer perimeter of the dike.

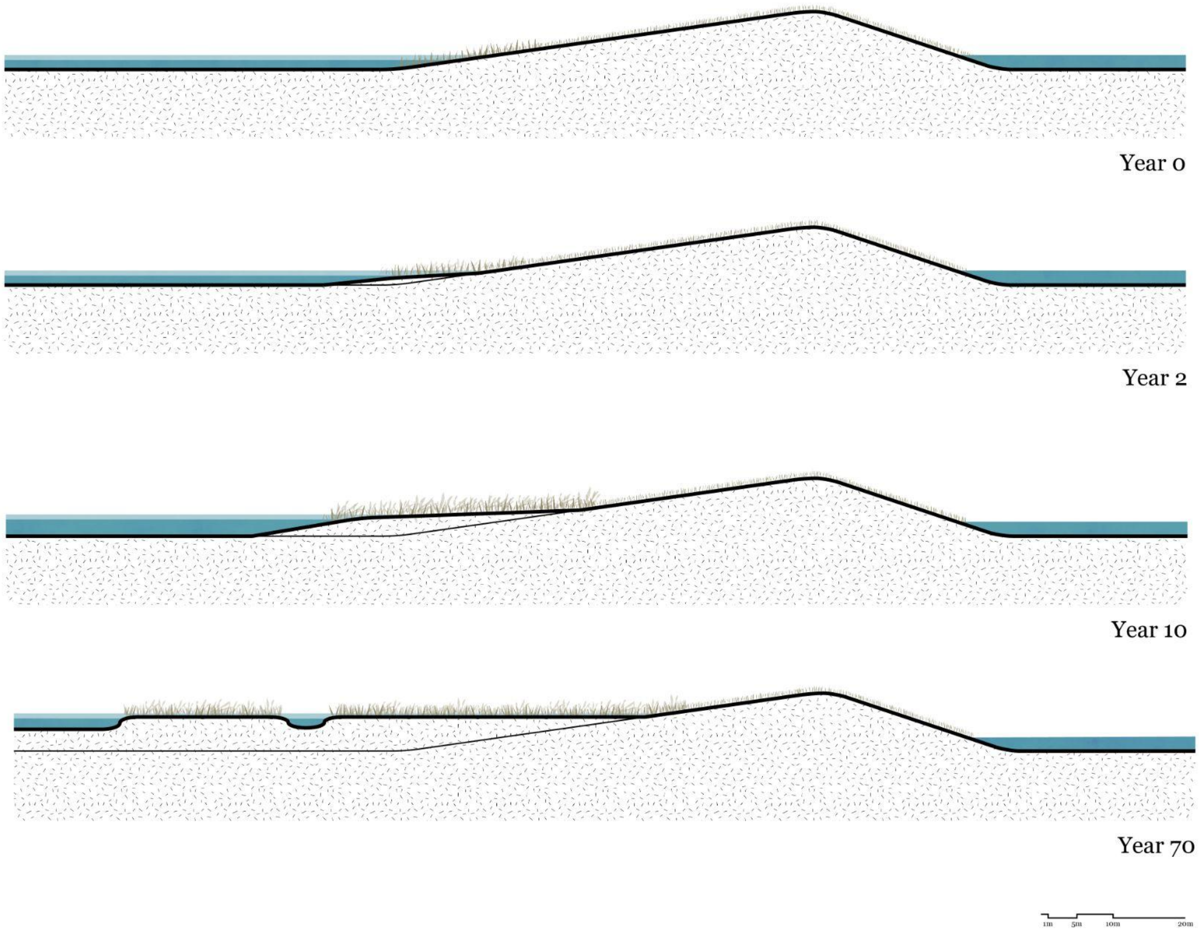


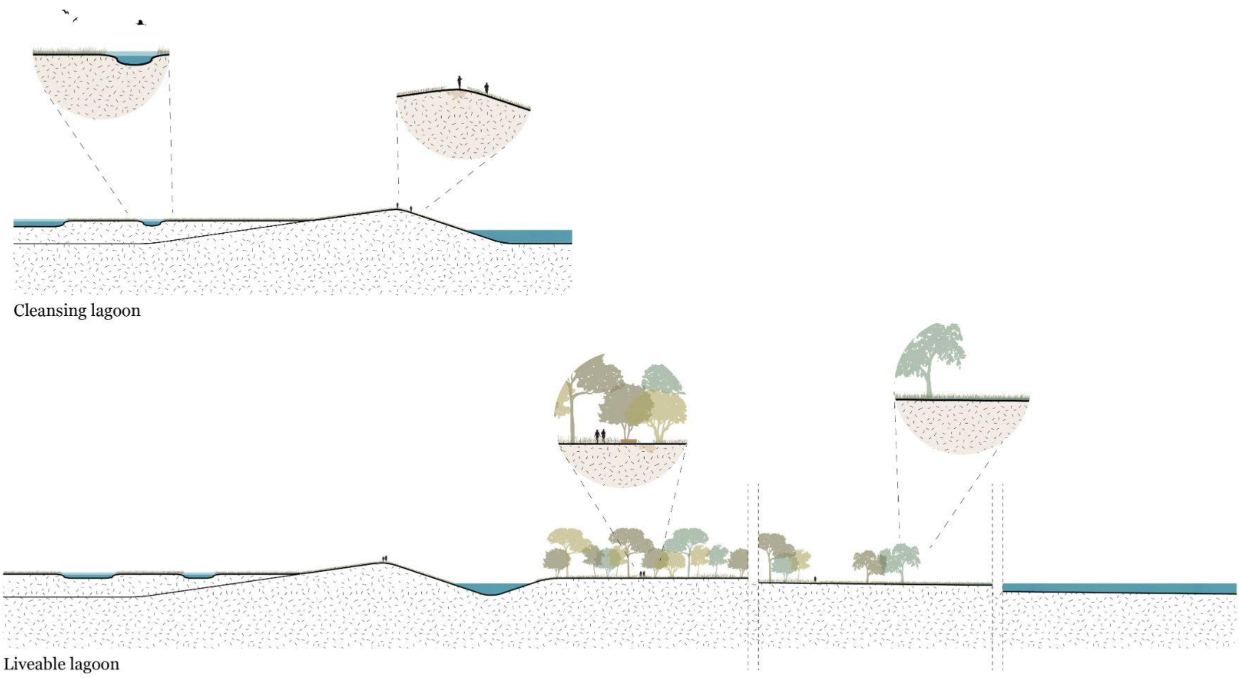
Figure 4.11: Evolution of the barene around the dike.

In order to create a bigger and better-connected space for recreation the top and inside of the dike essentially becomes a circular park. A walking and bike path on top connects the mainland with Lido and also allows visitors to experience the natural lagoon without interfering in it. Along the Southern part of the dike this path is connected to park spaces in the form of islands. Here visitors can engage with natural areas such as a small forest and marshlands more directly and spend a day in green surroundings *(livable lagoon)* as well as swim in the now clean lagoon *(liveable and cleansing lagoon)*. This is enabled by the development of (less salty) marshlands on the inner perimeter of the dike, most prominently in the Southeast, which act as a natural filtering device for the whole central lagoon *(cleansing lagoon)*. This filtering mechanism is also needed considering that, in order to minimize human impact on the lagoon outside of the dike, spaces within the lagoon (port and potentially airport) are transformed for agricultural production *(productive lagoon)*. These spaces are not only located on land, but also in the water, specifically connected to the Northern part of the dike (see Figure 4.13).

Figure 4.12: Impression of the wide green dike with agriculture (water-based farming) and recreation (hiking path) embedded in it.

Location

Considering the placement of this dike within the lagoon, the goal is to disrupt the lagoon processes as little as possible. This is done by placing the dike on the tidal watersheds (see also Appendix I).



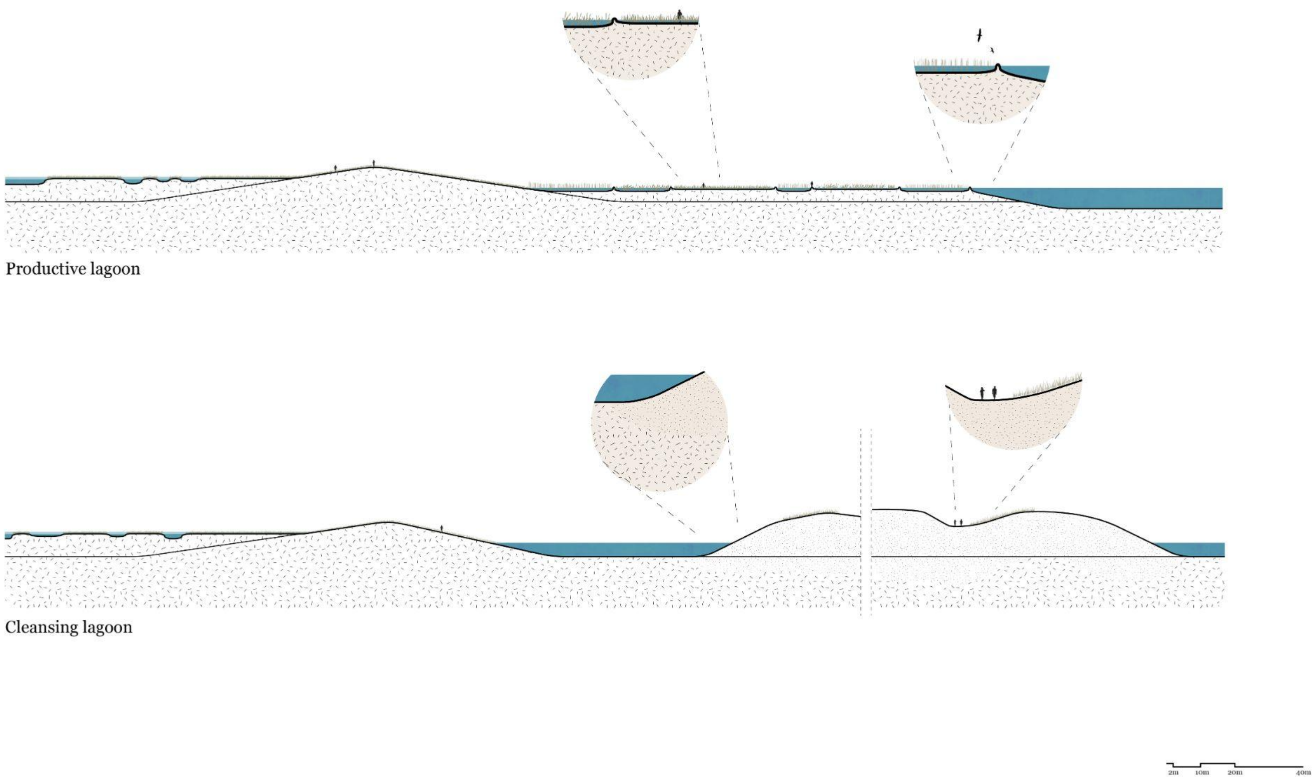


Figure 4.13: Sections depicting dike with its various functions embedded.

LIDO

In the plan of the Perfect Lagoon, Lido's role as barrier island is essential as it is part of the dike system. In order for Lido to be future-proof, additional measures need to be taken. The expectation is that the (relatively small) dune face in the south of the island will provide enough protection against sea level rise, however, a solution will need to be found for the rest of the island. Additional protection towards the back of the island is necessary. This is where the Dutch double-dike can come into play. This will be further researched in Section 5.1 and Section 5.2.

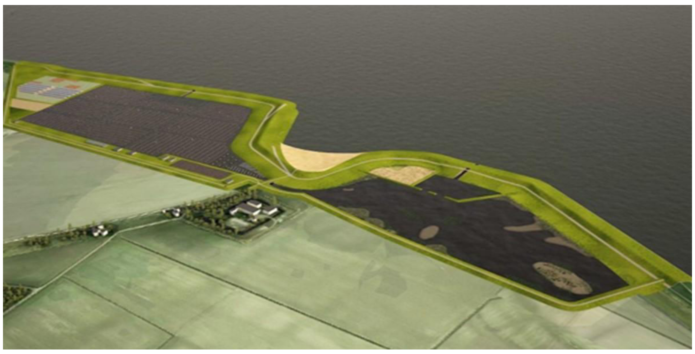


Figure 4.14: Concept photo of double dike at Eems-Dollard [3].

Figure 4.14 shows a concept photo of the double-dike. In the case of Lido the center would be made up of the island as it is now, with a more green dike towards the lagoon side. This is possible since the wave climate towards the lagoon side is far more moderate.

4.2 VISION 2 – THE SYMBIOTIC SYSTEM

The second vision is radically different to that from the first but shares the aim to create a sustainable relation between humans and nature. It introduces a more industrialized approach to protect Venice and the Lagoon. The historical and heritage preservation organizations in Venice have been known to protect the existing look and aesthetics of Venice, encouraging it to such an extent as even the view towards the lagoon from the islands. However, with the water level rising, it is only a matter of time when the more technocratic approach will be needed for protection. The choice is hard but clear: there is a strong need to prioritize between protecting the historical looks but letting them sink underwater in several years or keeping the islands above water with the help of drastic engineering solutions. The Symbiotic System focuses on the second of these two choices.

The proposal envisions a modern metropolitan area, being composed from a network of different spaces. The design strives to preserve the historical traditions and aesthetics as much as possible while adding a new level of connectivity. The islands are not just connected between themselves but also from and to the hinterland. Porto Marghera is kept as it is because of its huge economic importance. The existing boat routes are preserved as much as possible and new bridges are added for being able to move easier. In this way, mass tourism can be managed by better allowing easier distribution, adding more functions to surrounding islands and specified zoning. This will increase the quality of life of the locals as they will literally and figuratively have more space. This vision focuses on protecting nature by largely allowing the natural processes in the lagoon to run their course while focusing on protecting the human environment.

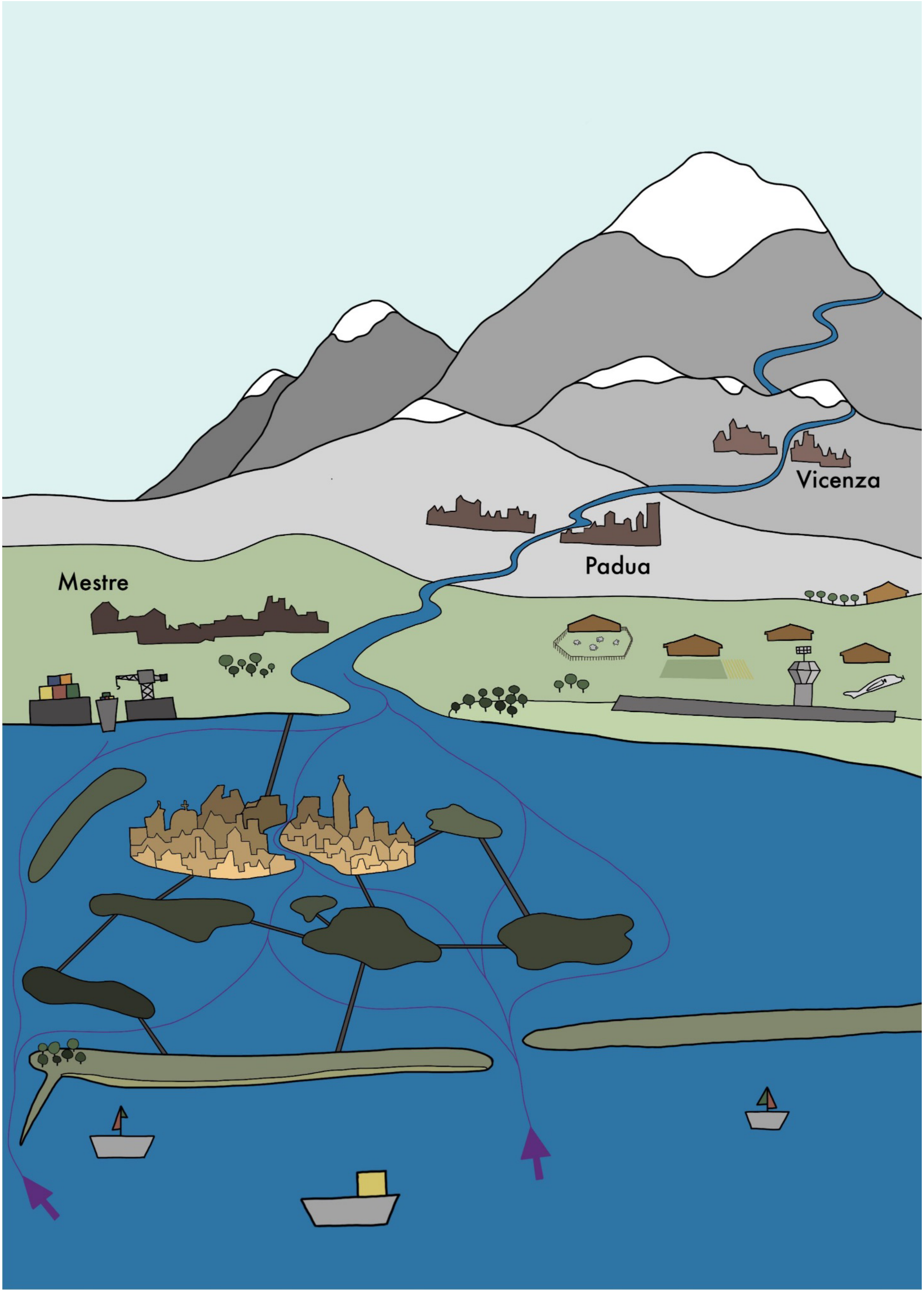


Figure 4.15: Territorial vision of the Symbiotic System.

4.2.1 THE SYMBIOTIC SYSTEM

The Symbiotic System is a separate network which exists and acts independently from the rest of the lagoon. This is done in order to have as little human and engineering interference towards the existing nature. Leaving the lagoon will enable it to restore itself and find a new balance. This might mean that eventually the lagoon will be swallowed by the Adriatic Sea. The term "building with nature" in this proposal was interpreted as allowing the ecology to run its course and not enforce regulations. The project focuses on protecting the cities and human habitat by implementing the necessary hydraulic interventions and ensuring the traditional and sensitive planning to preserve most and add more spatial qualities for the people. This section explores the technical solutions of the Symbiotic System vision.

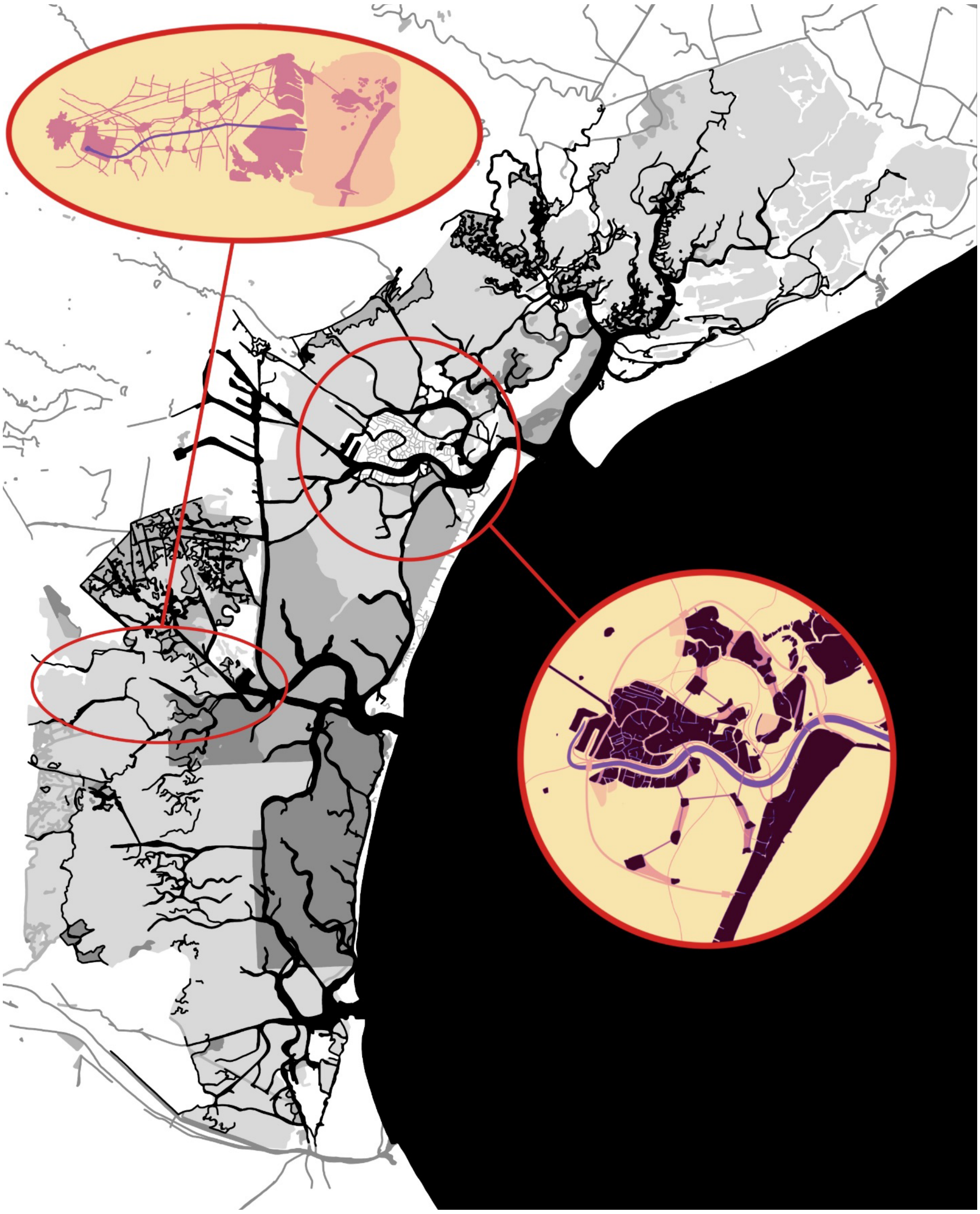


Figure 4.16: Overview Symbiotic System.

DAMS AND BRIDGES

The main function of the dam is to control the water levels inside Venice. However, this vision also explores the possibility of expanding the use of the dam and adding more useful functions to it. For example, the dam also acts as a part of the network that connects the islands. Being an outer ring, it hosts a metro system within and allows people to move easier. In order to find out which other functions should be added to the dam, an inventory of the existing functions of surrounding islands was made. This was also done to determine the positioning of the dam and the bridges thus ultimately deciding which islands will be a part of the systems and which won't.

Analysis current function islands

In Figure 4.17 an overview of the current functions of the islands is represented. A distinction is made between the following functions: ports, housing of residents/tourism, islands that are abundant and nowadays have no function, islands which only function as resorts/hotels, islands on which a monastery or military base is located and nature. Following from this overview, a dam is built including the biggest islands Murano, Le Vignole, Giudecca and Lido. The islands that already have hotels and resorts are included as well as islands with a military base or monastery that could be of use for new hotels or houses. Some small islands that are located too far away and have no function at the moment are not included as they are too small to add value to the metropolitan network.

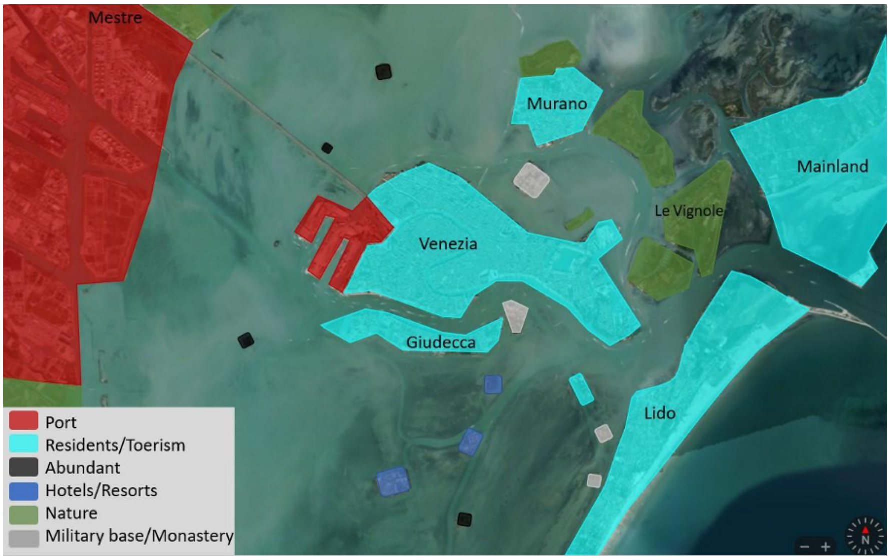


Figure 4.17: Functions of surrounding islands in the focus research area.

In the Symbiotic System Lido functions as an barrier island and is included in the dam-network. As a preliminary study the elevation map of Lido is taken in which can be seen that the northern part of the island should be high enough to function as a flood defense, see Figure 4.18. In Chapter 5.2 further investigation is done to ensure future safety of the dike at Lido.

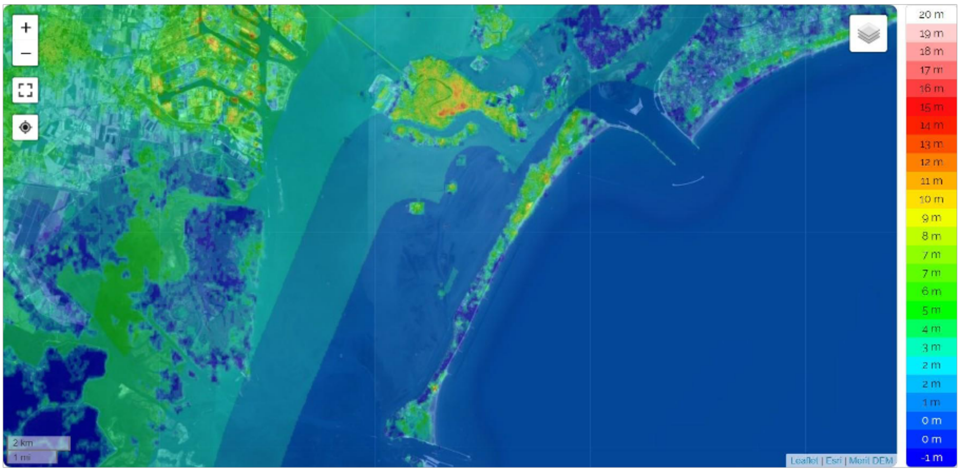


Figure 4.18: Elevation map Lido [4].

Bridges

The dam that is built has two functions, connecting people and controlling the water. However, only the dam does not suffice the connectivity between all the islands. Therefore bridges will be built to connect all the islands and create a future proof metropolitan network. In Figure 4.19 the bridges are represented in brown. The bridges should be high enough for small boats to pass. Otherwise the new logistic network will be interrupted too often when the bridges need to be opened for ships to pass.

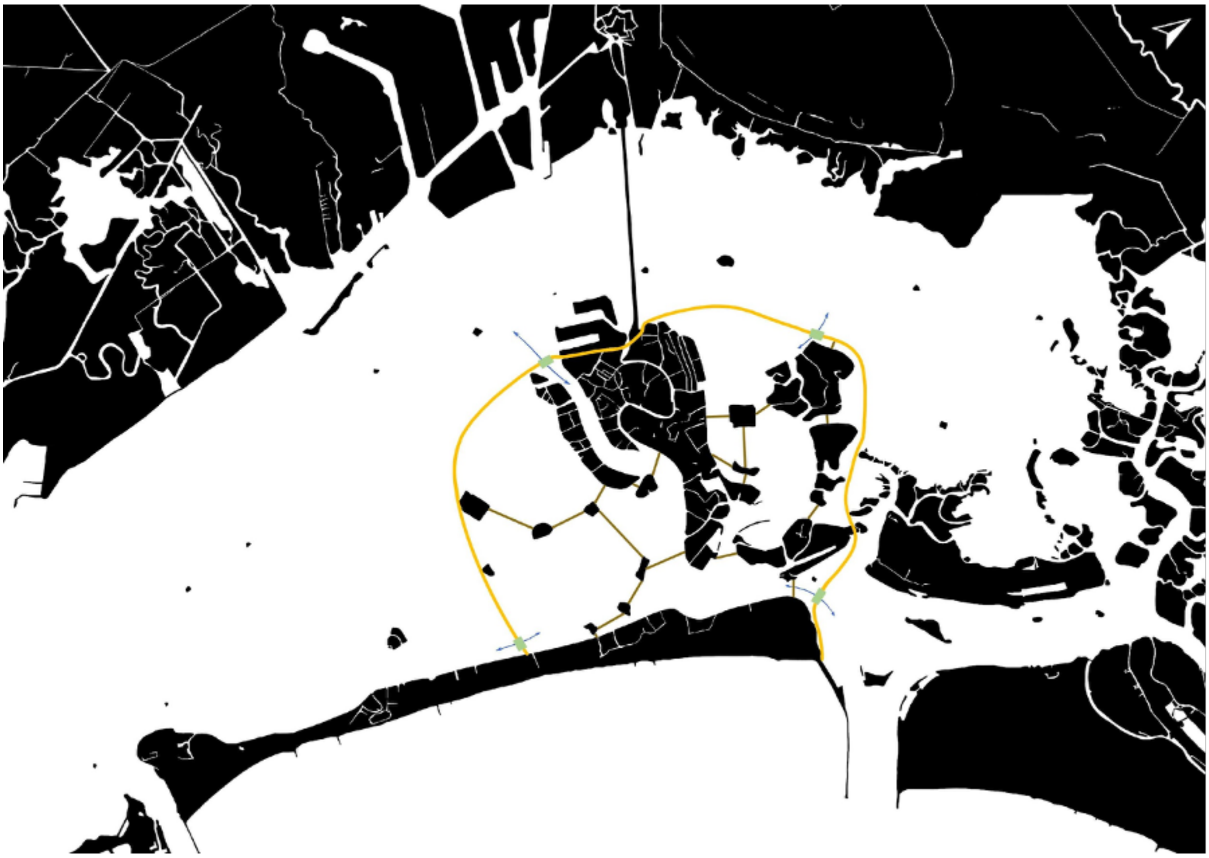


Figure 4.19: New dam (orange) and bridges (brown) network.

Port of Venice

The port of Venice (Marittima di Venezia) is excluded from the dam-network. As a motivation for this choice two factors were taken into account: first of all, the port gives easier access when outside of the barrier and secondly the amount of vessels making use of the port has decreased. Regarding the latter, as of August 2021 the Italian government banned cruise ships to moor at this port, this resulted in less touristic usage of the port. On the website of the Port of Venice statistics regarding the usage of the port are given [48]. Mostly smaller ships like passenger ships and water buses are still making use of it [49]. Therefore, the Marittima may be too large for the vessels which are making use of it. Within this Symbiotic System the choice can be made to elevate the parts of the port which are still being used and leave the unused parts for what they are.

The growth of artificial islands

As it is uncertain how the climate and the needs of Venetians will develop in the future, the Symbiotic System will be built in such a way that in the coming years the islands have the possibility to expand. The dredged materials from the lagoon could be used for the expansion of these islands in the future. However, in the past the sediments in the lagoon were highly polluted. Therefore, according to the current regulations, it is not allowed to dispose of the dredged material back into the lagoon. However current research shows that the level of contamination is rapidly decreasing, [13]. In Section 5.2 this will be further investigated. In Figure 4.20 a possible concept of these future islands are given which can be divided in three expansions over 75 years. The first expansion can be done simultaneously with the building of the dam. Some ground that is removed for the dam can be re-used for the building of the islands. Additionally, the building of the islands can be done on piles. The second expansion can be done after 25 years when enough sand is collected from the dredging in the lagoon and after 25 years more the final stage can be built. The main advantage of this is that the exact expansion and location of these islands can always be revised in the future when the climate change is developing differently than expected or when the needs of the Venetian peoples are changing.

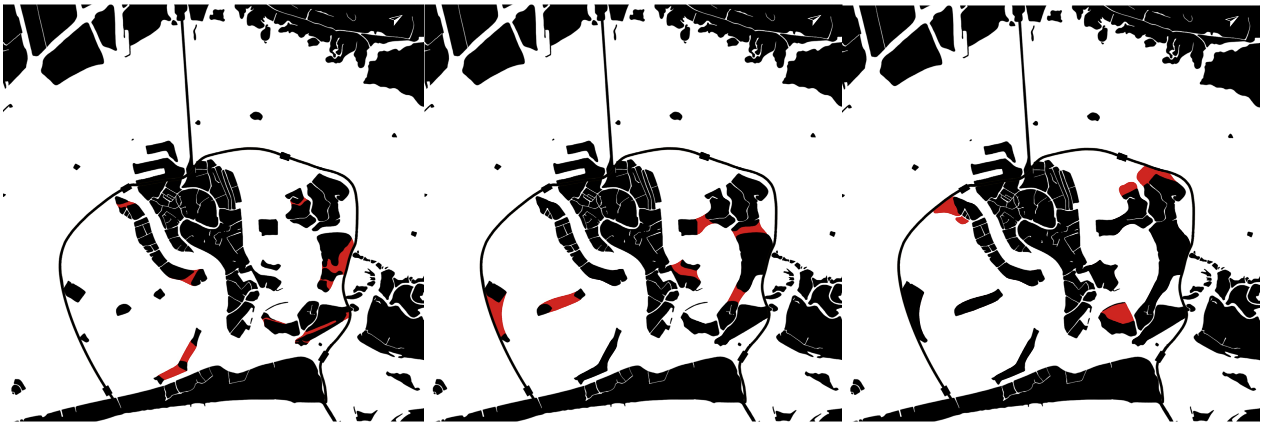


Figure 4.20: Growth of artificial islands in three steps represented in red.

THE PADUA-VENICE (PD-VE) WATERWAY

To maintain the vision of the Symbiotic System, an attempt was made to find a more human-based solution instead of a nature-based solution (see also Appendix B). Obvious was the use of the already existing waterway connecting Padua to the Venice Lagoon (PD-VE waterway). It was designed in the 1960s to replace the old and now inadequate Naviglio del Brenta. Nowadays, 10% of the total waterway has been constructed so far. The construction was interrupted in the 1980s when its commercial viability was doubted. At the end of the work it will have approximately a length of 27.6 kilometers and will have some new future proof measures along its way, see also Figure 4.14. The PD-VE waterway is a navigable canal for modern fluvial ships that, once completed, will link the industrial area of Padua with the Venice lagoon. Having this shipping route will also reduce the business on the hinterland roads, as these are now the only means of transporting. In addition, it will be able to better control future floods events. It has been verified that the waterway would have no problems to convey discharges up to 350 – 400 m^3/s; at the same time, high velocities in the waterway can maintain the suspended sediments in the water. What will lead to suspended sediments and freshwater input into the lagoon. This may help the erosion and salinity problem the lagoon now holds.

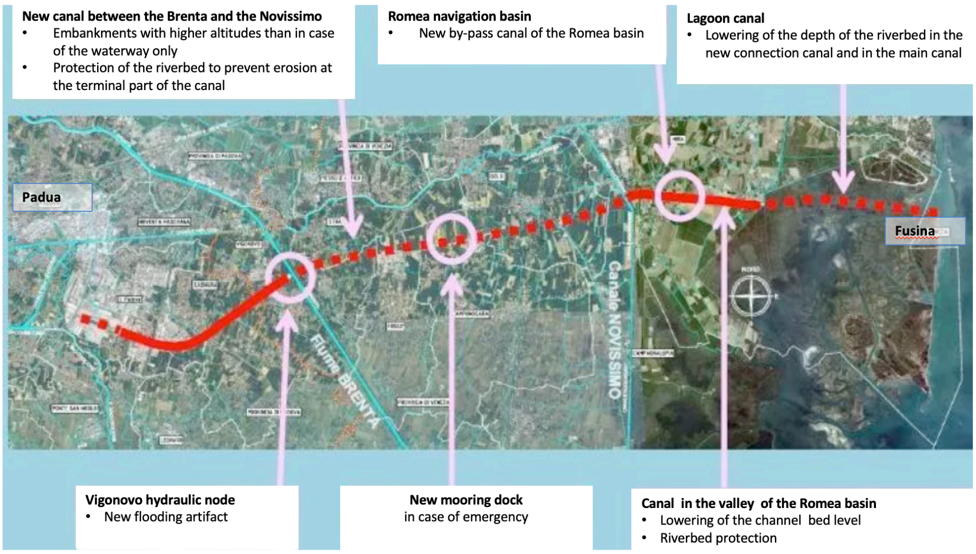


Figure 4.21: Implementation of the location of the PD-VE waterway between Padua and its estuary near Fusina. Along its branch, the intended future local measures are shown.

MOBILITY

The Symbiotic System allows bigger vessels, like container ships and cruise ships, to enter by the MOSE inlets. Inside of the dam, water buses are currently transporting people from island to island. This mode of transport will be preserved in the symbiotic system, just because people are used to it. Shipping locks are placed in the dam at main shipping route locations for water buses to move in and out of the system.

In order to connect people between the dam and its surrounding islands, bridges will be built which are represented in brown in Figure 4.11. This bridge will consist of a monorail which makes it a fast connection between people on the different islands.

To enhance mobility even further, the dam can be used as a transport mode: a metro system can be placed inside of the dam. On top there is room for pedestrian and cycling paths or even buildings for housing or shopping.

TOURISTS

Every year millions of tourists travel to Venice to enjoy the city. However, in the last few years Venice is having a hard time coping with the number of tourists and the tension between tourists and locals has grown. The pandemic in 2020 made the residents realize on the one side how much the city is economically dependent on tourists and on the other side how livable the city became when the tourists had left.

In Figure 4.22 the increase of tourist arrivals and total number of nights are represented. From this figure an even faster increase in the last 20 years can be observed. The tourists are spread over 570 hotels in Venice. Around 64% of the visitors will stay overnight in the historic center, the rest on the mainland and a very small part (3%) on Lido. Additionally, to these numbers there are even more tourists that are only staying for a few hours, this makes the number of visitors almost twice as high, [50]. On some days cruise ships bring 44,000 people to the city. They will only stay for a few hours and therefore bring no economic value to the city. Further distinctive tourist data can be found in Appendix M.

The increase of tourism has caused more and more residents to leave Venice. Three decades ago Venice had more than 120,000 residents. Nowadays there are only 55,000. By 2030 it is said by some demographers that there could be no more full-time residents as when the population falls below 40,000 Venice will not be a viable, living city any longer, [50].

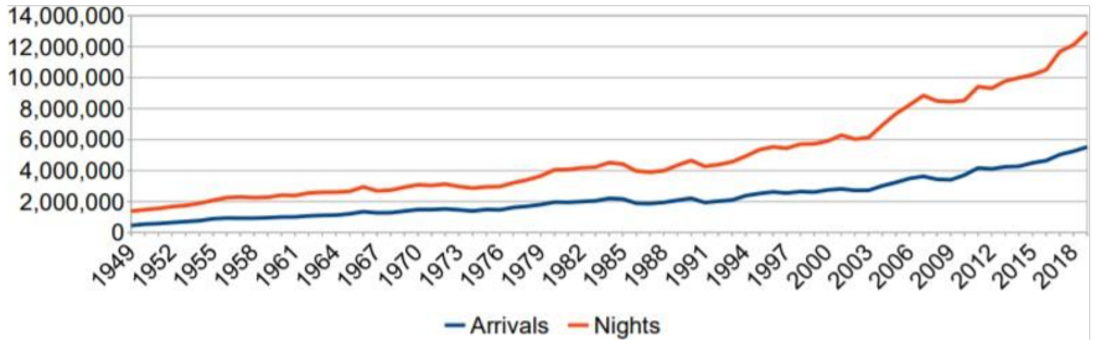


Figure 4.22: Tourism in the past century [5].

The Symbiotic System will make it possible to spread the tourists better over the (artificial) islands. By locating more hotels on the other islands which are well connected to the old city center more room for the residents in the old city center is made. But building a new symbiotic system is not the only answer to the problem. In our opinion, some regulation by the authorities should be made to control the number of tourists in the city and save Venice, not only for the tourists but moreover for the residents itself. This all is necessary to prevent Venice from becoming a sort of “Disney Land” and Italy will lose a precious city to tourists.

In the Symbiotic System it will not be possible for cruise ships to dock at Venice or at Marghera, cruise ships will be banned completely. Tourists that are staying overnight are preferred and the number of short-stay visitors will decrease because of the abandoning of cruise ships. Furthermore the hotels will be spread more evenly over the Symbiotic System and a maximum on the hotels is set to 450. It is striven for that Venice will go back to 100,000 residents and the number of tourists is going back to 3 million but with more nights staying in Venice. Visiting Venice for only one day may be discouraged. This can be done by "entrance tickets" for Venice. In this way the number of tourists can be controlled and the price for a longer stay could be lower to encourage tourists to stay longer in such a way that the peak-load is more distributed.

MOSE

The Symbiotic System allows ships to enter the lagoon and to navigate towards Porto Marghera. This means that the inlet at the south of Lido (Malamocco inlet) should stay open. For the inlet at the northern part of Lido the same holds, except that MOSE has to be kept down not for entering ships, but to maximize the connection between the lagoon and the Adriatic Sea. This means that in the Symbiotic System, the MOSE seems to be left without a purpose when sea level rise renders the MOSE unable to function as a storm surge barrier.

Maybe a way to still make use of the MOSE barrier would be to heighten it and use it as a secondary storm surge barrier for the next 100 years. This way, during extreme storm surges combined with the effect of sea level rise, MOSE could protect the primary coastal defense, preventing possible overflow/failure from happening.

5. TECHNICAL DESIGN

5.1 TECHNICAL DESIGN: PERFECT LAGOON

This chapter will discuss the technical design of the first concept, that of a Perfect Lagoon. Every discipline will input their knowledge on the concept and the feasibility within their discipline will be explored. Starting with hydraulic structures, then river engineering and finally coastal engineering.

5.1.1 HYDRAULIC STRUCTURES

The Perfect Lagoon contains a sand dike, used as a barrier, separating the lagoon into three parts. The northern and southern part of the lagoon will be connected with the Adriatic Sea. The water level in the middle part, in which the Venice islands are mostly located, is fully manageable by water inlets in the barrier. The dike will preferably be like the wide green dike. To blend in better with the surrounding environment, it is chosen to include as much vegetation as possible into the design. This chapter will deal with the feasibility of these design choices. The chapter ends with a preliminary static stability calculation with dimensions.

Sea-dike function

Following the vision as laid out in the previous chapter. The function of the sea-dike and its connections are explored. This is all done with Nature at its center (Figure 5.1). Soft, Nature Based Solutions (see also Appendix B) are sought after in this combination of functions.

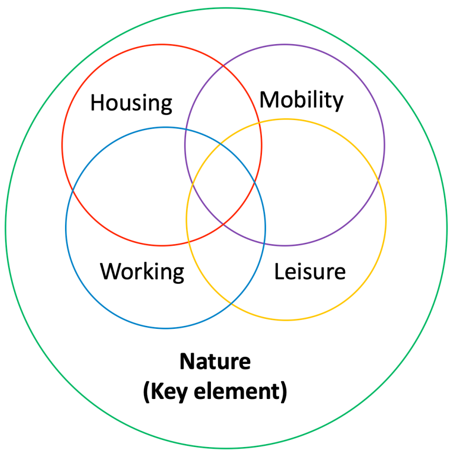


Figure 5.1: Intersections between functions within the theme of Nature.

Sea-dike interface of functions

In our vision, there is then idea to create agricultural areas on top of the dike, as well as forms of forestation. Combined with bicycle paths or pedestrian roads, this forms an intersection between most of the functions within the nature aspect as in Figure 5.1. The function left out of this aspect is the housing, as within our philosophy, there is no room for housing on the sea-dike.

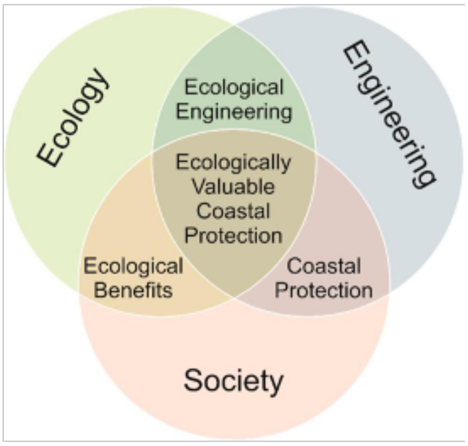


Figure 5.2: Bringing together the interests of ecology, engineering, and society to achieve ecologically valuable coastal protection [6].

This falls into our working with nature solutions. This subsection explores the possibility of nature-based solutions for the dike, the interface between society, engineering and ecology like in Figure 5.2 is sought after.

Within the nature concept, the first idea was to have vegetation in the form of trees on the dike. However, trees and other vegetation with large roots should be prevented on dikes. The root systems of large vegetation substantially increase risks of dike failure due to internal and external erosion patterns [51]. Additionally, trees and other obstacles cause increased risk in the case of overtopping, causing dike failure before the grass slope itself [52]. Ideally, no trees should grow on dikes with flood protection functions and growth of new trees should be prevented.

This leads to a new concept, which is making use of a broader dike crest to allow for agriculture. This would relate to the working function within the key element of nature. However, occasional over wash or overtopping of the dike can lead to salt intrusion into agriculture soils, damage to coastal infrastructure and potentially loss of human life [52]. Salt intrusion into the agriculture soil would quickly lead to soil quality degradation [53]. In order to make agriculture possible, over wash and overtopping will need to be prevented. Perhaps this can be done in the form of a vertical wall at the start of the crest of the dike or choosing to heighten the dike more. Infiltration of salt water into the subsoil should still be prevented, this can be done by using impermeable materials in the subsoil. The downside is that this will require enormous amounts of sediment, and put a very high demand on available space. Agriculture on the dikes would require infrastructure for the transport of crops, room for farmland and possibly housing for farmers. The plan for agriculture seems to be unrealistic in terms of space, available sediment, and costs. It would, on the other hand, be interesting to use the dike as pasture for grazing [6].

Grazing animals on dike is recommended, hoof prints act as natural manure and stimulate regeneration of ground cover. By controlled grazing of the grass on top of the dike, dike maintenance – like need for mowing – is reduced but still required, Mériaux and Royet [54] [6]. Lighter animals like sheep should be chosen over heavier ones, as cattle may leave deep ruts and tracks, Mériaux and Royet [54]. As well as creating room for the local shepherds to feed their livestock. In case of expected overwash or heavy overtopping occurrences, livestock can easily be transported back to the mainland. When combined with the concept of the wide green dike, additional land for grazing would be available.

Using the dike as a pasture seems like a win-win scenario. Combined with the concept of the wide green dike, making room for salt marshes and the possibility of a bicycle or pedestrian path on top, this combines mobility, working and leisure functions.

Figure 5.3: Dike in between the salt marshes with a bicycle path, an interface of the leisure and nature functions.

Water Level Extreme Scenario

The design is being evaluated for an extreme scenario. In this case, the extreme scenario includes a 1:1000 year storm inside the lagoon, having a water level of MSL +220*cm* [17] (derivation see Appendix A). For the running MSL the deepest part of where the dam is planned to be situated has to be used. These depths vary between 2 and sometimes even above 12*m* because of the dredged shipping channels. These shipping canals will be filled at the places where the flood defense will be located, resulting in a depth of 4*m* assumed to be governing as the deepest part at the locations of the flood defense. Furthermore, the sea level rise (SLR) is included by designing this structure for a period of 100 years, resulting in a SLR over these hundred years of 1.01*m* (as in Appendix A). Eventually adding all these factors, the water level on the lagoon side of the flood defense becomes 7.21*m* and the water level inside the flood defense stays the current water level, being 4*m*.

The increased river discharge due to the rearranged Brenta and Piave rivers is assumed to have negligible influence on the water level in the lagoon for these preliminary design calculations. See Appendix A for further substantiation.

Waves and Set-up

Calculations regarding the waves and set-up determination can be found in Appendix C. The total setup amounts 0.46 m and the total runup amounts 0.29 m.

Preliminary Design

The dike design is being evaluated for sliding, overturning, piping and overtopping. The full calculation can be found in Appendix C. The following dike dimensions were found.

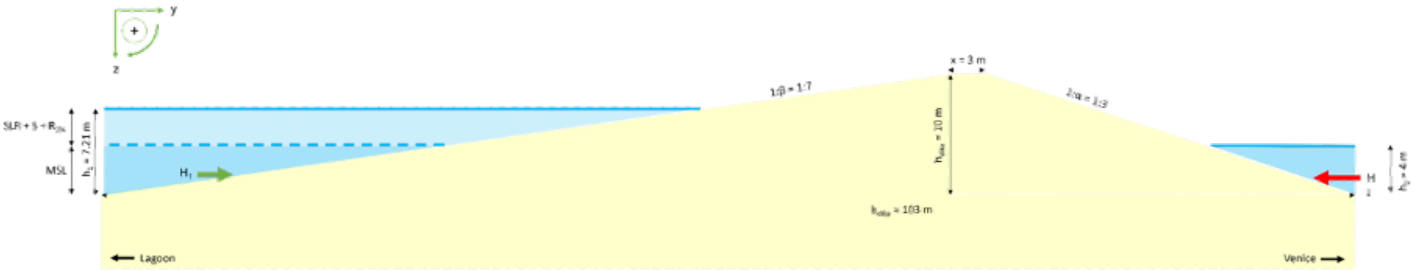


Figure 5.4: Dimensions primary flood defense dike perfect lagoon.

This gives a dike which has a volume of about 530m^2 per running meter. A 10–15km barrier is needed, resulting in a required amount of sand comparable with less than one sand engine at Kijkduin (NL).

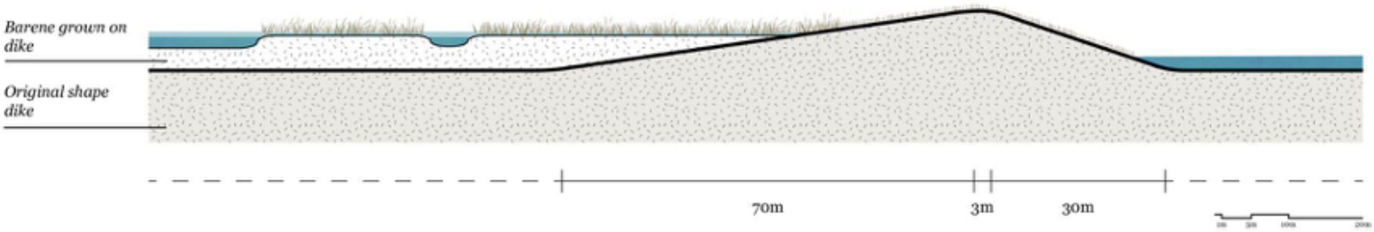


Figure 5.5: The Perfect Lagoon with integrated salt marsh development.

Wave overtopping and Piping

The great dike design turned out safe for wave overtopping and piping as well. These findings can be read in Appendix C.

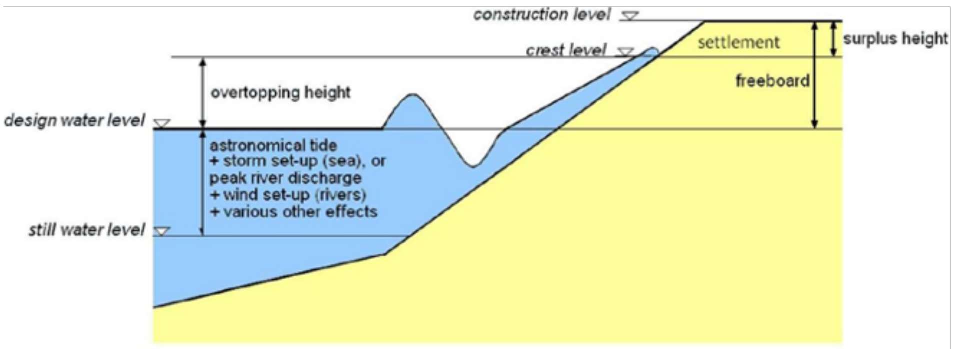


Figure 5.6: Determination of the construction level of a dike [7].

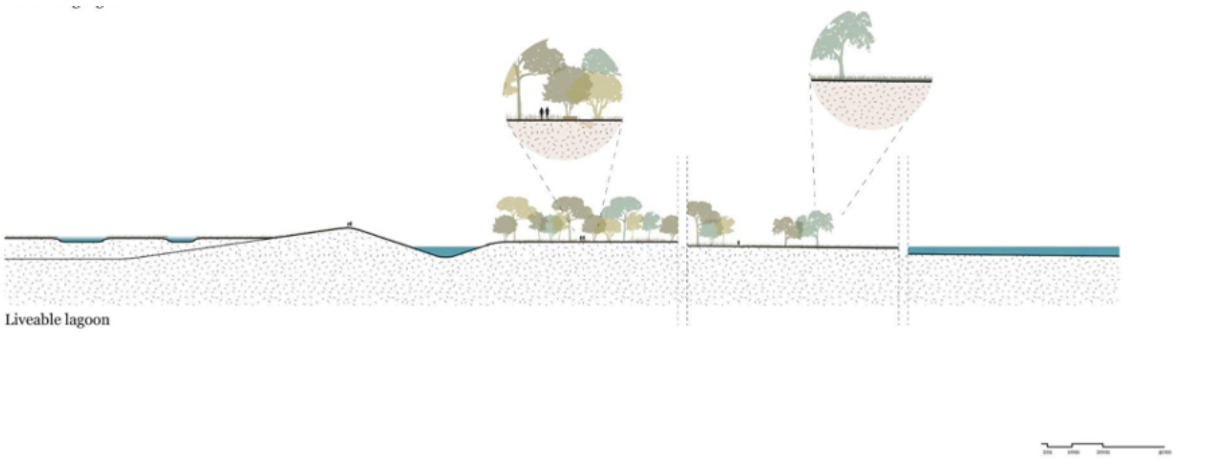


Figure 5.7: Determination of the construction level of a dike [7].

Small dike with trees

Figure 5.5 shows a sketch of Lea Hartmeyer about a landscape view of the Perfect Lagoon. Some parts of the dike contain a smaller dike in front with trees on top to increase the value of the landscape. Since this dike bears on both sides the same (controlled) water level, the expectation is that there will be no piping, sliding or overturn problems. To decrease the amount of overtopping problems also the small dike should be high enough. Including setup and run-up, a small dike height of $6m$ should in this case suffice, having a setup of $0.66m$, a runup of $1.12m$, a crest freeboard of $2m$ (Figure 5.6) and an overtopping discharge of $1.523701087 \cdot 10^{-5} l/s/m$. Calculations can be found in Appendix C. It is however still important to keep in mind that wave impact might be disastrous for this small dike with trees. Further research should be done regarding the waves present and measures, just like breakwaters, have to be taken if their impacts result in unsafe situations.

Spillways

The philosophy of the Perfect Lagoon aspires to soft measures indicating hydraulic structures which are built with for example sand and other materials which can be found in nature itself. The design choice for a pressurized pipe spillway was therefore easy made since it is invisible implemented in the dike. Deriving the dimensions and number of spillways is done using several equations. The principle of the calculation is to make sure that the evaporation discharge in the middle part of the lagoon is equal to the inflow of water from the lagoon towards the middle part (= spillway discharge). Iteration has to be done until these discharges are equal. The discharge through one pipe is being derived by using the maximum evaporation rate of the Adriatic Sea, which amounts $1.34m/yr$ [55]. Multiplying this number with the total wet surface of the dike surrounded part of the lagoon ($30 \cdot 10^6 m^2$) gives the total yearly evaporation volume. This amount should be compensated with the amount of water entering the middle part of the lagoon through the spillways. Since the spillways are not open 24/7, the time which they are activated needs also to be taken into account, just like the amount of pipes. Here it is assumed that the spillways are opened 1 hour per week, so $tactive = 52 \cdot 60 \cdot 60 = 187200 s/yr$. The full calculation can be found in Section C.6.

The iteration process gives eventually the need for 13 pipes with each a diameter of $2m$ at a height measured from the bottom of $2m$. The Reynolds number inside the pipe amounts in this case $10.4 \cdot 10^6$ indicating a very turbulent flow.

Since the Perfect Lagoon design has a new detached river output of the Brenta river close by where now Porto Marghera is situated a logical choice would be to place half of the pipes there. Freshwater supply inside the middle part of the lagoon is therefore guaranteed. The other half is placed at the northern part of Lido where now the MOSE is present and where in the Perfect Lagoon design a dike will be placed (Figure 5.8).

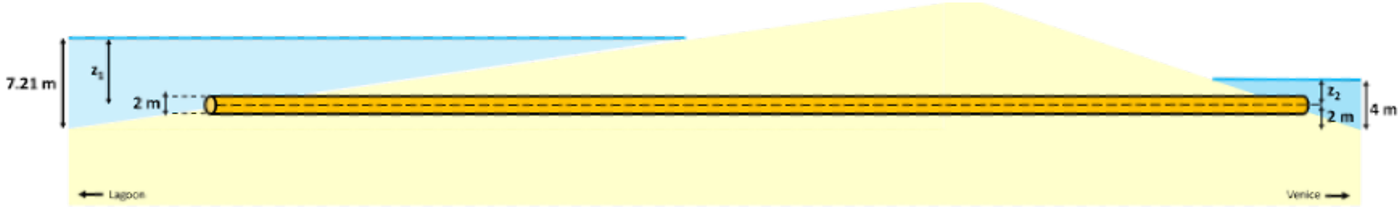


Figure 5.8: Dimensions pipe spillways for the dike cross-section.

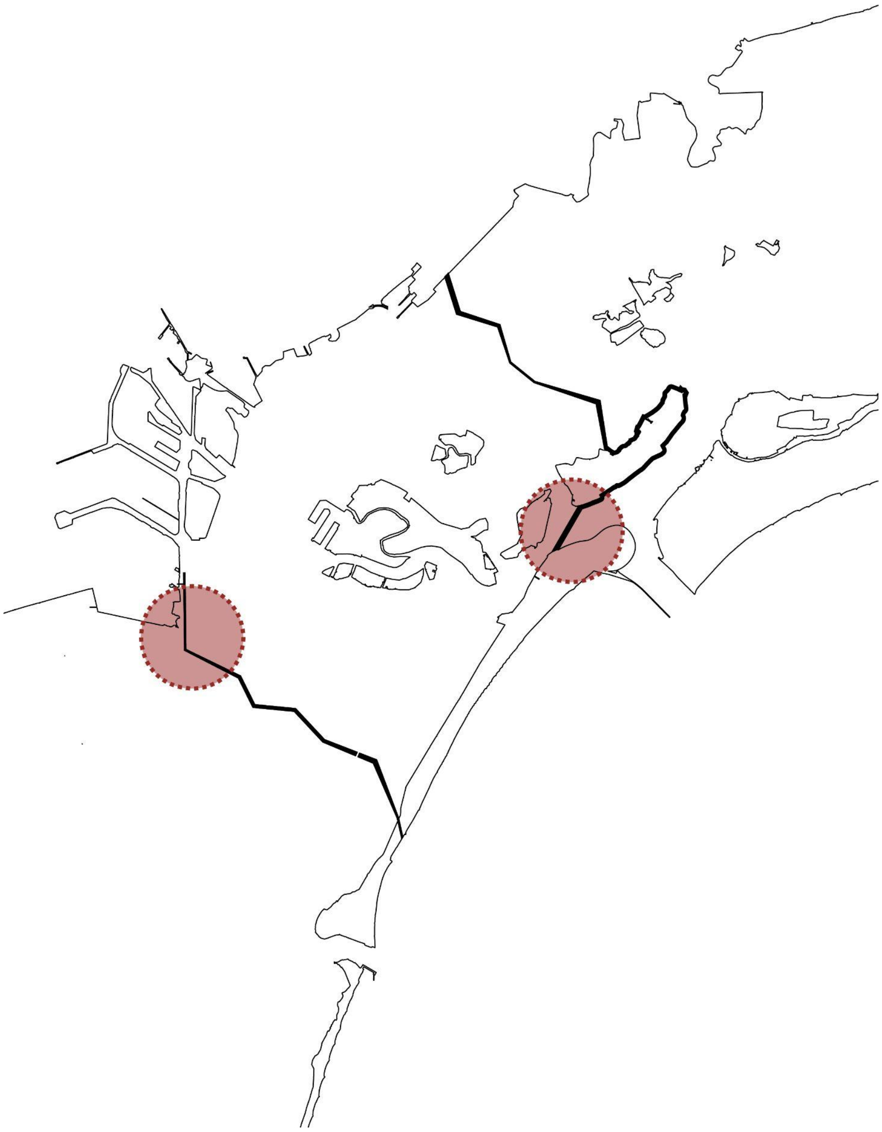


Figure 5.9: Location of spillways in wide green dike.

Shipping locks
The vision of the Perfect Lagoon in essence is prioritizing nature and giving nature the space to thrive. With this, it does not make sense to let all the boats in the dike ring go out freely into the lagoon, whereby the salt marshes erode more and more. Therefore the dike ring will not have any shipping locks. Inside the dike ring the water bus as well as personal shipping is still freely available, but nobody will be allowed into the lagoon. In the lagoon itself boats will not be prohibited as travel between islands still needs to be possible, but by this the traffic will be reduced. Boat logistics can still be done in the Venetian harbor, where they can be lifted over the dike. Doing this will lead to a lagoon which can thrive even more.

Combined spillway-shipping lock function
Since half of the spillways is preferred at the location where now the MOSE is present, another option (instead of the pressurized pipe flow spillways) can be to include a spillway function in a shipping lock. In this way ships are allowed to enter the lagoon during the periods when the spillway is opened. In this report however no further attention is paid to these kinds of structures. First more investigation has to be done into the design preferences of the stakeholders.

5.1.2 RIVER DYNAMICS

This chapter gives a feasibility study with respect to the purpose of the Perfect Lagoon River system, which will lay in the regime of Nature-Based Solutions (NBS) as described in Subsection 4.1.1. First, research will be done about the debouching location of the rivers Brenta and Piave when diverting them into the Venice lagoon. Subsequently, a quantitative study for both rivers about the river sediment transport rates flowing into the lagoon is performed and discussed.

Spatial feasibility study
As mentioned in Section 4.1, the Perfect Lagoon vision, the diversions, and debouching location of the two rivers will broaden the basic needs of people and be a stimulus for nature. This will be achieved in the form of a Room for the River implementation (see also Appendix H). The Room for the River measures will lead to a whole new spatial design. See also Figure 5.10 for an example of a braided river where nature slowly develops. Time will tell how the river branches and estuaries will behave in terms of morphology.

Figure 5.10: Rendering of a braided river.

Brenta

Nowadays it has little influence in terms of Room for the river ideology. To implement the Room for the River measurements along this branch, a whole new spatial design needs to be made for the cities and agriculture which are located here. The new natural Brenta needs to cross roads and smaller rivers. Therefore its debouching location is still uncertain. Despite the advantages of this solution, the underlying debate will remain whether the (now still very polluted) freshwater influx will do more good than harm to the Venice lagoon. Otherwise, a good cleanup policy plan has to be made and maintained.

Piave

As seen in Subsection 4.1.1, the right debouching location of the Piave river is very uncertain. Especially because it currently has a very strong and clear branching. Rediverting the Piave river in combination with the Sile river, the third main river, would be a plausible solution. The Sile river already flows along the northern edge of the lagoon, so redirecting would have less spatial impact. For both rivers, the freshwater and sediment plume will spread out due to natural systems like tidal flow, shipping waves and wind, picked up by dredging activities. A visual representation can be found in Appendix J.

Sediment Transport

In diverting the Brenta and Piave rivers into the lagoon, the sediment input of this system is important for Subsection 5.1.3. Research shows that estimating sediment transport of a river has proven to be quite hard. However, Yuce *et al*. [8] shows a discharge to sediment transport relation for the Ceyhan River Basin in Turkey (see figure Figure 5.11). This relation was used to estimate a sediment discharge for the rivers Brenta and Piave. Two assumptions were made; first, the hydro-morphological conditions of the Brenta and Piave catchment are more or less the same as in the Ceyhan catchment. Second, the discharge of the Brenta and Piave remain constant at their annual average discharge. Note, the discharge of these rivers is variable. During high rainfall events, like the big flood event in 1966, the extreme discharge can go up to approximately 1500 m^3s^{-1}. Taking into account that the sediment transport is non-linear with increasing velocity, it may be expected that the sediment transport will be higher. However, due to the absence of literature and research about yearly discharges, the above assumptions were made.

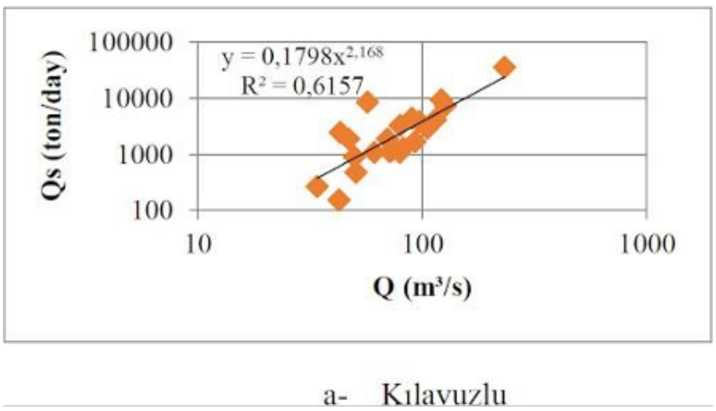


Figure 5.11: Graph taken from Yuce *et al*. [8], figure 4a. The plot shows the measured sediment transport rates Qs with the associated water discharges Q for the Ceyhan River Basin in Turkey. The trend line is also shown.

As stated, the annual average discharges of the Brenta and Piave rivers were 100 $m^3 s^{-1}$ and 125 $m^3 s^{-1}$ respectively. These were used as input for the trend-line formula, which was obtained from Figure 5.10 and is explicitly shown below.

$$Qsed = 0.1798 * Q^{2.168} \qquad (5.1)$$

It follows from Equation 5.1 that the annual sediment transport for the Brenta and Piave rivers is $948,400$ $m^3 y^{-1}$ and $1,538,000$ $m^3 y^{-1}$ respectively. Concluding, these rivers bring 2,487,000 $m^3 y^{-1}$ of sediment in total into the lagoon.

5.1.3 COASTAL DYNAMICS

This section will explore the coastal dynamics of this concept. Starting with the sediment budget, and finally how the MOSE will be used in this concept.

Sediment Budget

The sediment of the lagoon plays a big part in the health of the lagoon. First the present sediment budget will be explained and next the sediment budget of the perfect lagoon. Finally, the steps in order to achieve this balance will be laid out.

Present situation

The sediment budget of the lagoon is laid out in A.Sarretta *et al*. [39], both the evolution from 1927 to 2002, as well as the current situation. The two main conclusions are the decrease of salt marshes by 50%, and the deepening of the lagoon itself. This is driven by an erosion rate which increased from 300,000 $m^3 y^{-1}$ to 800,000 $m^3 y^{-1}$, solely due to human intervention in the lagoon. A further 343,750 $m^3 y^{-1}$ is dredged annually. These to sinks in the lagoon, combined with sea level rise prove to be a threat to the lagoon.

The Perfect Lagoon - a new sediment budget

In the concept of Perfect Lagoon the best future for the lagoon must be found. This means compensating for harm done in the recent decades, as well as creating a sustainable sediment balance for the lagoon. For the Perfect Lagoon, this means the salt marshes need to grow back to the levels they were in 1927 [39]. In these years there was a net sediment loss of $110,000,000 m^3$ in the whole of the lagoon. This is the net sediment loss of the system, in order to restore the sediment balance, $110,000,000 m^3$ need to be added to the system. After the addition of this sand, the sustainability of this new system must be explored. In a perfect lagoon, the net erosion is next to zero. Next to stopping the erosion and dredging, this also means compensating for sea level rise. In compensating for sea level rise, it is assumed that the lagoon must grow with the same amount by which the sea level rises. Of course, in the extreme scenario, this assumption will not hold, however, in pursuit of the perfect lagoon this extreme scenario will be assumed.

In this sediment budget, the new dike in the system must be considered as well. As shown in Figure 4.11 the dike is placed on the tidal watershed, which means it does not influence the morphology of the lagoon, only the area, which is reduced. Having this information, a calculation can be made about what the annual sediment net transport must be in order to create a sustainable perfect lagoon.

As stated in Appendix A, the sea level rise is $1cmy^{-1}$. The Venice lagoon has an area of $550km^2$ [56]. The area which is surrounded by the dike has an area of $75km^2$, see Figure 5.11. Combined with the fact that $40km^2$ of this area is covered by dikes and embankments, which do not need sedimentation, see Chapter 1, the new lagoon area is $435km^2$. Multiplying this by the annual sea level rise gives $4,350,000m^3$ of sediment import required annually.

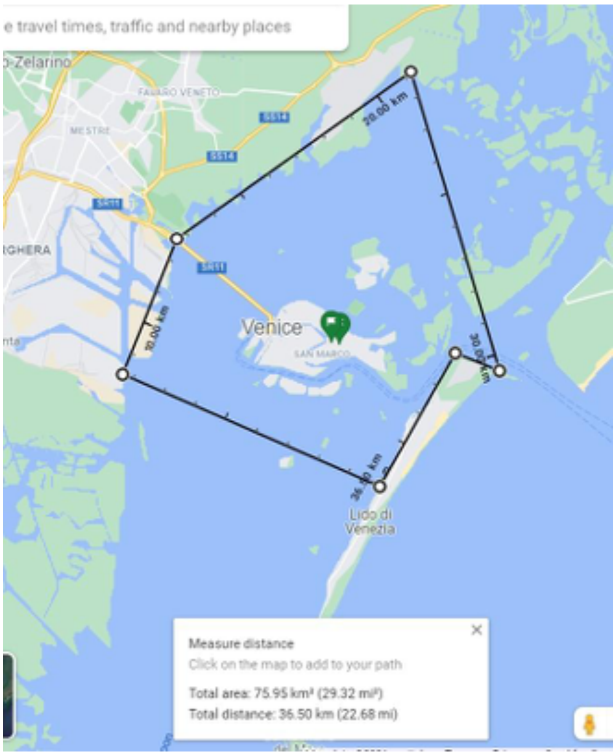


Figure 5.12: Area calculation of the tidal watershed according to Figure 5.29, using Google Maps.

Furthermore, the current erosion rate must be compensated as well, which is $800,000m^3$ annually, as well as the dredging volume of $343,750m^3$ according to A. Sarretta *et al*. [39]. This will stop the lagoon from eroding over time. Concluding, setting these standards, the lagoon has an immediate shortage of $110,000,000m^3$, and an annual shortage of $5,500,000m^3$. It must be noted that by implementing the dike, the lagoon is cut in half. This calculated sediment budget is for both parts of the lagoon combined.

Solving the sediment budget

Solving the sediment budget will be done with a few measures. First of all, the annual shortage. As explained in Chapter 4 and Subsection 5.1.2, the Brenta river, as well as the Piave river, will be diverted into the lagoon. As shown in Subsection 5.1.2, this will bring with it 948,400 $m^3\ y^{-1}$ and 1,538,000 $m^3\ y^{-1}$ respectively. Next, as a result of removing the port, the dredging of the lagoon can be stopped, as the channels do not need to be so deep for the large vessels. This puts a hold on the 343,750 $m^3\ y^{-1}$ net loss by dredging. Finally, as described in Table 5.1.2 and Appendix F, the MOSE will be repurposed to stop the erosion of the lagoon, acting as a weir during low water tides, stopping sediments from flowing out. An overview of the new sediment budget can be seen in table Table 5.1.

Table 5.1: An overview of the annual sediment budget, numbers are in $m^3 y^{-1}$.

Sediment “sources” (by measure)		Sediment “sinks” (in old situation)	
Stop Dredging	343, 750	343, 750	Dredging
River Brenta input	948, 400	800, 000	Erosion
River Piave input	1, 538, 000	4, 350, 000	Sea Level Rise
Total	2, 830, 150	5, 493, 750	

Next, the initial shortage will be solved by means of a nourishment in the lagoon. If done strategically over time, this gives the system enough time to adapt to the sand, and for the ecology to thrive, while building back the lagoon.

MOSE

Using the MOSE as sediment trapping seems like an interesting solution to our sediment budget deficit. When MOSE would be used for sediment trapping during falling tide, there needs to be a mechanism in place to remove the accumulated sediment behind the barrier, otherwise it will no longer be able to close. The accumulated sediment will be too large to be removed by divers like it is done today. The sediment would also need to be removed daily, as it might be necessary to use the MOSE as submerged weir during every falling tide (twice a day). A few examples for possible solutions can be seen in Figure 5.13. In Appendix F, these considerations are discussed. After consideration, allowing the MOSE to also turn seaside is chosen as the best solution in terms of costs versus functionality.

(a) Normal MOSE

(b) Lift gate using existing infrastructure

(c) Turning MOSE towards seaward side

Figure 5.13: Figure with different concepts of MOSE as submerged weir, rightmost design was chosen as best solution.

Lido

In the plans of the Perfect Lagoon, Lido will act as part of the to be constructed dike system. Appendix D goes in depth on the using Lido as part of the flood defense. Additional construction will be required but it seems feasible to make Lido function as a barrier.

PORTO MARGHERA

Porto Marghera, the port of Venice, is the 7th largest port of Italy [57] in terms of flow of goods. Due to disturbance of the lagoon by navigation of large vessels towards the port, as well as bringing large amounts of pollutants (Frignani *et al.* [58] Zonta *et al.* [59]) to the Venice lagoon, the port has become a major nuisance to the surrounding area. The plan of the Perfect Lagoon aims to remove the port (*treat the disease, not the symptoms*) from the lagoon, reducing total pollution and necessary dredging. Here we aim to explain the relevance and consequences of such a severe measure and try to find a suitable new location for this important port system.

Finding a new, more suitable location

As just discussed, the pollution and dredging that comes along with having a large trade port stands perpendicular to having a perfect lagoon. The lagoon is already in an eroding state, additional dredging for maintenance of the shipping canals increases this sediment deficit. Furthermore, the pollution by the harbor and the vessels passing through, releasing large amounts of dangerous metals to the lagoon and the clay underneath, undermines the restoration of the salt marshes and enhancement of wildlife abundance and diversity.

Figure 5.14: Figure that shows the current lay-out of the Porto Marghera.

It has become clear that for the lagoon to thrive, the port has to be removed and relocated to a different area. The relocation of this port is no easy task, there will need to be easy connection to the hinterland for flow of goods and possibly passengers as well. All of this must happen outside of the current boundaries of the lagoon. The placement of jetty's offshore off of Lido seemed like a suitable option, after careful considerations however, this only solves one of the problems. Offshore jetty's would remove the need for dredging of the main channels to the port, during rising tide however, pollution from these ships will still be able to enter the lagoon at a reduced rate. Below, Figure 5.15 shows this potential location just in front of the barrier island of Lido. Another problem of jetty placement here is that Lido is currently a very popular area for beachgoers.

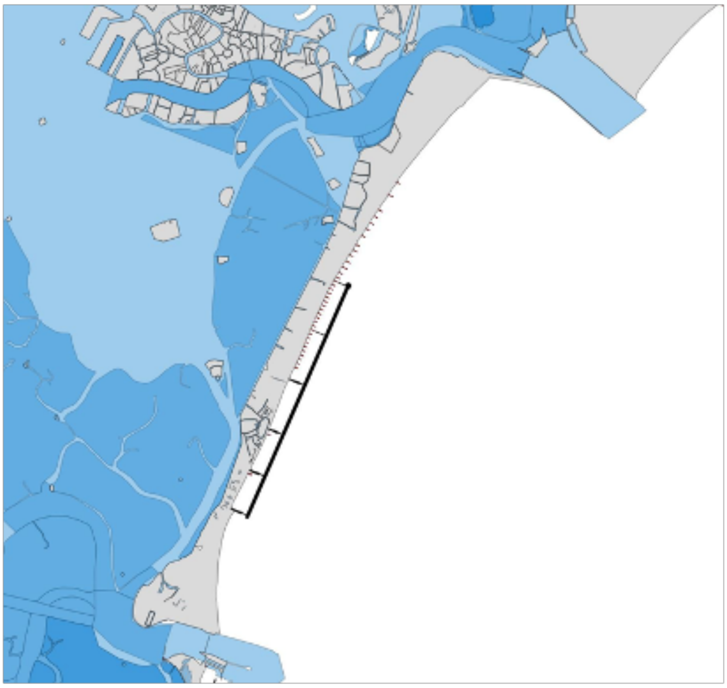


Figure 5.15: Potential location for the offshore jetty's.

This diverts our attention to different areas. Sottomarina/Chioggia and just south-east of Cortelazzo. These are both further away than the earlier proposed location of Lido, but with a good hinterland connection, both might be suitable alternatives. For the Sottomarina/Chioggia, the potential flow of pollution into the lagoon persists, yet it seems like a more suitable location than in front of the barrier island of Lido. In the plans of the perfect lagoon, the Piave river is diverted to the lagoon, this could create the necessary space to lay down the foundation of the new port, just southeast of Cortelazzo. Additional road infrastructure will need to be created for a better connection to the hinterland infrastructure. This will be the preferred place for the placement of the new trading port of Venice.

Figure 5.16: New port location for Porto Marghera.
(a) GIS image of new port location; (b) Satellite image of potential new port location

5.1.4 STAKEHOLDER STRATEGY

This paragraph will assess the feasibility of the Perfect Lagoon design by looking at the relevant stakeholders in the project. In Section 3.2 we have already determined the stakeholders in the project, and executed a network analysis. This showed the underlying relations between different stakeholders and their issues. Furthermore, we have determined their power, level of interest and whether they are critical stakeholders or not. With this knowledge, we will further evaluate the stakeholders and their typology, using the three-dimensional stakeholder analysis. As a result, we can identify possible risks and define a strategy to prevent these risks. Appendix N shows the complete stakeholder analysis, imported from Microsoft Excel.

THREE-DIMENSIONAL STAKEHOLDER ANALYSIS

The three-dimensional stakeholder analysis consists of three axes: power, interest and attitude. We have already defined power and interest in Section 3.2. In order to complete the analysis, we will assess per stakeholder their attitude towards the Perfect Lagoon and determine the stakeholder typology.

The attitudes of the stakeholders are:
Savior - Saviors can be identified by their high power, high interest and positive attitude towards the project, and are often described as an influential active backer. The savior type stakeholders are in favor of the project and will actively and progressively contribute to the process of the project.
Saboteur - High power, high interest and a negative attitude towards the project are the characteristics of a saboteur. Saboteurs are influential active blockers and will actively try to hamper the process of the project in order to prevent the execution of it.
Trip Wire - A trip wire is described as an insignificant passive blocker, meaning that this relatively insignificant stakeholder type will not actively try to block the project. The trip wire will therefore not be a major threat to the process and project.
Friend - This stakeholder has low power, high interest and a positive attitude to the project. Since the farmers are labeled as a non-critical stakeholder, they are less important to process.
Irritant - Irritants are characterized by their low power, high interest and negative attitude towards the project. These stakeholders are identified as insignificant passive blockers of the project. Due to the fact that these stakeholders are insignificant, they will not pose a large threat
Acquaintance - This type of stakeholder has low power, low interest and a positive attitude towards the project. The acquaintance can be seen as an insignificant passive backer and will passively contribute to the process of the project.

- **Comune di Chioggia**

The municipality of Chioggia has a **positive** attitude towards the Perfect Lagoon, since the design makes sure that the lagoon is being preserved. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Comune di Padova**

The municipality of Padua has a **positive** attitude towards the Perfect Lagoon. This is because of the construction of the new canal, connecting Padua to the Venice lagoon and the Adriatic Sea, which improves the economic position of Padua. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Comune di Venezia**

The municipality of Venice has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation of the lagoon and the historical center of Venice. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Città Metropolitana di Venezia**

The metropolitan city area of Venice has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation of the lagoon and the historical center of Venice. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Regione del Veneto**

The Veneto region has a **negative** attitude towards the Perfect Lagoon. This is because of the removal of the Porto Marghera. This will have economic consequences for the Veneto region, due to harbor workers becoming unemployed and thus the rising level of unemployment. Combined with its high power and high interest, the stakeholder type is **Saboteur**. Furthermore, this stakeholder is considered critical.

- **Soprintendenza Archeologica, belle arti e paesaggio per il Comune di Venezia e Laguna**

The Superintendence of Archeology, Fine Arts and Landscape for the City of Venice and Lagoon has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the lagoon and the historical center of Venice. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Ministero della transizione ecologica**

The ministry of environment and ecology has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the Venice lagoon. Furthermore, the Perfect Lagoon improves ecological connections within the lagoon. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Ministero dell'Ambiente e della Tutela del Territorio e del Mare**

The ministry of environment, land and sea protection has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the Venice lagoon and the hinterland from sea level rise and sedimentation. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Ministero delle infrastrutture e della mobilità sostenibili**

The ministry of sustainable infrastructures and transport has a **negative** attitude towards the Perfect Lagoon. Even though the Perfect lagoon is a sustainable solution for the preservation of the historical center of Venice and the lagoon, the removal of Porto Marghera is not favorable. After removing this major infrastructural intersection, a new one needs to be constructed. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is considered critical.

- **Ministero della cultura**

The ministry of culture has a **positive** attitude towards the Perfect Lagoon, since the historical center of Venice is being preserved and protected, safeguarding Italy's cultural heritage. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Italian Government**

The Italian Government has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the Venice lagoon and the historical center of Venice. Furthermore, the Perfect Lagoon is the least expensive, compared to the Symbiotic System, thus preferable. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **AVM/Actv**

AVM/Actv has a **negative** attitude towards the Perfect Lagoon, since the design decreases the amount of routes available for public transport. This will result in lower revenues for this public transport operator. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is not considered critical.

- **Cargo ships**

Cargo ships have a **negative** attitude towards the Perfect Lagoon, since the design removes the Porto Marghera and thereby also the possibility to dock at this harbor, resulting in reduced revenues. Combined with its medium high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is not considered critical.

- **Cruise ships**

Cruise ships have a **negative** attitude towards the Perfect Lagoon, since the design removes the Porto Marghera and thereby also the possibility to dock at this harbor, resulting in reduced revenues. Combined with its medium high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is not considered critical.

- **Porto Marghera**

Porto Marghera has a **negative** attitude towards the Perfect Lagoon, since the design removes the Porto Marghera from its current location. This will cause Porto Marghera to relocate somewhere else, and lose its connection with the hinterland. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is considered critical.

- **Giovanni Nicelli Airport**

Giovanni Nicelli Airport has a **negative** attitude towards the Perfect Lagoon, since the imposed creation of new dunes may limit the amount of air traffic making use of this airport, and thus reducing its revenues. Combined with its medium low power and medium high interest, the stakeholder type is **TripWire**. This stakeholder is not considered critical.

- **Marco Polo Airport**

Marco Polo Airport has a **negative** attitude towards the Perfect Lagoon. Marco Polo Airport is located on the edge of the lagoon. Since the design is focused on the protection of the Venice lagoon, the airport will not be allowed to expand in the future. Furthermore, a limitation on the number of flights could arise in order to protect the wildlife in the lagoon. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is considered critical.

- **Treviso Airport**

Treviso Airport has a **positive** attitude towards the Perfect Lagoon, since the design will limit the number of flights and the possibility for Marco Polo Airport to expand, thus the competition will be hampered in its operations. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is not considered critical.

- **Farmers**

Farmers have a **positive** attitude towards the Perfect Lagoon, since the dykes in the design will be used to create extra farmland, thus creating more land for farmers to utilize. Combined with its low power and high interest, the stakeholder type is **Friend**. This stakeholder is not considered critical.

- **Fishermen**

Fishermen have a **negative** attitude towards the Perfect Lagoon, since the design mostly closes off the lagoon from human intervention. This will decrease the opportunity of fishing in these waters. Combined with its low power and high interest, the stakeholder type is **Irritant**. This stakeholder is not considered critical.

- **Hunters**

Hunters have a **negative** attitude towards the Perfect Lagoon, since the design mostly closes off the lagoon from human intervention. This will decrease the opportunity of hunting on the lands in the lagoon. Combined with its low power and high interest, the stakeholder type is **Irritant**. This stakeholder is not considered critical.

- **OTS Laguna di Venezia**

The Association of Sustainable Tourism Operators of the Venice Lagoon has a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the Venice lagoon. This will ultimately create more room for nature and sustainable tourism. Combined with its medium high power and high interest, the stakeholder type is **Saviour**. This stakeholder is considered critical.

- **Residents of Venice**

The residents of Venice have a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the historical center of Venice, without constructing highly visible protective measures. Combined with its medium high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Tourists**

Tourists have a **positive** attitude towards the Perfect Lagoon, since the design safeguards the preservation and protection of the historical center of Venice. Combined with its low power and low interest, the stakeholder type is **Acquaintance**. This stakeholder is considered critical.

PROJECT RISKS STAKEHOLDERS

Now the three-dimensional stakeholder roles for the Perfect Lagoon design have been determined, we can identify the stakeholder risks which come into play. Per stakeholder role we will summarize the relevant stakeholders, highlight the critical stakeholders and identify the consequences it may have for the process of the project.

Savior

Comune di Chioggia, Comune di Padova, Comune di Venezia, Città Metropolitana di Venezia, Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna, Ministero della transizione ecologica, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Ministero della cultura, Italian Government, Treviso Airport, OTS Laguna di Venezia and the residents of Venice are labeled as Saviours according to the three-dimensional stakeholder analysis. Saviors can be identified by their high power, high interest and positive attitude towards the project, and are often described as an influential active backer. The savior type stakeholders are in favor of the project and will actively and progressively contribute to the process of the project. All of the savior type stakeholders, except for Treviso Airport, are critical stakeholders. During the project we should keep close attention to the critical stakeholders in the process, in order to prevent opposition of these critical stakeholders. The proposed strategy for each type of stakeholder will be further elaborated upon in Subsection 5.1.4.

Saboteur

Regione del Veneto, Ministero delle infrastrutture e della mobilità sostenibili, AVM/Actv, Cargo ships, Cruise ships, Porto Marghera and Marco Polo Airport are labeled as Saboteurs according to the three-dimensional stakeholder analysis. High power, high interest and a negative attitude towards the project are the characteristics of a saboteur. Regione del Veneto, Porto Marghera and Marco Polo airport are critical stakeholders within these saboteurs. Saboteurs are influential active blockers and will actively try to hamper the process of the project in order to prevent the execution of it. This type of stakeholder can be seen as a major threat in the process. However, project strategy can be used to steer these stakeholders in the preferable direction. This strategy will be further explained in Subsection 5.1.4.

Trip Wire

Giovanni Nicelli Airport is a stakeholder with a low amount of power and interest, and has a negative attitude towards the project, making this stakeholder a TripWire. Furthermore, Giovanni Nicelli Airport is labeled as a non-critical stakeholder, making it less important to the process. A trip wire is described as an insignificant passive blocker, meaning that this relatively insignificant stakeholder type will not actively try to block the project. The trip wire will therefore not be a major threat to the process and project. In Subsection 5.1.4 we will define a strategy to further decrease the risk these stakeholders pose.

Friend
Farmers are defined as a Friend according to the three-dimensional stakeholder analysis. This stakeholder has low power, high interest and a positive attitude to the project. Since the farmers are labeled as a non-critical stakeholder, they are less important to process. However, they should still be kept into account. As a friend, they have an insignificant role and will actively contribute to the process of the project. Subsection 5.1.4 will elaborate on the strategy we will apply to the stakeholders.

Irritant
The fishermen and hunters are non-critical stakeholders which are labeled as Irritant. Irritants are characterized by their low power, high interest and negative attitude towards the project. These stakeholders are identified as insignificant passive blockers of the project. Due to the fact that these stakeholders are insignificant, they will not pose a large threat, but they need to be taken into account. Further elaboration on the strategy can be found in Subsection 5.1.4.

Acquaintance
The tourists are a group of stakeholders which is identified as an Acquaintance. This type of stakeholder has low power, low interest and a positive attitude towards the project. The acquaintance can be seen as an insignificant passive backer, and will passively contribute to the process of the project. Even though they will not pose a threat to the process, we have defined a strategy for this stakeholder in Subsection 5.1.4.

STRATEGY PER STAKEHOLDER

The problems and opportunities we face for the process of the project have been identified by labeling each stakeholder. Per stakeholder type, as determined by making use of the three-dimensional stakeholder analysis, we will determine a strategy in order to steer them in the desired direction during the project. Extra attention will be paid to the critical stakeholders, as they are crucial to the project outcome.

Savior strategy
The stakeholder type savior does not pose an immediate threat to the project since it has a positive attitude to the project. However, this could change into a real threat when their expectations are not met. With their high power and high interest, these stakeholders can change into a strong opposition instead of a companion. Therefore, we need to pay attention to these types of stakeholders and do whatever is reasonable and necessary to keep them on our side of the project. We will have to attend to their needs. From Subsection 5.1.4 we know that every savior-type stakeholder is critical except for Treviso Airport. For this reason we prioritize the needs for the critical stakeholders over the needs for Treviso Airport. During the project, it may occur that we cannot comply with the needs and wishes of the critical stakeholders. When this is occuring, we will try to steer the stakeholders in a desirable direction. This can be done with legal, economic or communicative instruments. Since

the largest part of the savior-type critical stakeholders are governmental organizations which operate collaboratively in a network, we advise to use communicative instruments like regular meetings, early involvement in the process and the joint decision on common goals and targets. Furthermore, legal instruments in the form of contracts and economic instruments like subsidies and competition could be used to steer the stakeholders.

Saboteur strategy

The saboteur-type stakeholders will pose an immediate threat to the project, due to its negative attitude towards the project and its high power and high interest. It is necessary to prevent the saboteur from gaining an advantage. This can be done by engaging them during the project from the start, providing the saboteurs with the feeling that they are being heard in the process. This will result in the saboteurs being "disengaged" from the process and preventing them from inflicting an enormous negative impact on the project. However, we should be prepared for some small negative impacts. From Subsection 5.1.4 we know that Regione del Veneto, Porto Marghera and Marco Polo Airport are critical stakeholders. We will pay extra attention to these stakeholders. In order to steer the saboteurs in the desired direction, we will use legal, economic and communicative instruments. Economic instruments that could be used for Porto Marghera and Marco Polo Airport, because of the limitations the design has on both parties, are subsidies and reimbursements for the inconveniences. A legal instrument such as a commandment can be used for the removal of Porto Marghera, based on highly polluted soil on which it is built. Above all, it is advised to include these saboteur-type stakeholders in all communications from the beginning of the project.

TripWire

With its low power, low interest and negative attitude towards the project, the tripwire poses a minor threat to the project. However, this does not exclude the probability of the negative consequences actually occurring. Tripwires are the kind of stakeholders which are often overlooked in the process, leading to problems in a later stage when it could have been prevented. To reduce negative impact on the project, we will involve them in the process and make sure the trip wires are understood. This will prevent unexpected problems from arising. Subsection 5.1.4 shows us that only Giovanni Nicelli Airport is a stakeholder labeled as tripwire and is assessed as non-critical. It is advised to use a steering method for this trip wire. Due to its relative insignificance, one steering method will be sufficient. This will be the communicative steering method wherein the stakeholder will be involved early on in the process, in order for the stakeholder to fully elaborate on its viewpoint and achieve understanding.

Friend

The friend-type stakeholders are stakeholders with low power, high interest and a positive attitude towards the project. They are usually not a threat to the project unless they are treated wrongly. Even when it goes wrong, friends do not have enough power to make a substantial difference. However, we will involve them in the process by using these stakeholders as a confidant or sounding board. As written in Subsection 5.1.4 there is only one stakeholder labeled as friend, these are the farmers. We have concluded that this stakeholder is not a critical stakeholder. Further steering methods are not necessary, although it is advised to involve them in the entire process.

Irritant
The irritant-type stakeholders are stakeholders with a low power, high interest and negative attitude towards the project. This makes them a minor threat, due to their low power. However, their high interest makes them actively try to push their contrary views. In order to prevent the irritant-type stakeholders from obstructing the process, it is advised to apply the same strategy as with the saboteur-type stakeholders. This is engaging them in the process in order to prevent them from causing further nuisance. As shown in Subsection 5.1.4 there are no irritant-type stakeholders labeled as critical. Except for early involvement in the project, there is no steering mechanism that needs to be implied.

Acquaintance
The final stakeholder-type that is relevant for the Perfect Lagoon design is the acquaintance. This type is characterized by its low power, low interest and positive attitude towards the project. These stakeholders are usually not actively connected to the project and often don't want to. Furthermore, they agree to most parts of the project. A strategy for these stakeholders is to keep them informed on a transmit-only basis. This way they stay updated on the process and are satisfied with the involvement. From Subsection 5.1.4 we know that there is only one critical stakeholder labeled as an acquaintance, which are the tourists. Except for keeping this stakeholder constantly informed about the project and the process, there is no further steering mechanism that needs to be applied.

5.2 TECHNICAL DESIGN: SYMBIOTIC SYSTEM

This chapter discusses the feasibility of the second vision; that of a Symbiotic System. As described in Chapter 4, the symbiotic system focuses on interconnections between the islands.

5.2.1 HYDRAULIC STRUCTURES

The flood defense structure of the Symbiotic System contains a dam surrounding the historic city center of Venice, including the northern part of Lido and some surrounding islands. First, the location of the dam and bridges will be elaborated following with a suitability of Lido using it as a barrier. After this subsection, the preliminary design calculations for the dam is given. The dam is chosen to be made out of concrete and has a squared shape. It is open on the inside, allowing a metro line to be built. From [60] it is found that this open space on the inside should be at least 9.60m in diameter for a double metro track.

Location of the dam
Following from the spatial analysis made in Figure 5.16 the location of the dam is determined. When determining the location of the dam a minimum radius of 400m [60] is taken into account. This is considered because of the metro that is located inside the dam. In Figure 5.17 in orange the dam is represented. In this figure the red circles are representing the minimum angle the dam should have. In green the four shipping locks are given. A bridge will be used for the metro to pass the shipping locks as the shipping lock divides the dam.

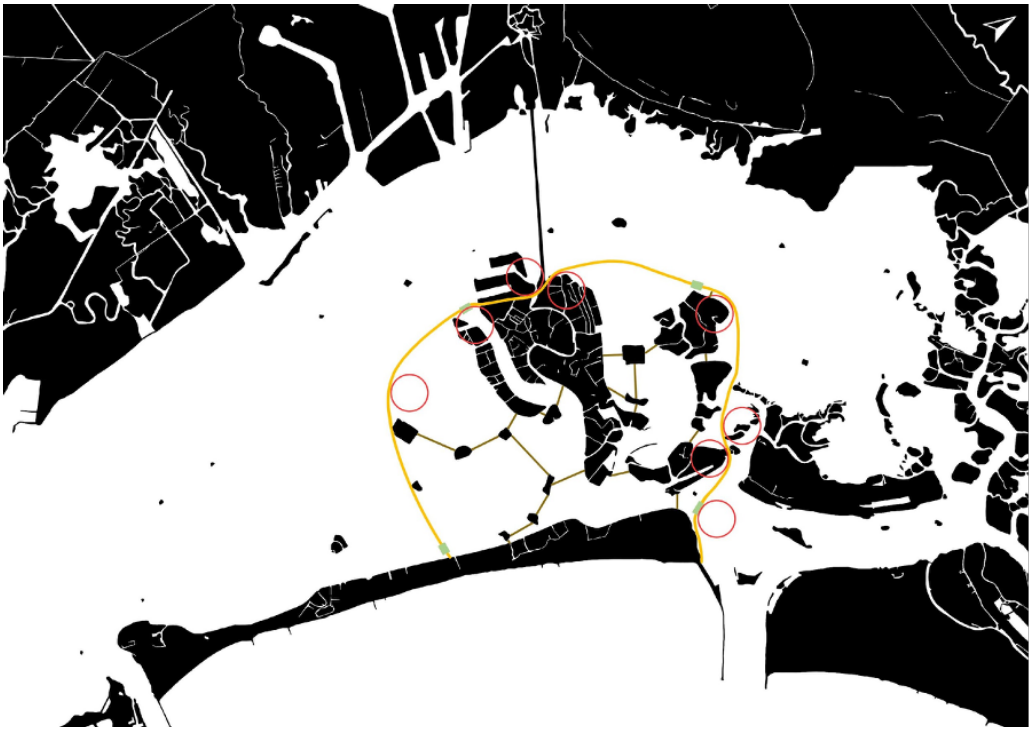


Figure 5.17: Location of the Dam represented in orange.

The location of the shipping locks is determined from the analysis of the major and secondary water transportation routes shown in Figure 5.18. In the places where the metro line located inside of the dam is disturbed by a shipping lock, the rails go above the dam and over the lock with a bridge

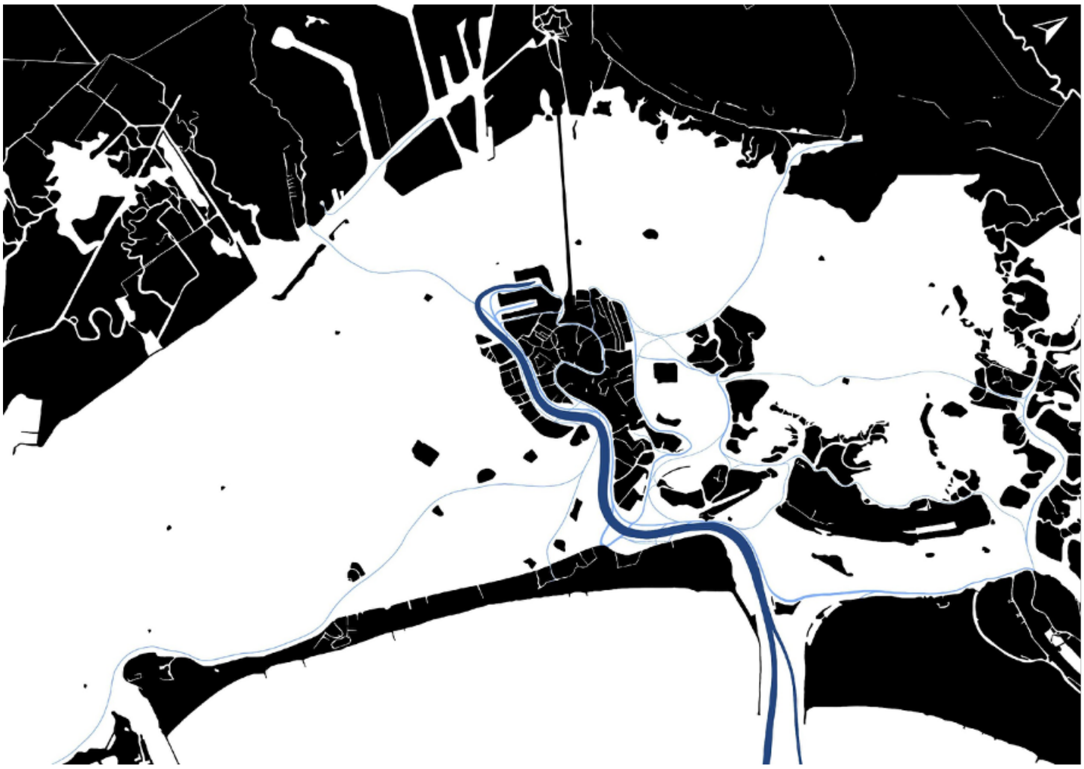


Figure 5.18: Main water route (military, produce, cruise, transportation) represented in dark blue, secondary water routes (transportation) represented in light blue.

Bridges

The Symbiotic System will make use of bridges to connect the islands and dam with each other. In this chapter not an exact design of the bridge is made as this is out of the scope of the project. However, an idea is made of how the bridge could look like and what the main dimensions should be.

First an inventory is made of the boats that are currently navigating inside Venice. These are represented in Appendix L. In the Symbiotic System the ferry that connects Lido with Venice will navigate outside the dam. This is necessary as it is still possible to transport the car from Lido to Venice. All the other boats from Appendix L will still be possible to navigate inside the Symbiotic System. The Rialto bridge has a height of 7.5m. So, for the rest of the bridges in the Symbiotic System also a height of 7.5m will be assumed as this is high enough for the ships to pass.

There will be two types of bridges: one for short distances which is only for pedestrians and one bridge for long distances on which a monorail is connecting the people on the islands. Because only pedestrians will pass the short bridge a light structure can be built. Furthermore, it has to be taken into account that in the future the bridges will be included in the expansion of the artificial islands, therefore the design bridge should be able to merge with the island in the future. In Figure 5.19 an overview of the location of the bridges is represented.

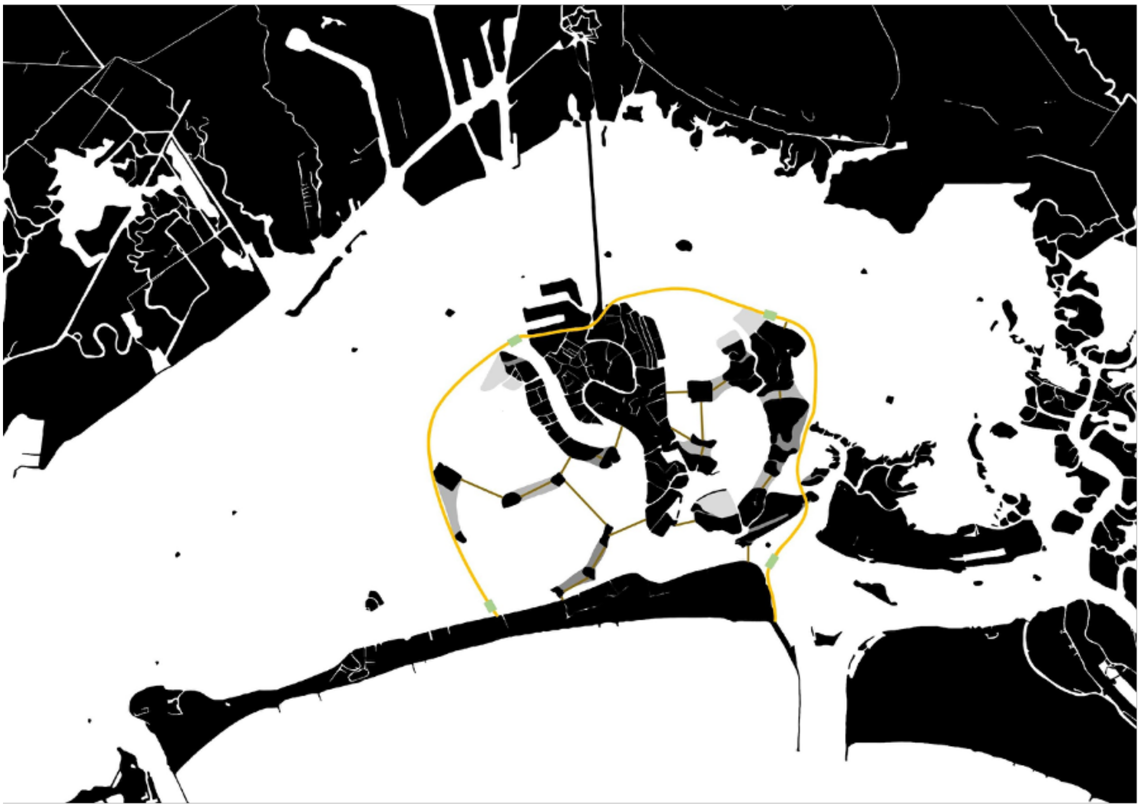


Figure 5.19: Location of the bridges represented in brown.
Secondary water routes (transportation) represented in light blue.

Water Level Extreme Scenario

For the determination of the design water levels and the influence of waves the reader is referred to paragraph Figure 5.1.1. Wind setup is not present since the dam is completely vertical. On the other hand, this shape gives the opportunity for waves to fully reflect against the vertical wall. The incoming significant wave will be twice as high at the boundary of the structure ($Href = 0.84m$).

Northern part Lido as flood defense

As can be read in the vision, Section 4.2, the northern part of Lido preferably has to be included in the primary flood defense lane. In Appendix D the full analysis can be read. It can be concluded that some parts of the current flood defense lane at Lido have to be elevated, either by a vertical wall, by using the current buildings as a flood defense or by a heightened dune as can be seen in Figure D.3.

Preliminary Stability Calculations

The dam is fully symmetric. The design is being evaluated for floating transport, immersing, sliding and overturning. Furthermore it is being checked if it is possible to construct buildings on top of the dam. Preferably the dam is constructed prefab on land and transported by boats towards the exact location where it can be immersed (Figure 5.20). The biggest advantage of this construction method is that it costs less than constructing the structure in situ (at location, see Figure 5.21). The complete calculation is explained in Appendix E.

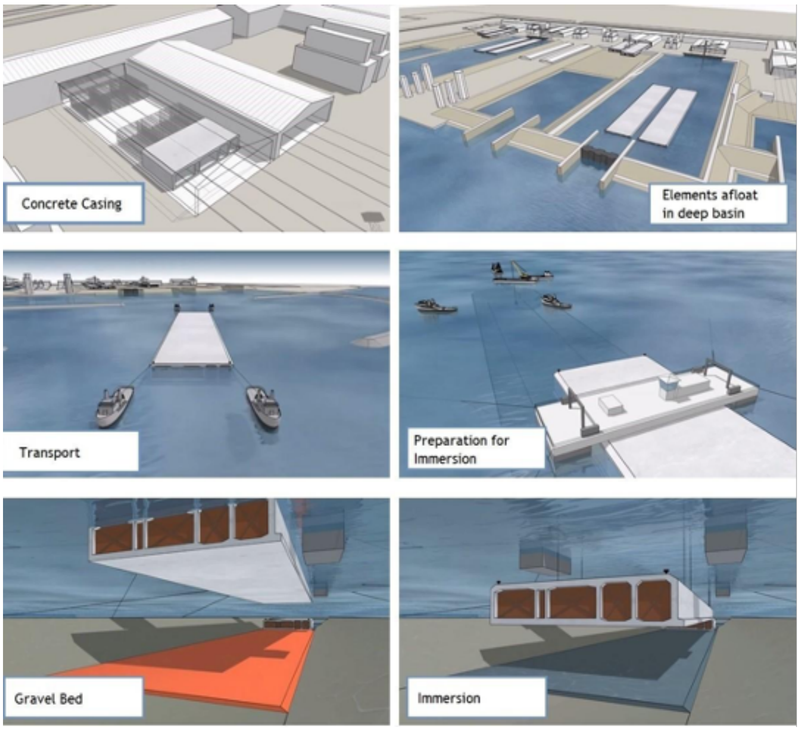


Figure 5.20: Construction stages of immersed dam construction [9]. NB: the tunnel shown is lower than the water level, in the Symbiotic System design the dam emerges from the water.

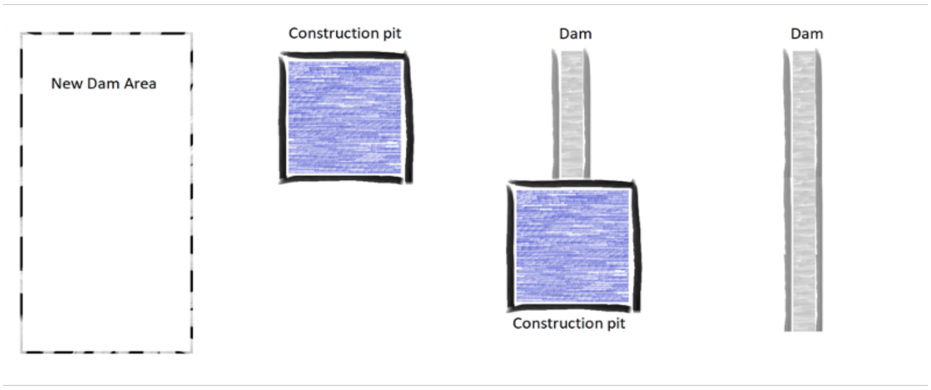


Figure 5.21: Construction stages of in-situ dam construction. Step 1: Define the building area inside the lagoon. Step 2: Build a construction pit, pump dry and build a dam inside the pit. Step 3: Repeat Step 2 for the other areas of the lagoon. Step 4: Finish the dam and remove the construction equipment.

As can be seen in Appendix E the dam cannot be built on land and being floated towards position due to the shallow water depth inside the lagoon. This means that the dam has to be built in situ. The following dimensions in Table 5.2 were found to give a stable preliminary dam design. It should be noted that these dimensions are also approved according to the guidelines for double metro tracks according to the TU Delft dictation for the geometrical design of roads and railways [61], provided that the total free height of the metro tracks is > 5 m (excl. installations etc.).

Table 5.2: Dam dimensions.

	4 m (design)
h_{dam} [m]	**9**
b_{dam} [m]	**19**
l_{dam} [m]	**22**
t_w [m]	**2.5**
t_b [m]	**1.5**
$b_{platform}$ [m]	**4**
h_{free} [m]	**6**

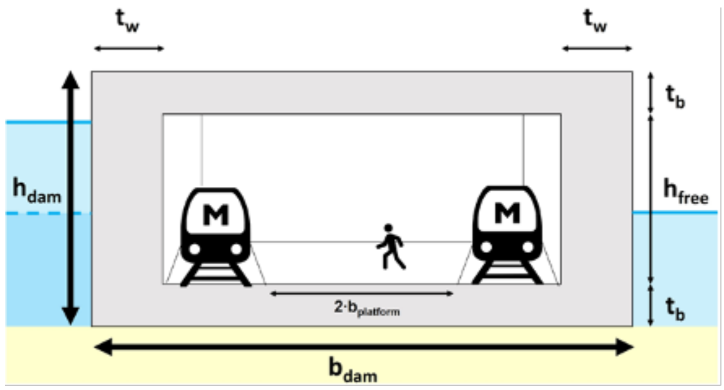


Figure 5.22: Cross-sections dam surrounding city center of Venice.

Shipping Locks

In Figure 4.19 the locations of the shipping locks are given. These shipping locks will be incorporated into the primary flood defense lane and for this reason their gates must be strong enough. According to the TU Delft manual about locks [10] there are two shipping lock gates which are suitable for these conditions: single leaf gates and rolling gates (Figure 5.23). A single leaf gate can be visualized as an opening door because of the radial way of opening. A rolling gate can be more or less visualized as a sliding door. The shipping lock gates have to be incorporated into the dam design. For this reason a single leaf gate is preferred since it occupies less space of the dam and thus the metro system can be used in a more optimal way. A drawback of this type of gate is its dimensions: single leaf gates can be used for widths up to a maximum of 16*m* so this is a thing to keep in mind for the vessels making use of the shipping locks.

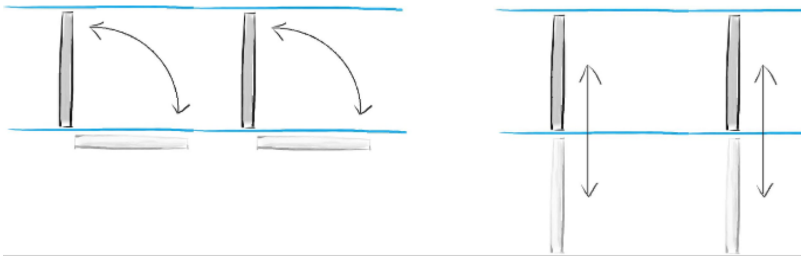


Figure 5.23: Top view of two suitable shipping lock gates. Left: single leaf gate. Right: Rolling gate.

Only small vessels are allowed to enter the middle part of the lagoon. Moreover due to the height limitations at the locations of the shipping locks only small vessels are able to enter the middle part of the lagoon. For now it is assumed that at least a CEMT II class vessel should enter the lagoon, requiring a shipping lock chamber width of 7.5*m* [10]. Furthermore the shipping lock consists of at least two gates which are connected to the dam. Having a dam width of 19*m* this means that each gate has a width, just like the shipping lock chamber, of 7.5*m*. Preferably the lock heads are in this case in between the width of the dam, but further investigations have to be done.

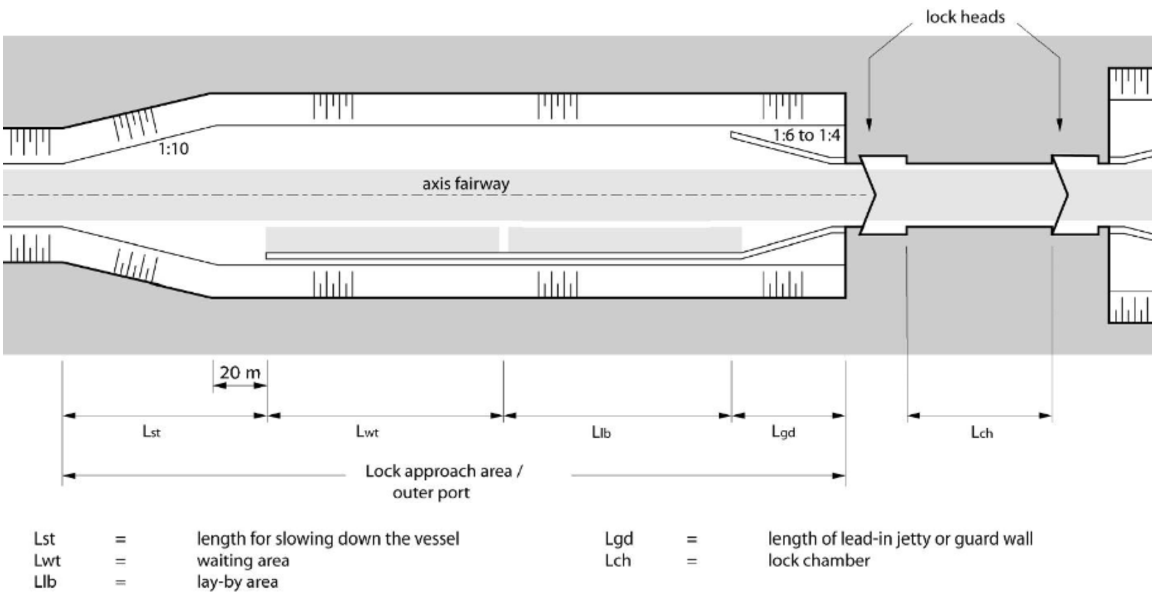


Figure 5.24: Top view shipping lock structure Symbiotic System [10].

Table 5.3: Approximations of lock dimensions Symbiotic System for a CEMT II class vessel.

	Dimensions
$B_{max,\,vessel}$ **[m]**	**6.6**
$L_{max,\,vessel}$ **[m]**	**≈ 7**
B_{ch} **[m]**	**7.5**
L_{ch} **[m]**	**≈ 15**
L_{lb} **[m]**	**≈ 15**

In order to make it possible for the metro-line which is located inside the dam to pass the shipping lock, a bridge will be built over the shipping lock. Not an exact design will be given but with some rule of thumb a rough estimate of the needed space can be made. Following from Appendix E a maximum slope of 7% for the bridge is assumed as this is the maximum angle that is allowed for metro's. Furthermore the bridge will be designed for a height of $7.5m$ above water level ($14.7m$ above the ground). Considering this, roughly $200 meter$ is needed for the bridge to reach a height of $14.7m$. So in total $407.5m$ should be reserved for the bridges at the shipping locks in the dam-design. In figure Figure 5.25 a sketch of the cross section is represented.

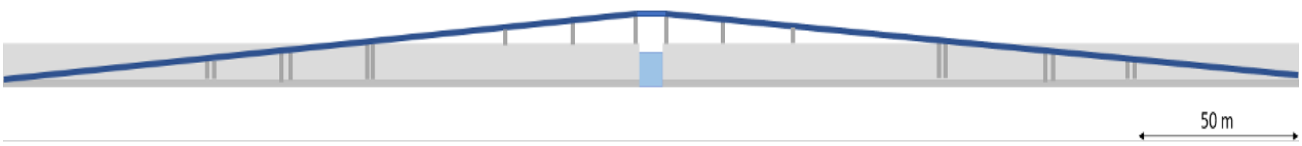


Figure 5.25: Cross-section shipping lock with bridge.

In figure Figure 5.26 a top view of the bridge over the shipping lock is represented. Because the bridge is high enough for all the ships to pass, the bridge will not need to close when the doors of the shipping lock are open.

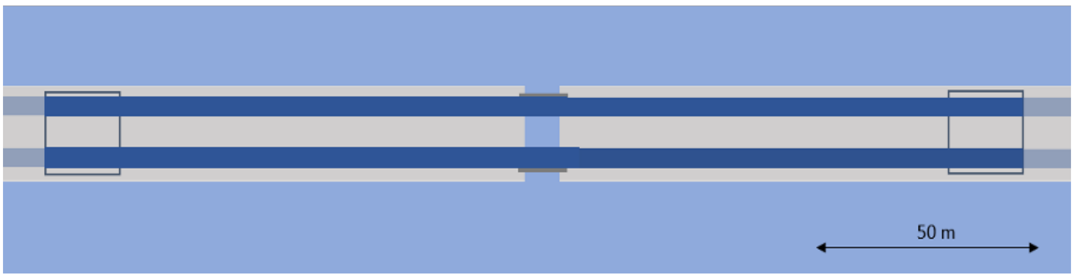


Figure 5.26: Top-view bridge over shipping lock.

Figure 5.27: 3D view bridge over shipping lock.

Spillways

The best and most efficient option for a spillway inside the dam design would be pipes which can be placed beneath the metro line. To determine the amount of pipes the same elaboration is performed as with the Perfect Lagoon (see Section 5.1). The full elaboration for the spillways inside the dam can be found in Equation E.2. The iteration process gives eventually the need for 11 pipes with each a diameter of $2m$ at a height measured from the bottom of $2.5m$. The Reynolds number inside the pipe amounts in this case $1.22 \cdot 10^7$ indicating a very turbulent flow.

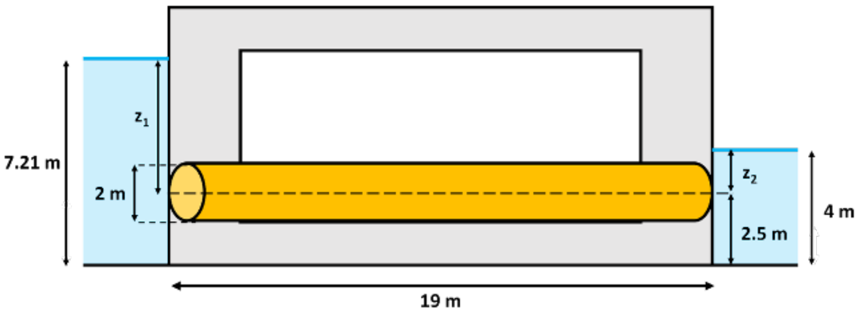


Figure 5.28: Dimensions pipe spillways for the two different dam cross-sections.

As can be seen in Figure 5.25 the metro track elevates towards the roof of the dam to eventually move over the shipping locks. This elevation results in extra unused space inside the dam which can be used to put the spillway pipes. Since about 11 spillway pipes are needed, the two best shipping lock locations suffice as spillway locations as well, which are the two shipping lock locations located on the main shipping route in Figure 5.18. Further research should be done to investigate the influence of vessels moving in and out at the shipping locks and the turbulent spillway outflow at the same location.

Foundation
The subsoil in the Venice environment is very weak (Section A.2). For this reason a shallow slab foundation is not recommended and the dam foundation would be made out of piles. No further calculations regarding this pile foundation are given in this report.

5.2.2 ARCHITECTURE

The goal of the design proposal was to not only ensure protection of Venice and (some) islands from the rising water level in the lagoon, but also to protect the architectural and urban heritage of Venice. This section elaborates on the spatial interventions that were implemented into the Symbiotic System vision.

The growth of artificial islands
The concept of expanding the land by building artificial islands next to the existing ones was introduced in Chapter 4.2.1. In order to continue the traditions of Venetian construction, during the second stage of island expansion the construction on piles method was used. This type of foundation is used in Venice historically and still exists and supports most of the streets and buildings. The principal of the method is using the wooden piles and inserting them around 10m under the ground until they reach a layer of soil made of hard clay. For each 1m² area around 6-12 piles are put. To prevent soil erosion, crushed stone and debris is filled between the piles. The Symbiotic System makes use of this technique. A section with the artificial island expansion shows the use of pile foundation in Figure 5.29.

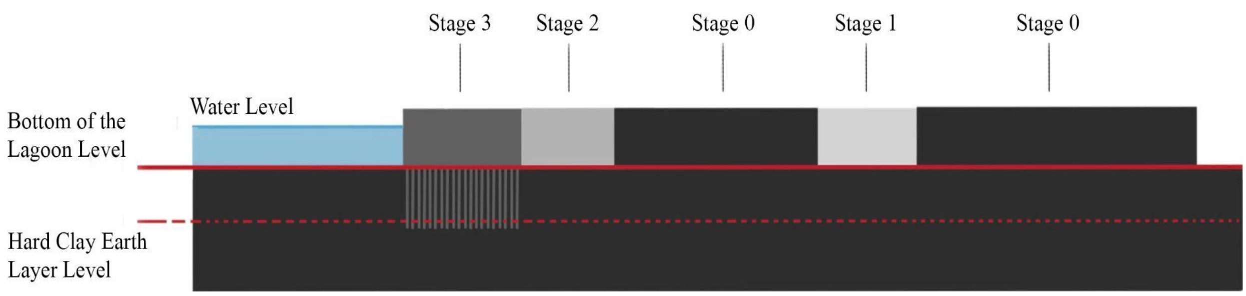


Figure 5.29: Pile foundation in growth of artificial islands.

Stage 0 represents the existing islands with the darkest color showing the existing earth. During stages 1 and 2, the dredged earth is used for building the artificial land. This earth is obtained from dredging the place for building of the dam and from the lagoon earth dredging. During stage 3, the traditional method of building on piles foundation is used.

Dam urban dimension
The dam is built along the existing islands. Later, artificial islands are added to extend the land inwards and along the dam. Figure 5.30 represents the conceptual analysis and design of the area next to the dam located in the North of the design next to the Murano island. The existing composition of buildings, structures and parks is continued on the extended land to create a homogeneous urban environment.

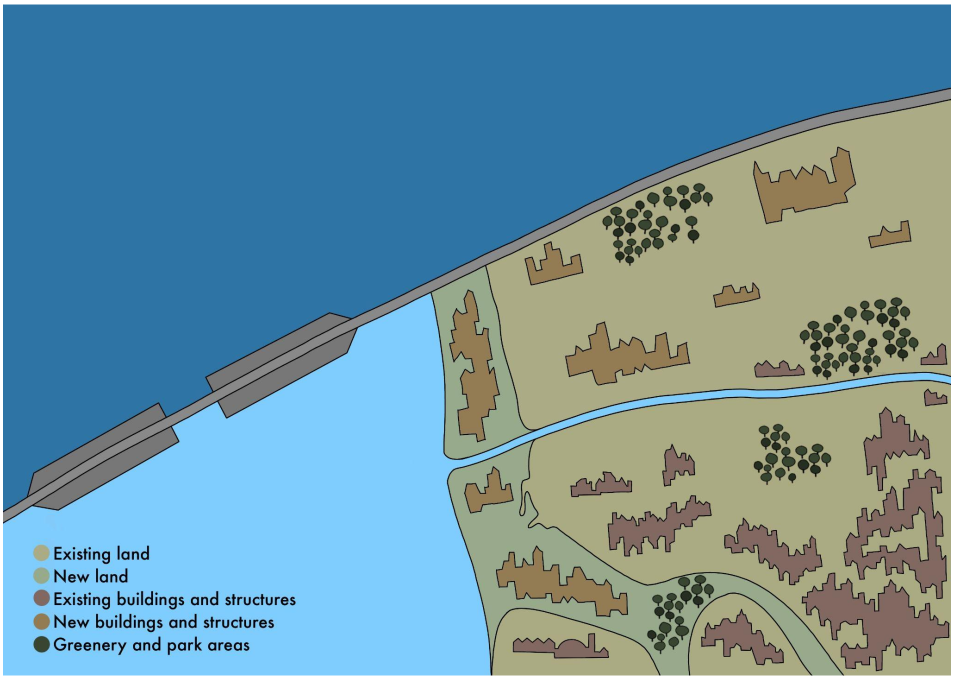


Figure 5.30: Urban organization next to the dam scheme.

The concept represents the existing land, building and structures and the additional land continuing the building and park areas pattern. This area is a good choice for analysis and further design elaboration as it contains all the main spatial elements of the Symbiotic System vision: existing and added land, the dam and the shipping lock that connects the inner protected system to the outside lagoon.

Figure 5.31 shows a more detailed view on the urban situation next to the dam. In the area close to the shipping lock and the bridge, the row of houses is placed right next to the dam to utilize the maximum of the space.

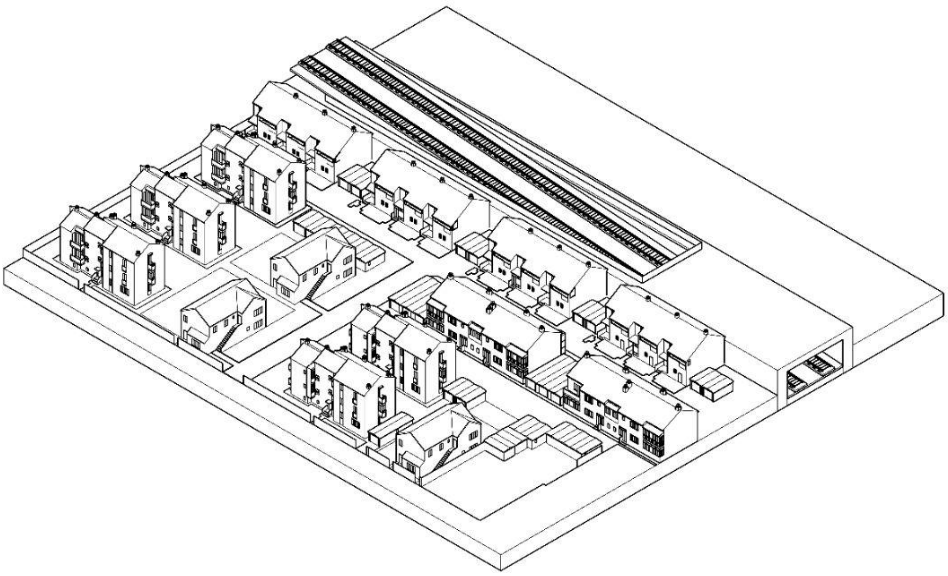


Figure 5.31: Urban organization next to the dam scheme.

Dam architectural dimension and function

To improve the spatial quality of the dam surrounding the islands, it was decided to increase its potential from merely being a water defense system to a structure holding other important functions. Firstly, to make use of the inside of the structure, a metro line was placed there that would improve the connection and infrastructure in the system. Secondly, additional structures can be built on top of the dam and hold various functions, such as residential, office and retail. In order to make the most use of the space inside the dam, some buildings continue inside of it. Because it is impossible to have any windows or openings inside the dam structure, the functions positioned there are those that meet these requirements, such as the storage spaces.

The buildings on top of the dam don't only follow the edge lines of the dam structure but also continue "over" it. This is done for two main reasons. First of all, this improves the functionality of dam "walls" and makes use of more space on the outside part of the dam, but also this improves the aesthetical view of the dam by covering up the plain concrete.

There are three ways of connecting the dam to the land: with a building, with a staircase and with a park. In the first scenario, the building on top of the dam goes over the dam edge lines and partially stands on the island inside of the dam. In this case the building can have multiple entrances on both the level of the island and the level of the top of the dam. In some places, staircases can be built to connect the streets on ground level of the island to the streets on top of the dam. Urban parks are the third scenario. In addition to acting as a connection, parks can add to the urban quality of the area and provide space for sports and leisure activities. The Figures 5.32 and 5.33 show the two options for the architectural section of the dam.

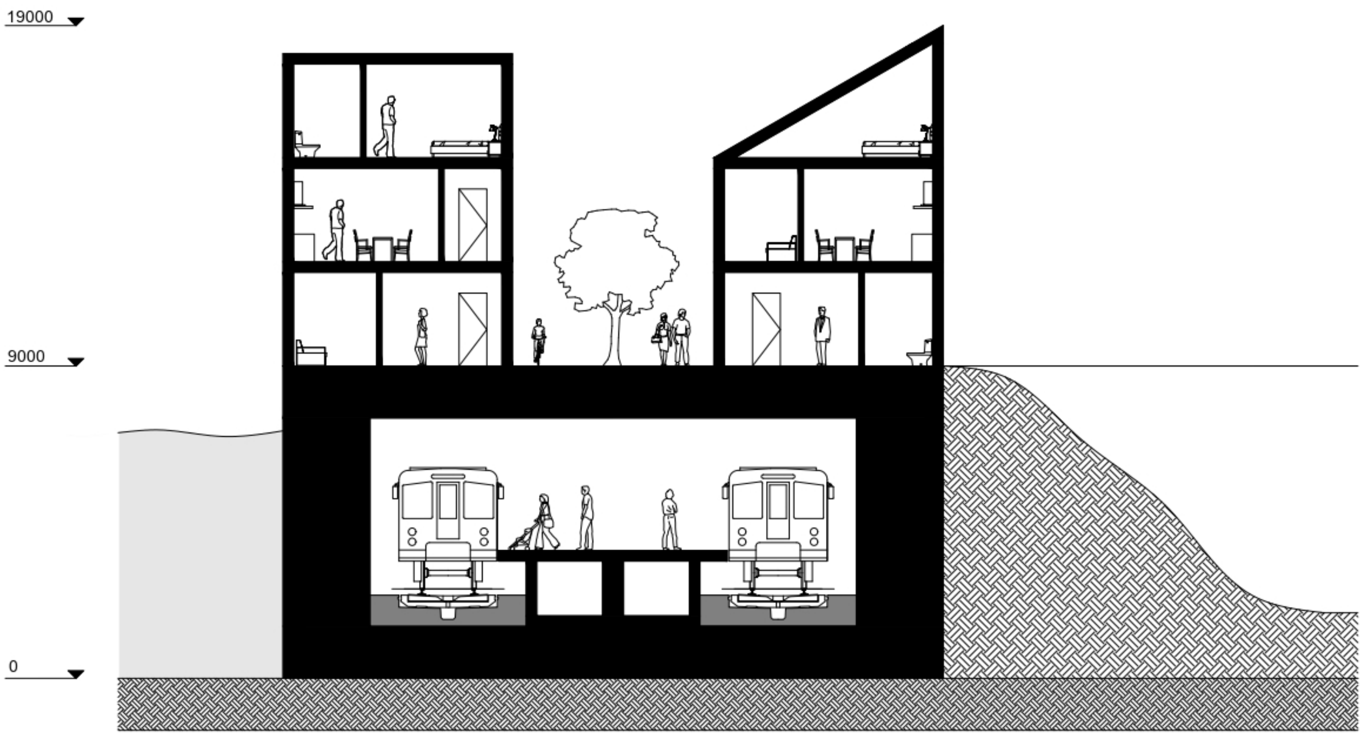


Figure 5.32: Section 1: metro line inside the dam, buildings on top of the dam, park connection to the island.

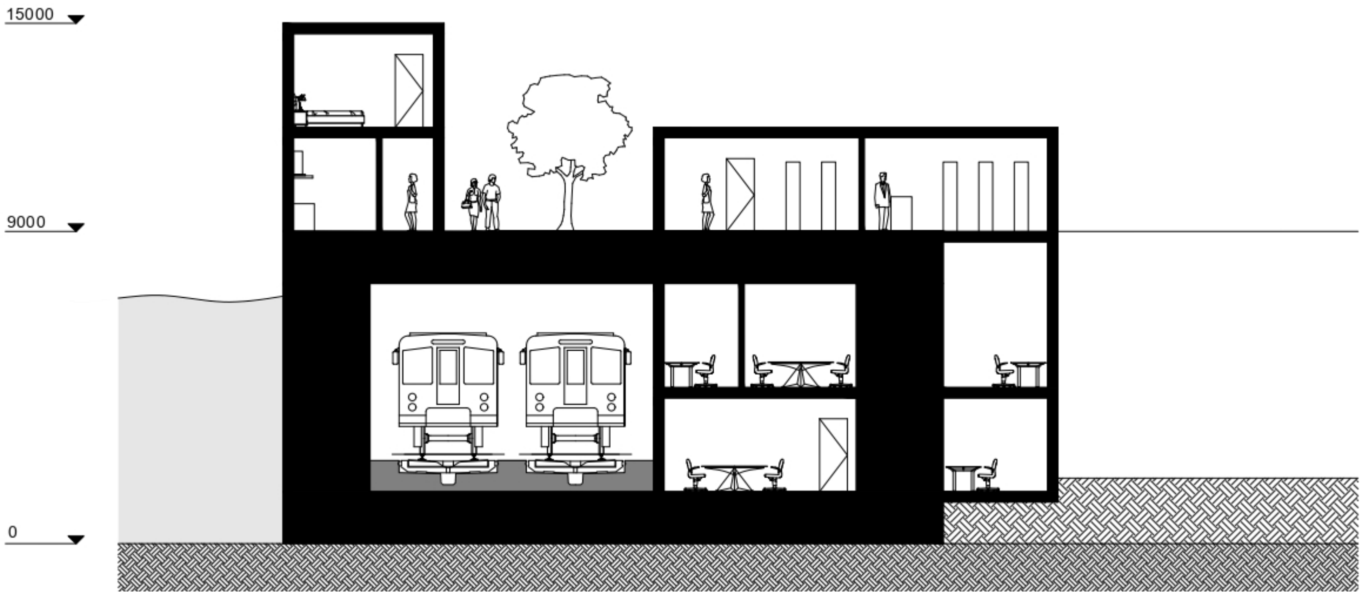


Figure 5.33: Section 2: metro line inside the dam, buildings on top, partially inside and over the dam, building connection to the island.

Following the dimensions of the dam provided by hydraulic engineering calculations, the sections shown in Figures 5.32 and 5.33 explore the further functional and spatial possibilities of the dam structure. Figure 5.32 shows the metro line with two trains going opposite directions positioned inside the dam. It shows the scenario of the metro station with the platform positioned in the middle so that people could access the trains. There are two rows of buildings erected on top of the dam with the street between them. A park is made on the inside of the dam for accessibility and leisure. Earth that is needed to create the park can be taken from that, gotten from dredging for the dam structure. In Figure 5.33 there is also the metro line inside the dam. However, this section represents the part of the line where there is no station, so the two lines can be placed right next to each other, leaving space for the buildings to be also placed inside of the dam structure. This scenario shows how the island level can be connected to the top level of the dam with the building that is supported by both.

Dam aesthetics and view from Venice

Building a continuous high concrete structure around Venice and islands is a drastic solution both, from the engineering and also from the historic and aesthetics points of view. A rare person would find a plain concrete wall beautiful and adding to the aesthetic quality of the area. To minimize the effects of the dam, several design interventions were implemented.

According to the calculations of hydraulic structures and urban drawings, it turned out that the visual effects of the dam would already be less than initially thought, as the height of the dam is not big enough to be seen from very far away, especially if one is standing in the middle of the streets on any island where the view would be obstructed by surrounding buildings. Figures 5.34 and 5.35 show the urban section where the heights of the different islands, building structures, the dam and water levels can be seen.

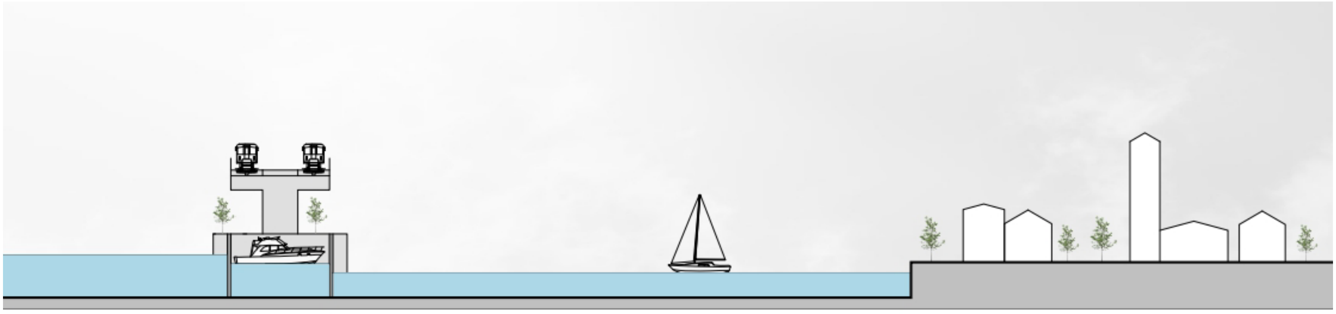


Figure 5.34: Urban section Symbiotic System: shipping lock.

Figure 5.35: Urban section Symbiotic System: dam.

It is seen that the only scenario where the dam can cause visual discomfort is when the island is not directly adjacent to the dam but has water in between. According to the planned growth of artificial islands, most length of the dam will be connected to the land directly and therefore the factor of aesthetical discomfort would be minimized. The only places where the dam can't be directly connected to the land of the islands is in the four places along the length of the dam where the shipping locks are located.

Another method of improving the aesthetics of the dam was already mentioned in this chapter. By building structures and parks on top and around the dam, the plain concrete is covered and not visible. It just looks like a continuation or extension of the already existing structures or towns of Venice. Figure 5.36 presents an impression of the view of Venice and the dam from the bird eye level.

Figure 5.36: Bird eye view impression of Symbiotic System.

It is clearly seen that the dam structure is barely noticeable due to its height. The new structures on top of the dam blend with the existing towns.

5.2.3 RIVER DYNAMICS

This section discusses the feasibility of realizing the PD-VE waterway, described in Figure 4.2.1, as a hard human made construction and will mention its consequences to the Venice lagoon.

The Padua-Venice (PD-VE) Waterway

The PD-VE will give a economical boost to the hinterland cities of the Venice lagoon, as the waterway connects the industrial areas of Padua and Venice. To allow the navigation of modern fluvial boats, the waterway PD-VE consists in a channel of trapezoidal shape (about 5m-deep and 34m-wide at the bottom) connecting Padua to the Venice lagoon and crossing the Brenta river downstream of Padua. The waterway will be debouching near Fusina, as will be the case for the natural solution for diverting the Brenta river described in Subsection 5.1.2. In particular, a partial reduction of the flood risk could be achieved using the PD-VE waterway, when conveying part of Brenta river discharges into the lagoon of Venice.

5.2.4 COASTAL DYNAMICS

Contrary to the approach of the Perfect Lagoon, in the Symbiotic System, Venice and its surrounding islands are isolated from the rest of the lagoon which enables the lagoon to find a new balance by itself with as little human intervention as possible. Below, the consequences to the lagoon are explored and explained.

Present and future situation without symbiotic system

In Subsection 5.1.3 the current situation of the lagoon was already explained. Here a change in erosion rate from $0.3Mm^3 y^{-1}$ to $0.8Mm^3 y^{-1}$ in the last century was obtained, solely caused by human intervention in the lagoon. In Figure 5.37 the expected erosion in the future is represented. From this figure it can be obtained that behind the Maramocco inlet a lot of erosion is expected. Because the container ships will not pass the northern part of the lagoon less dredging is needed there. Therefore the lagoon in the northern part is in some sort of stable equilibrium and in the future less morphological change is expected.

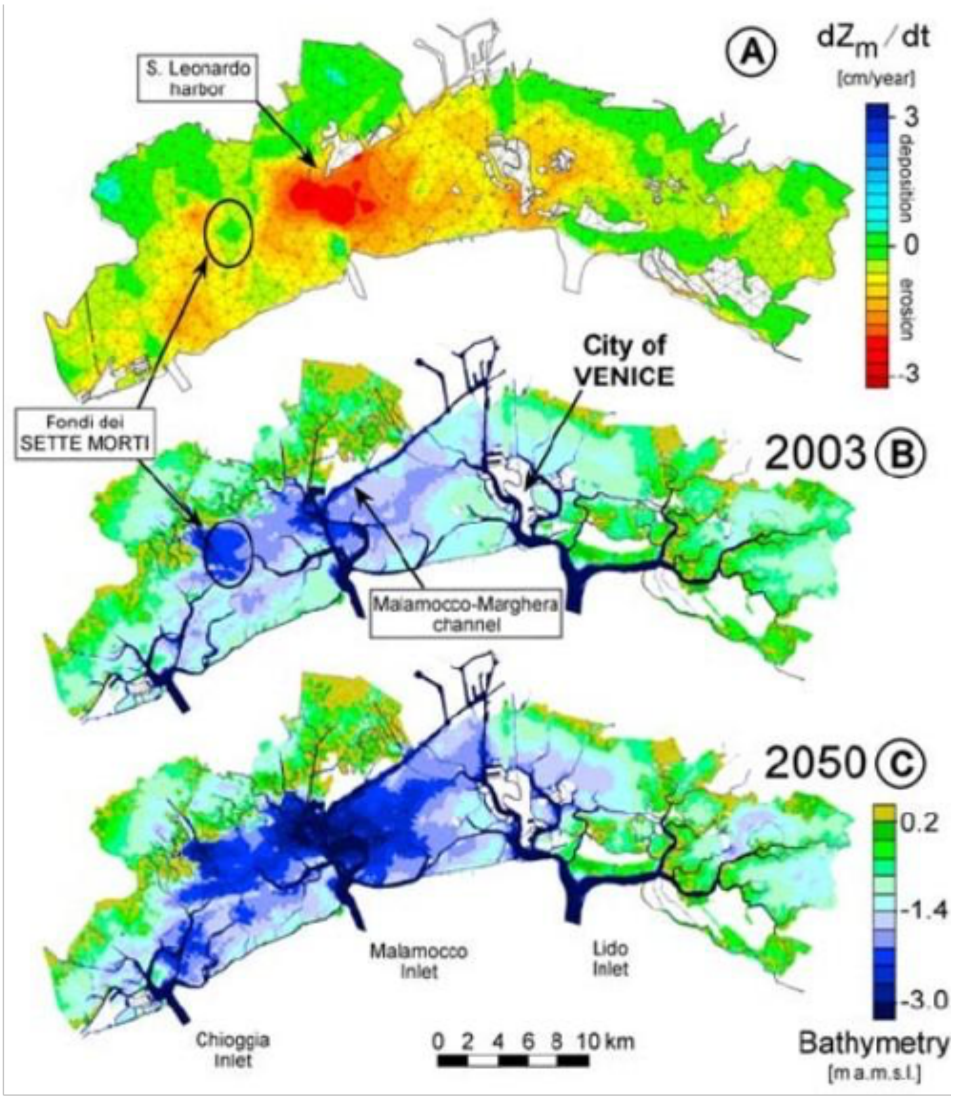


Figure 5.37: Expected erosion in the lagoon [11].

Future Sediment budget

In the Symbiotic System concept Venice and the surrounding islands are priority. The dam secures the future safety of these islands. However this dam will have an impact on the rest of the lagoon as the tidal prism is affected, this is the volume of water that flows in and out during one tidal cycle. Because the dam is located between two watersheds it is assumed that the effect of the dam will only influence the morphology in Area 2, see Figure 5.39. Also the Brenta that is diverted back to the lagoon for better connectivity with the hinterland will bring more sediment into the lagoon which will decrease the expected erosion as it is now. This will mostly influence Area 3. Here it is assumed that the location of the watersheds will remain the same after the interventions which in reality will slightly differ from the current locations.

Tidal Prism

In the Symbiotic System Venice and its surrounding islands will be excluded from the rest of the lagoon by a dam which causes no tide to occur anymore inside this Symbiotic System. Therefore less water is “needed” between these two watersheds and the tidal prism decreases. In Figure 5.38

the waterflow and the area that decreases the tidal prism is represented. Equation 5.2 shows the relation between the channel volume of the cross-section and the tidal prism, [62].

$$Ac = xP^n \qquad (5.2)$$

Where Ac is the cross-section of the channel, $x = 7,489 \cdot 10^{-4}$ (for jettied inlets), P is tidal prism (H (tidal range)$\cdot$ A(surface area)), and $n = 0.86$ (for jettied inlets), [63]. Rewriting this formula which can be found in Appendix G results in a new stable channel cross-section of:

$$Ac2 = 0.79 \cdot Ac1 \qquad (5.3)$$

Further, from this it can be concluded that because of the building of the dam the channel volume will decrease, this is only possible when extra sediment is supplied from outside. Therefore sediment will erode from the ebb-tidal delta and surrounding coasts into the lagoon. Therefore it is expected that there will be more deposition at the inlet (so covering MOSE) and also more dredging is needed to suffice the required water depth for access to the channel. Following from Equation 5.3 an increase of 20% is expected for the annual dredging. Following from this the beaches at Lido will experience more erosion as the sediment demand is higher from the lagoon.

Figure 5.38: The waterflow (purple) and the decrease in tidal prism (orange).

Sediment budget

For the sediment budget it is difficult to conclude where exactly the sediment will erode and dispose. Therefore for the sediment budget the lagoon is first simplified assuming equal erosion/deposition all over the lagoon. Afterwards the expected differences within the lagoon will be discussed. Assuming a simplified lagoon the sediment budget will be:

Table 5.4: An overview of the annual sediment budget, numbers are in $m^3 y^{-1}$.

Future sediment "sources"		**Future sediment "sinks"**	
River Brenta input	948, 400	412, 000	Dredging
		800, 000	Erosion
Total	948, 400	1, 212, 000	

Following from this the lagoon will erode with 262, 000m^3 per year which is reasonable. This is almost equal to the erosion prior to all the human interventions in the past century. But in the future the lagoon will keep eroding which results in retreat of land which is not protected by the symbiotic system. However because of the import of the Brenta this will be less than represented in Figure 5.37.

Now a closer look is taken when we do take the watersheds and different inlets into account. As seen in Figure 5.37 most of the erosion takes place in area 3. This however is also the place where the Brenta will dispose of its sediments. Therefore the expected erosion at this place will be lower than is assumed. The expected erosion in Area 1, 2 and 4 are expected to be less different than now expected. Also some extra dredging in Area 3 might be needed as there are navigation channels here that should be maintained. The decrease of tidal prism in Area 2 will result in sediment import at the Lido inlet. Therefore more dredging in the future will be needed to maintain the Lido inlet and suffice the channel required channel depths.

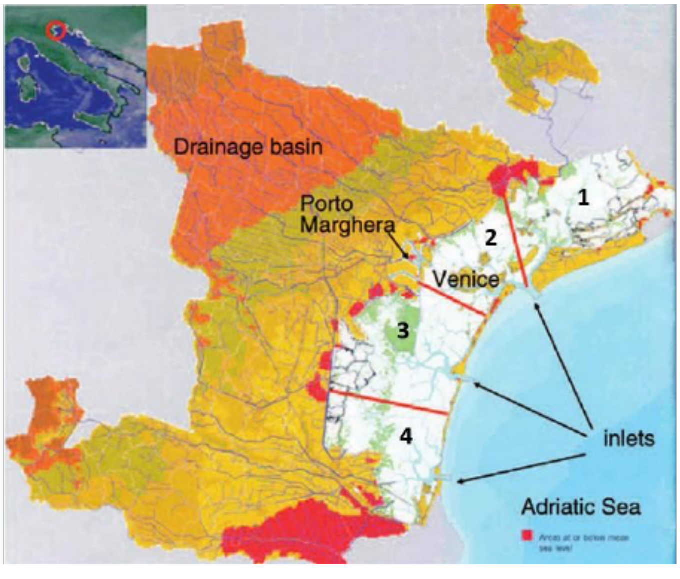


Figure 5.39: Figure illustrating the watersheds dividing the Venice lagoon into 4 sub-basins [12].

Dredging
In the Symbiotic System the accessibility of the port of Porto Marghera is of great importance. The access channels and the port will need to be dredged on an annual basis to maintain the required water depths for the vessels. The lagoon channels are undergoing siltation of 412.000m^3 on an annual basis, [64]. So on average in 25 years there is $10.3 \cdot 10^6 m^2$ sediment available to be disposed back into the lagoon. Moreover some additional dredging will be needed to enable vessels with an increasing draught to more at Porto Marghera.

Unfortunately the use of the dredged materials is not allowed as it is polluted with metals. However some researches show that the concentration of metals is decreasing over the past years, [13]. In Figure 5.40 it can be seen that the concentration of metals is decreasing, however the metal Cu is still too high. Further research on the risk analysis could be of use as it would be highly valued if this dredged material could be used to expand the islands. According to the surface area obtained from Figure 4.13 the amount of material that is needed for the islands is around $9 \cdot 10^6 m^3$ sand for the blue area, $10 \cdot 10^6 m^3$ sand for yellow, $12 \cdot 10^6 m^3$ sand for orange. So if the dredged soil would be accepted by the authorities the dredged materials could be of use for the artificial islands. In this way the sediment is kept inside the lagoon which is a sustainable solution.

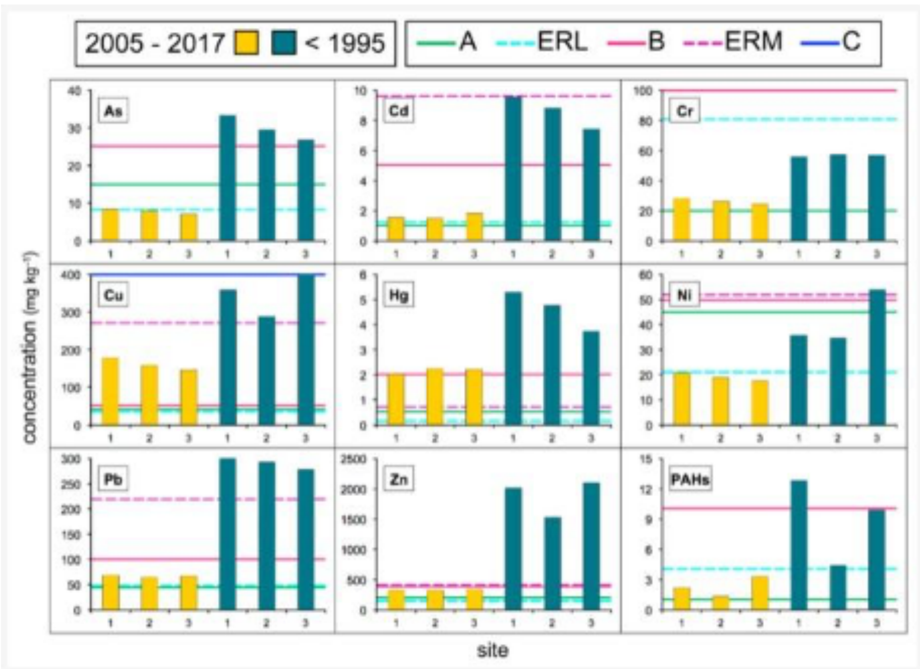


Figure 5.40: Comparison of mean contaminant concentrations (mg kg 1, dry weight) in recent (2005–2017) and past (<1995) canal sediments with local (Italian Ministry of the Environment; limits A, B, C) and international (NOAA; ERL and ERM) Sediment Quality Guidelines (SQGs) [13].

MOSE
In the plans of the symbiotic system, the lagoon inlets play a huge role in the interconnectedness of the system. In the case of sea level rise rendering the MOSE unable to act as storm surge barrier after the next thirty years, a new function is hard to find that still promotes this interconnectedness. This does not mean that the MOSE does not fit in the plans of the Symbiotic System however. By

changing the gates for larger ones and keeping the current gate lifting/lowering mechanism intact, an affordable option to use the MOSE in the next 100 years to come is available. By swapping the gates for larger ones, the MOSE will be able to act as a secondary flood defense system protecting the inner dam against extreme storm surge scenarios. By using the MOSE as a secondary flood defense system, the primary flood defense system can be designed for less extreme storm scenarios, reducing potential costs as well as risks for the city of Venice. Additional research needs to be done on a cost benefit analysis of changing the MOSE life gates versus extra heightening of the dam to see if this is truly beneficial.

5.2.5 STAKEHOLDER STRATEGY

In this paragraph we will elaborate upon the stakeholder analysis and determine a strategy in order to deal with the stakeholders in the Symbiotic System design. We used the same method and sequence as elaborated upon in Subsection 5.1.4, only this time while keeping the design of the Symbiotic System in mind. For the complete stakeholder analysis, as imported from Microsoft Excel, see Appendix N.

THREE-DIMENSIONAL STAKEHOLDER ANALYSIS

As explained before in Subsection 5.1.4 and Subsection 3.2.3 the three-dimensional stakeholder consists of three axes: power, interest and attitude. In Section 3.2 we already determined the values on two of the axes, namely power and interest. To complete the three-dimensional stakeholder analysis, we start by evaluating the attitude of each stakeholder towards the design of the Symbiotic System. This results in a typification of every stakeholder. The attitude and typology of the stakeholders are:

- **Comune di Chioggia**

The municipality of Chioggia has a **positive** attitude towards the Symbiotic System, since the design leaves the lagoon as it is, and implies no radical changes to the environment. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Comune di Padova**

The municipality of Padua has a **positive** attitude towards the Symbiotic System. This is because of the construction of the new canal, connecting Padua to the Venice lagoon and the Adriatic Sea, which improves the economic position of Padua. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Comune di Venezia**

The municipality of Venice has a **positive** attitude towards the Symbiotic System, since the design safeguards the preservation of the historical center of Venice. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Città Metropolitana di Venezia**

The metropolitan city area of Venice has a **positive** attitude towards the Symbiotic System, since the design safeguards the preservation of the lagoon and the historical center of Venice. Combined with its high power and high interest, the stakeholder type is **Savior**. Furthermore, this stakeholder is considered critical.

- **Regione del Veneto**

The Veneto region has a **positive** attitude towards the Symbiotic System. This is because of the new connections that will be made in the city, the lagoon and the region. This will strengthen the regional network. Furthermore, the historical center will be protected in this design. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Soprintendenza Archeologica, belle arti e paesaggio per il Comune di Venezia e Laguna**

The Superintendence of Archeology, Fine Arts and Landscape for the City of Venice and Lagoon has a **negative** attitude towards the Symbiotic System, since the design safeguards the preservation and protection of the historical center of Venice, but the lagoon is not being protected. Combined with its high power and high interest, the stakeholder type is **Saboteur**. Furthermore, this stakeholder is considered critical.

- **Ministero della transizione ecologica**

The ministry of environment and ecology has a **negative** attitude towards the Symbiotic System, since the design includes no ecological or nature protective measures. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is considered critical.

- **Ministero dell'Ambiente e della Tutela del Territorio e del Mare**

The ministry of environment, land and sea protection has a **negative** attitude towards the Symbiotic System. This is because in the design only the historical center of Venice will be protected from sea level rise and sedimentation, but not the surrounding islands and the hinterland. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is considered critical.

- **Ministero delle infrastrutture e della mobilità sostenibili**

The ministry of sustainable infrastructures and transport has a **positive** attitude towards the Symbiotic System. By reconnecting the hinterland with a canal, a new infrastructural connection has been made. Furthermore, the creation of the metro and trams between the islands, improves the infrastructural connectivity in the area. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Ministero della cultura**

The ministry of culture has a **positive** attitude towards the Perfect Lagoon, since the historical center of Venice is being preserved and protected, safeguarding Italy's cultural heritage. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Italian Government**

The Italian Government has a **negative** attitude towards the Symbiotic System, since this design is the most expensive one, compared to the Perfect Lagoon. Thus financially, this design is not preferable. Combined with its high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is considered critical.

- **AVM/Actv**

AVM/Actv has a **positive** attitude towards the Symbiotic System. More means of public transport will be created in the design. This will create more opportunities for this public transport operator to operate these lines. This will lead to an increase in the revenues. Combined with its medium high power and high interest, the stakeholder type is **Saboteur**. This stakeholder is not considered critical.

- **Cargo ships**

Cargo ships have a **positive** attitude towards the Symbiotic System, since the design improves the connection to the hinterland with the new canal, resulting in increased revenues. Combined with its medium high power and high interest, the stakeholder type is **Savior**. This stakeholder is not considered critical.

- **Cruise ships**

Cruise ships have a **positive** attitude towards the Symbiotic System, since the design has no radical impact on the current operations of the cruise ships. Combined with its medium high power and high interest, the stakeholder type is **Savior**. This stakeholder is not considered critical.

- **Porto Marghera**

Porto Marghera has a **positive** attitude towards the Symbiotic System, since the design has no radical impact on the current operations of Porto Marghera. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Giovanni Nicelli Airport**

Giovanni Nicelli Airport has a **negative** attitude towards the Symbiotic System, since the island of Lido will be used as a barrier from the Adriatic Sea. This may hamper operations of this airport. Combined with its medium low power and medium high interest, the stakeholder type is **Irritant**. This stakeholder is not considered critical.

- **Marco Polo Airport**

Marco Polo Airport has a **positive** attitude towards the Symbiotic System. This is because the current operations of Marco Polo Airport will not be radically changed, and the opportunity to expand is still present. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Treviso Airport**

Treviso Airport has a **positive** attitude towards the Symbiotic System, since the design will have no radical impact on the operations of the airport. It might even see an increase in the number of flights arriving in this airport. Combined with its high power and high interest, the stakeholder type is **Savior**. This stakeholder is not considered critical.

- **Farmers**

Farmers have a **positive** attitude towards the Symbiotic System, since their current operations will not be hampered in this design. Combined with its low power and high interest, the stakeholder type is **Friend**. This stakeholder is not considered critical.

- **Fishermen**

Fishermen have a **negative** attitude towards the Symbiotic System, since the opportunity of fishing in these waters will be limited by the bridges and sluices in the design. Combined with its low power and high interest, the stakeholder type is **Irritant**. This stakeholder is not considered critical.

- **Hunters**

Hunters have a **positive** attitude towards the Symbiotic System, since their current operations will not be hampered in this design. Combined with its low power and high interest, the stakeholder type is **Friend**. This stakeholder is not considered critical.

- **OTS Laguna di Venezia**

The Association of Sustainable Tourism Operators of the Venice Lagoon has a **negative** attitude towards the Symbiotic System. This is because this design enables more tourists to visit Venice, which makes it harder for this organization to achieve sustainable tourism in the lagoon. Furthermore, there are no protective measures taken in order to preserve and protect the lagoon itself. Combined with its medium high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Residents of Venice**

The residents of Venice have a **positive** attitude towards the Symbiotic System, since the design will move functions from the main island of Venice to the artificial islands over the years. This will ultimately create more room for the local residents. Combined with its medium high power and high interest, the stakeholder type is **Savior**. This stakeholder is considered critical.

- **Tourists**

Tourists have a **positive** attitude towards the Symbiotic System, since the design safeguards the preservation and protection of the historical center of Venice. Furthermore, the surrounding islands will be easier to visit and more room for tourists is created with the artificial islands. Combined with its low power and low interest, the stakeholder type is **Acquaintance**. This stakeholder is considered critical.

PROJECT RISKS STAKEHOLDERS

The stakeholder types for the Symbiotic System design have been determined. Each different type of stakeholder can introduce risks to the project. We will now look at those stakeholder risks. Per stakeholder typology we will summarize the relevant stakeholders, highlight the critical stakeholders and identify the consequences it may have for the process of the project.

Savior

Comune di Chioggia, Comune di Padova, Comune di Venezia, Città Metropolitana di Venezia, Regione del Veneto, Ministero delle infrastrutture e della mobilità sostenibili, Ministero della cultura, AVM/Actv, Cargo ships, Cruise ships, Porto Marghera, Marco Polo Airport, Treviso Airport and the residents of Venice are labeled as Saviors according to the three-dimensional stakeholder analysis. Saviors can be identified by their high power, high interest and positive attitude towards the project, and are often described as an influential active backer. The savior type stakeholders are in favor of the project and will actively and progressively contribute to the process of the project. All of the savior type stakeholders, except for Treviso Airport, are critical stakeholders. We will focus on these critical stakeholders in the process, in order to prevent opposition of these critical stakeholders. The proposed strategy for each type of stakeholder will be further elaborated upon in Subsection 5.2.4.

Saboteur

Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna, Ministero della transizione ecologica, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Italian Government and OTS Laguna di Venezia are labeled as Saboteurs according to the three-dimensional stakeholder analysis. Saboteurs are characterized by their high power, high interest and a negative attitude towards the project and are described as influential active blockers. These stakeholders will actively try to obstruct the process and prevent the project execution. All of the saboteur-type stakeholders are labeled as critical stakeholders. It's thus a disadvantage that all of the saboteurs are critical. However, we are still able to steer these stakeholders in a desirable direction by implementing certain project strategies. This strategy will be further explained in Subsection 5.2.4.

Friend

Farmers, hunters and tourists are defined as a Friend according to the three-dimensional stakeholder analysis. A friend-type stakeholder is characterized by its low power, high interest and a positive attitude to the project. This stakeholder type is described as an insignificant active backer, and will, despite its low power, actively participate in the project process. From the friend-type stakeholders, only the tourists are a critical stakeholder. Even though these stakeholders may not pose a threat, a strategy should be defined. Subsection 5.2.4 will elaborate on the strategy we will apply to the stakeholders.

Irritant

Giovanni Nicelli Airport and the fishermen are non-critical stakeholders which are labeled as Irritant. Irritants are characterized by their low power, high interest and negative attitude towards the project. These stakeholders are identified as insignificant passive blockers of the project. Due to the fact that these stakeholders are insignificant, they will not pose a large threat, but they need to be taken into account. Further elaboration on the strategy can be found in Subsection 5.2.4.

STRATEGY PER STAKEHOLDER

The problems and opportunities that come with the characteristics of the stakeholder types have been identified. Per stakeholder type, as determined by making use of the three-dimensional stakeholder analysis, we will determine a strategy in order to steer them in the desired direction during the project. Extra attention will be paid to the critical stakeholders, as they are crucial to the project outcome.

Savior strategy

The high power, high interest and positive attitude to the project makes the stakeholder type savior not an immediate threat to the project. However, this could change for the worse when their expectations are not met. Using their high power and high interest , these stakeholders can change from a savior into a strong opposition or saboteur. instead of a companion. Therefore, we need to pay attention to these types of stakeholders and do what is necessary to keep them on our side of the project. We will have to attend to their needs. From Subsection 5.1.4 we know that every savior-type stakeholder is critical except for Treviso Airport. For this reason we prioritize the needs for the critical stakeholders over the needs for Treviso Airport. At some point during the project, it may occur that we cannot agree to the needs and wishes of the critical stakeholders. What we can do in this situation is try to steer the critical stakeholders in the direction we prefer. We have a range of legal, economic and communicative mechanisms at our disposal. Since the majority of the savior-type critical stakeholders are governmental organizations, which operate in a network across Italy, we recommend the use of communicative mechanisms. Communicative mechanism proves to be the best steering mechanism in a network. Early involvement in the early phases of the project, regular meetings, and joint decision-making on common goals and targets are communicative instruments that can be used. early involvement in the process and the joint decision on common goals and targets. Furthermore, legal instruments in the form of contracts and economic instruments like subsidies and competition could be used to steer the stakeholders.

Saboteur strategy

Due to the combination of a negative attitude and its high power and high interest, the saboteur-type stakeholder poses an immediate threat to the project. To prevent this stakeholder-type from negatively influencing a project, they need to be engaged to the project from the get-go. It is necessary that this role feels needed during the entirety of the process. Doing this will cause these stakeholders to become "disengaged" which in turn will prevent them from negatively impacting the project. In this project extreme caution must be had for there are 5 critical saboteur type stakeholders. These include the Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna, Ministero della transizione ecologica, Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Italian Government and OTS Laguna di Venezia. Steps will need to be taken into putting enough time in engaging these stakeholders. In order to steer the saboteurs in the desired direction, we will use legal, economic and communicative instruments. The large number of governmental parties makes it even more difficult. Due to the large costs of the project in its entirety, economic instruments are the most attractive. Providing subsidies will be a major instrument used to steer the stakeholder. Furthermore, legal instruments can also be applied in the form of area restrictions or limitations. Further specification of the strategy can be determined in a later stage of the project.

Friend strategy

As also explained in Subsection 5.1.4, friends are high interest and positive attitude stakeholders without a lot of power. Unless unjustly treated, they do not perform a threat to the project. Their lack of power means that even if failure occurs that they do not have a significant impact. They can however either be used as sounding boards or confidants in the process. As can be seen in Subsection 5.2.4, there are a total of three stakeholders that fall within this friend category, these are the farmers, the hunters and the tourists. From these stakeholders the tourists are a critical stakeholder in this process. While the farmers and hunters do not require further steering, this is necessary for the tourists. This means that the tourists are a higher priority than the farmers and hunters. An additional effort must be put into keeping this group content so the project can lead to a success. The friend-type stakeholders, and especially the tourists are in need of some steering for achieving the desired project outcome. In this case, steering can be done by applying communicative instruments. Providing the stakeholders constantly with information and being transparent about the process and project are simple instruments which can steer friends and will prevent them from turning into an opposition.

Irritant strategy

Irritant-type stakeholders are the same stakeholder as the saboteur-type, the only difference being that they have low power. Despite this single difference, they have to be treated the same as the saboteur-type stakeholder. Engaging them in the project ensures they don't cause nuisance with their contrary views. For this project, local fishermen and Giovanni Nicelli Airport fall into this category, however, they are not labeled as critical stakeholders, see Subsection 5.2.4. This means that apart from early involvement, no steering mechanisms need to be applied.

6. DISCUSSION

As in any research also here is dealt with uncertainties and lack of information. Therefore, we had to make certain assumptions. In this chapter we will then discuss the results and the assumptions made. For each assumption, we propose a suggestion about the improvements and future investigation that can be done in order to reach more accurate results.

Coastal Engineering

For the coastal engineering part the lagoon is in this report very simplified. The only way to really make a detailed assumption on where and how much deposition and erosion of sand will take place is by modeling. This is something that we did not do during this project as this was too ambitious given the time we had. Therefore general assumptions are made and only total numbers of sediment transport are given with an expectation of where and how most of the erosion will take place. For the future it may be interesting to model the expected morphological changes because of these interventions that are proposed in this report.

River Engineering

Relocation of rivers is very difficult to plan, therefore predicting the morphological developments will be insufficient. This prediction is one of the main discussion points regarding the river system. For the location of the river branches, a detailed investigation of the spatial planning is needed as well as for its debouching location. To have a better computation of the yearly averaged sediment input, a deeper study is required of the discharge fluctuations over the year and specified measurements about the river sediment characteristics needs to be performed.

Hydraulic Structures

The major discussion point regarding the hydraulic structure calculations is the reliability of the designs, which on itself can be subdivided into three parts. First, due to time reasons assumptions have been made about the different boundary conditions, being the (extreme) design scenario (Subsection A.1.2) and the subsoil characteristics (Section A.2). For future research these numbers have to be more precise in order to come with increased design reliability. As a follow-up on this, calculations can be done with numbers having a certain range, so increasing the reliability even more the recommendation is to include statistical uncertainty for further research. Lastly, more in-depth calculations are needed to really assure safe construction designs. Some examples are: concrete calculations, dynamic calculations, (sub)soil calculations, calculations regarding the reliability of the northern part of Lido as flood defense and calculations regarding the bearing capacity of the dam. On top of this design preferences of the included stakeholders should be made more clear, which is of mayor importance for for example the choice of a combined spillway-shipping lock as explained in Subsection 5.1.1 or the choice of two centered metro tracks instead of placing the platform centered in the dam (Subsection 5.2.1). Furthermore, bridges connecting two dams located at the shipping locks are currently not being touched upon in this report. To conclude, after mentioning these discussion points, one still needs to take into account that this report is intended as a preliminary design meaning not in need for in-depth calculations. Nevertheless, these in-depth calculations have to be included in future research and therefore are given here in this discussion paragraph.

Construction Management and Engineering

The stance of the stakeholders towards the different designs have been assumed considering income limitations, required surface area and general social perspective towards projects. In order to construct a comprehensive stakeholder analysis for this project, it is advised to arrange interviews with stakeholders involved and execute surveys. The stakeholder strategy is based on the roles we defined in the stakeholder analysis. A more comprehensive and detailed strategy can be determined when the designs of the concepts are of a more detailed level. This way we can evaluate the stance of stakeholders towards the project more accurately, resulting in a tailormade strategy for each individual stakeholder.

Architecture

Architectural discipline also dealt with some uncertainties and assumptions for this study. For example, the expansion of the islands could but does not have to follow the proposed design, especially its last phases. During the first phase, the islands that are close to each other are connected. The further expansion within the created symbiotic system is done with the traditional wooden piles foundation method and therefore can grow organically in any shape around the already existing islands. This could depend on the needed functions, population decrease/growth and other factors. Also, several sections with the different spatial solution for the dam need to be taken as concepts. To gain better scientific credibility, the structures should be further elaborated and tested in stability and overall feasibility in combination with the dam. Furthermore, the study can be complimented by researching various types of housing in Venice and making a detailed proposal for residential and other functions inside and on top of the dam.

Landscape Architecture

Due to time restrictions but also the extremely complex situation at hand, the landscape architectural elaboration of the dike or rather the re-established lagoon around Venice remains at the level of a first sketch design. Several multiple-gain relationships are explored that frame the potential benefits of the newly established flood defense zone for humans, plants and animals alike. But in order to highlight the nature first approach that forms the basis of “the perfect lagoon” a more holistic approach to the territory is omitted. Decidedly anthropogenic processes and functions such as industry, mobility, infrastructure and even housing are left out of the design, which strengthens the vision of an undisturbed landscape in equilibrium, but at the same time makes the design more of an utopian statement, rather than a possible future reality. Even the more detailed proposed solutions, such as achieving a new sediment balance in the lagoon, are mere first ideas, of which the feasibility is highly questionable. While the new proposed solutions of a wide green dike that bleeds into the landscape and becomes one with it, is a direct reflection of the qualities of the Venetian lagoon – its horizontality and openness, its reflectiveness, its subtle and constant transitions from land to water – the spatial and sensorial impact of the dike could have been explored further. These both technical and experiential questions should be examined more in future research.

7. CONCLUSION

In this chapter first the sub-questions will be answered. Consequently this will lead to the answer on the main research question which will be concluded upon.

7.1 RESEARCH SUB-QUESTIONS

How does the future expansion of the existing flood defense systems influence the spatial aspects of the territory?

Creation of new primary flood defense does not make outdated defense obsolete (it can give new purpose). Flood defense structures can add to, and give additional functions to an existing spatial layout. This can be in the form of a sediment trapping mechanism as an extra function, working in this case towards sustaining a system of estuarine lagoons or more so directed towards aspects in the form of recreation or agriculture.

How does the alteration of the flood defense system impact the local natural systems?

Analyzing the impact of the hydraulic interventions, the largest impact can be seen in morphology. This impact may not be visible immediately after the hydraulic intervention but can take decades of time. This is the time needed for the new situation to adapt to the new situation in finding its new balance.

How does the river system morphologically impact the spatial aspects of an urbanized territory?

Diverting rivers into a basin is not a special strategy to deal with water and sediment problems. It is difficult not to pay attention to the details at the smaller spatial scale during the primary design phase with such a drastic intervention. Thereby it will have an enormous morphological impact on the spatial aspect of a basin catchment. A detailed analysis is needed to come up with the right location of the river branches and for the amount of freshwater and sedimentation inflow. Some problems can be mitigated by applying the new Building with Nature philosophy and the Room for the River solution strategy. When implemented well, the river system can make a positive contribution to the ecosystem services.

What is the risk of changing the flood defense strategy when considering stakeholders in the territory?

Changing the flood defense strategy or implementing new flood defense measures will have consequences for the stakeholders in the territory. For each stakeholder these consequences could either be positive or negative, dependent on the type of flood defense measures taken. The risks that will arise consist of stakeholders trying to actively or passively hamper the project's process. However, by implementing economic, communicative and legal instruments, the stakeholders can be steered and thus the project risks, from a stakeholders perspective, can be mitigated.

How can a primary flood defense lane reduce the risk of flood and, at the same time, increase the spatial value of the landscape?

Primary flood defense lanes are assured of a present, visible position in the landscape. Such a defense can be used in a multifunctional manner instead of merely functioning as the hard distinction between the high water and the protected landscape. The needs of the area will have to be carefully considered and these wishes and shortcomings will have to be incorporated into the design as much as possible. During the drafting of the vision, at the beginning of the design process, it is important to stimulate out-of-the-box thinking and to ignore reasons such as money and feasibility as much as possible. The pragmatic thinking from the civil sector comes into play at a later design stage when the design is being converged. It is important throughout the design process to maintain constant feedback between these two disciplines: the pragmatic and the creative.

How can flood defense zones function as a shared territory for humans and flora and fauna alike?

Flood defense infrastructure or zones lend themselves well to be used and designed in a way that allows for multiple uses and also benefits non-humans or silent stakeholders. They are often naturally situated in ecologically highly interesting areas, as land and water meet here and form a multitude of biotopes and ecosystems. This meeting of land and water is also highly interesting to humans, due to its often natural beauty and recreational and economic potential.

However in order to design successfully for both nature and humans, various strategies and ideas need to be kept in mind resulting in a shift of what one would traditionally consider flood defense infrastructure. Rather than minimizing the spatial impact of the flood defense infrastructure and thinking of it as a line dividing two landscapes, it should be considered a landscape itself and given the appropriate amount of space according to that. This also means that the infrastructure is not a static space, but rather a dynamic one that facilitates ever evolving natural processes throughout time and space. In order to allow for this the needs of human and natural stakeholders have to be assessed carefully in order to find use scenarios that can benefit both stakeholders, such as slow tourism or nature inclusive agriculture. This can only succeed if feasibility is considered in a less profit driven and more holistic way and if risk assessment and safety standards for flood defense are incorporated early in the shaping of the landscape.

7.2 MAIN RESEARCH QUESTION

We started this research by identifying a problem worth solving, which has led us to the formulation of the main research question:

How do flood defense systems influence the spatial aspects of the territory in the context of a high dynamic landscape in the Anthropocene?

Flood defense systems have a major influence in the spatial aspects of the territory. Not only in its primary function, but more importantly in the secondary functions. Both primary and secondary functions can be used to create a paradigm shift for the territory. Using the multidisciplinary approach, an integral design can be made for flood defense, in which the opportunities in a territory can be maximized.

8. RECOMMENDATIONS

The two designs made in this report may seem for some people far from realistic. But with the current challenges we face as a society, radical intervention should be made in the near future to save Venice and/or its Lagoon. In the coming decades decisions should be made in “who” and “what” Venice wants to save and direct action must be undertaken. Therefore it will be interesting to take these designs to the next step and go more into detail. A good step towards adding more details would be additional iteration steps and adding in more disciplines with different backgrounds.

Modeling of the sediment transport followed by these interventions could be valuable in predicting the future morphology of the Lagoon and the surrounding coastlines. For the calculation regarding the hydraulic structures recent soil and hydraulic data should be obtained. This can be done by taking soil samples and making use of different hydraulic data devices around Venice. Also the architecture design could go in the next phase where more details of its surroundings are taken into account. Additional research will need to be done in the form of modeling to work out if indeed a submerged storm surge defense structure can be used as a sediment trapping system. The expectation is that as time passes, a higher certainty can be expected of the estimated sea level rise. As the sea level rise expectancy forms the basis of many of the calculations and dimensions in the design, many of the calculations and technical designs will have to be revised if a significant change in sea level rise expectancy occurs.

This all will contribute towards bringing these ideas to a more realistic design, which actually can be executed and makes Venice future proof with the upcoming challenges in the near future. Close cooperation between architects and engineers is recommended to create a new Venice where the hydraulic defense lane is included in the spatial aspects of the city.

9. BIBLIOGRAPHY

[1 C. A. Ferguson, *Venice and the Water; A Model for Our Planet* (Polar Bear anc Company Solon, Maine, 2009, 2014).

[2 M. van Dorst, *Concepts of sustainable development,* in *The 2004 internationa sustainable development research conference*, edited by s.n. (University of Manchester United Kingdom, 2004) pp. 176–183.

[3 N. Montenegro Navarro, *The economisation of nature conservation. An analysis of the pros and cons of economic valuation of ecosystem services by public institutions*, Ph.D thesis, Wageningen University and Research (2017).

[4 Esri / Imagery, *Topographic map italy,* (2021).

[5 S. Venturini, M. Carlin, E. Piccin, M. Vezzà, E. Marini, G. Zen, and L. Niero, *Yearbook of tourism data 2019,* - (2020).

[6 B. Scheres and H. SchÃŒttrumpf, *Enhancing the ecological value of sea dikes,* Wate **11** (2019), 10.3390/w11081617.

[7 dr.ing. M.Z. Voorendt and ir. W.F. Molenaar, *Manual Hydraulic Structures*, februar 2020 ed. (TU Delft, Delft, 2020).

[8 M. I. Yuce, M. Eslt, and B. Ercan, *A relationship between flow discharge, sedimen discharge and sub-basin areas in ceyhan catchment,* 13th International Congress o Advances in Civil Engineering (2018).

[9 Railsystem.net, *Immersed tube tunnel,* (n.d.).

[10 W. M. e.a., *Hydraulic Structures: Locks*, 2020th ed. (TU Delft, Delft, The Netherlands 2011).

[11 L. Carniello, A. Defina, and L. D'Alpaos, Morphological evolution of the venice lagoon Evidence from the past, trend for the future, Journal of geophysical research 1, 11 (2009).

[12 S. E. Apitz, *The assessment of sediment screening risk in venice lagoon and other coasta areas using inter- national sediment quality guidelines,* (2007).

[13 Z. R., C. D, P. R., and D. J., *Substantial decrease in contaminant concentrations in the sediments of the venice (italy) canal network in the last two decades — implications fo sediment management,* Water (2020).

[14 A. Bondesan and P. Furlanetto, *Artificial fluvial diversions in the mainland of the lagoo of venice during the 16th and 17th centuries inferred by historical cartography analysis* OpenEdition Journals, 175 (n.d.).

[15 Istituto Superiore per la Protezione e la Ricerca Ambientale, *Le stazioni meteo mareografiche,* (n.d.).

[16 L. PICCO, L. MAO, R. RAINATO, and M. A. LENZI, *Medium-term fluvial islanc evolution in a disturbed gravel-bed river (piave river, northeastern italian alps)* Geografiska Annaler. Series A, Physical Geography **96**, 83 (2014).

[17 P. A. Pirazzoli, A. Tomasin, and A. Ullmann, *Extreme sea levels in two northerı mediterranean areas,* OpenEdition Journals , 59 (n.d.).

[18 F. Rizzetto, L. Tosi, M. Zecchin, and G. Brancolini, *Modern geological mapping anc subsurface lithostratigraphic setting of the venice lagoon (italy),* Rend. Fis. Acc. Lince **21**, 239–252 (2010).

[19 Haseeb Md. Irfanullah, *Nature-based solutions should be an integral part of locally-lec adaptation,* (2021).

[20 H. Eggermont, E. Balian, M. Azevedo, V. Beumer, T. Brodin, J. Claudet, B. Fady, M Grube, H. Keune,
P. Lamarque, K. Reuter, M. Smith, C. Ham, W. Weisser, and X. Roux, *Nature-basec solutions: New influence for environmental management and research in europe,* Gaia Okologische Perspektiven in Natur-, Geistes- und Wirtschaftswissenschaften **24**, 24: (2015).

[21 Google Maps, *Google maps,* (2021).

[22 A. Sarretta, S. Pillon, E. Molinaroli, S. Guerzoni, and G. Fontolan, *Sediment budget iı the lagoon of venice, italy,* Continental Shelf Research **30**, 934 (2010), the Coasta Morphodynamics of Venice Lagoon and its Inlets.

[23 S. van Alphen, *Room for the river: Innovation, or tradition? the case of the noordwaard* Hein C. (eds) Adaptive Strategies for Water Heritage (2019).

[24 Emily Harrington, *Why river floodplains are key to preserving nature and biodiversit in the western us,*
(2016).

[25 E. Molinarolia, S. G. A. Sarrettab, M. Masiola, and M. Pistolatoa, *Thirty-year changes 1970 to 2000) in bathymetry and 1 sediment texture recorded in the lagoon of 2 venic sub-basins,* (2008).

[26 Allaboutvenice, *Boats in venice,* (2021).

[27 Statista, *Number of tourist arrivals in the italian municipality of venice from 2003 t 2020(in 1,000s),* - (2021).

[28 Dario, *A brief history of venice,* (2018).

[29 R. P. Allan, P. A. Arias, and S. Berger, *Climate change 2021, the physical science basis* Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (2021)

[30 *Verdict media limited,* (2021).

[31 D. M. Vouldjef, J. L. Wey, J. W. Devine, and M. P. Lundgren, *The boundaries of venice Digitally mapping historical venetian borders and their modern day implications* Worcester Polytechnic Institute (2016).

[32 P. Martini, L. Carniello, and C. Avanzi, *Two dimensional modelling of flood flows and suspended sediment transport: the case of the Brenta River, Veneto (Italy),* Natura Hazards and Earth System Sciences **4**, 165 (2004).

[33 Delta Futures Lab, *Delta futures lab, tu delft,* (n.d.).

[34 D. Urbanism, *People,* (n.d.).

[35 L. I. Lorenzo Fabian, *Paleoalvei of the lagoon. four scenarios for venice,* (n.d.).

[36 W. R. Lennertz, A. Lutzenhiser, and A. Duany, *The Charrette Handbook: The Essentia Guide to Design based Public Involvement* (IL: APA Planner Press., Chicago, 2014).

[37 *Report of the world summit on sustainable development, johannesburg, south africa, 26 august-4 septem- ber 2002,* (2002).

[38 R. Zonta, M. Botter, D. Cassin, R. Pini, M. Scattolin, and L. Zaggia, *Sediment chemica contamination of a shallow water area close to the industrial zone of porto marghera (venice lagoon, italy),* National library of medicine **1**, 10 (2007), -.

[39 A.Sarretta, S.Pillon, E.Molinaroli, S.Guerzoni, and G.Fontolan, *Sediment budget in the lagoon of venice,italy,* Elsevier **30**, 934 (2010).

[40 Wikipedia, *Salt marsh,* (2021).

[41 P. Lionello, R. J. Nicholls, G. Umgiesser, and D. Zanchettin, *Venice flooding and sea level: past evolution, present issues, and future projections (introduction to the specia issue),* Natural Hazards and Earth System Sciences (2021).

[42 A. Colamussi, *Venice high water barriers problems analysis and design approach* (1992).

[43 Tuttitalia, *Città metropolitana di Venezia,* (2021).

[44 *Ministry of sustainable infrastructure and mobility,* (2021).

[45 *Ministry of cultural heritage, activities and tourism,* (2021).

[46 G. Johnson, K. Scholes, and R. Whittington, *Explored corporate strategy* (Prentice Hall

Harlow, 1999).

[47 R. Murray-Webster and P. Simon, *Making sense of stakeholder mapping,* PM Worl Today **VIII**, n.d. (2006).

[48 Port of Venice, *Q2 2021 statistics. Venice and chioggia,* (2021).

[49 MarineTraffic, *Live map,* (2021).

[50 J. Simmons, *Overtourism in Venice,* - (2021).

[51 C. Zanetti, M. Vennetier, P. Mériaux, P. Royet, M. Provansal, and S. Dufour, *Tree roo systems architecture in earth dike,* in *7th ISRR Symposium'Root Research anc Applications'(RootRAP)* (2009).

[52 van der Meer, J. W., Allsop, NWH, Bruce, T., D. Rouck, Julien, Kortenhaus, Andreas Pullen, T., Schüttrumpf, H., Troch, P. Zanuttigh, and Z. B., *Eurotop: Manual on wav overtopping of sea defenses and related structures: an overtopping manual largel based on european research, but for worldwide application,* (2016).

[53 H. Shao, L. Chu, H. Lu, W. Qi, X. Chen, J. Liu, S. Kuang, B. Tang, and V. Wong *Towards sustainable agricul ure for the salt-affected soil,* Land degradation & development **30**, 574 (2019).

[54 P. Mériaux and P. Royet, *Surveillance, maintenance and diagnosis of flood protectio dikesnull* (éditions Quae, 2007).

[55 P. Oddo and A. Guarnieri, *A study of the hydrographic conditions in the Adriatic se from numerical mod- elling and direct observations (2000–2008),* Ocean Science , 54 (2011).

[56 Wikipedia, *Venetian lagoon,* (2021).

[57 *Porti d'italia per flusso di merci,* (2021).

[58 M. Frignani, L. G. Bellucci, C. Carraro, and M. Favotto, *Accumulation o polychlorinated dibenzo-p- dioxins and dibenzofurans in sediments of the venice lagoo and the industrial area of porto marghera,* Marine Pollution Bulletin **42**, 544 (2001).

[59 R. Zonta, M. Botter, D. Cassin, R. Pini, M. Scattolin, and L. Zaggia, *Sediment chemica contamination of a shallow water area close to the industrial zone of porto margher (venice lagoon, italy),* Marine Pollution Bulletin **55**, 529 (2007), measuring anc Managing Changes in Estuaries and Lagoons.

[60 I. K. Reinders, *Bored and Immersed Tunnels*, January ed. (TU Delft, Delft, 2020).

[61 prof. dr. ing. I.A. Hansen, *Geometrical Design of Roads and Railways*, 2011th ed. (TU Delft, Delft, The Netherlands, 2011) -.

[62 J. Bosboom and M. Stive, *Coastal Dynamics* (TU Delft, Delft, Netherlands, 2021).

[63 G. Umgiesser, R. Helsby, C. Amos, and C. Ferrarin, *Tidal prism variation in the venic lagoon,* Curriculum in natural environment (2010).

[64 SedNet, *Moving sediment management forward,* River basin case studies (2014).

[65 *Brenta (river),* (2021).

[66 *Piave (river),* (2021).

[67 E. Commission, *Eu overview of methodologies used in preparation of flood hazard an flood risk maps,* n.d. (2015).

[68 *Nature-based solutions for people and planet,* (2021).

[69 C. L. A. D. S. Fagherazzi and L. D'Alpaos, *A combined wind wave–tidal model for th venice lagoon,* JOURNAL OF GEOPHYSICAL RESEARCH **110** (2005).

[70 Navionics, *Navionics - a garmin brand,* (2021).

[71 M. Voorendt, W. Molenaar, and M. S. K.G. Bezuyen, *Hydraulic Structures: Caissons* february ed. (TU Delft, Delft, 2020).

[72 ir. F.A.M. Soons, B. van Raaij, prof. ir. L.A.G. Wagemans, ir. S. Pasterkamp, and ir S.H.J. van Es, *Quick Reference*, 2014th ed. (TU Delft, Delft, The Netherlands, 2014).

[73 van Loon-Steensma and J. M., *Salt marshes to adapt the flood defenses along the dutc wadden sea coast,*
Mitigation and Adaptation Strategies for Global Change **20**, 929 (2015).

[74 T. Simas, J. Nunes, and J. Ferreira, *Effects of global climate change on coastal sal marshes,* Ecological Modelling **139**, 1 (2001).

[75 M. J. Kennish, *Coastal salt marsh systems in the us: a review of anthropogenic impacts* Journal of Coastal Research , 731 (2001).

[76 R. Marijnissen, P. Esselink, M. Kok, C. Kroeze, and J. M. van Loon-Steensma, *Hov natural processes contribute to flood protection - a sustainable adaptation scheme for wide green dike,* Science of The Total Environment **739**, 139698 (2020).

[77 J. M. van Loon-Steensma and H. A. Schelfhout, *Wide green dikes: A sustainabl adaptation option with benefits for both nature and landscape values?* Land Use Polic **63**, 528 (2017).

[78 N. L. Poff, J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, R. E Sparks, and J. C. Stromberg, *The natural flow regime,* BioScience **47**, 769 (1997).

[79 E. Molinaroli, S. Guerzoni, A. Sarretta, M. Masiol, and M. Pistolato, *Thirty-yea*

changes (1970 to 2000) in bathymetry and sediment texture recorded in the lagoon o
venice sub-basins, italy, Elsevier **258**, 115 (2009).

[80 R. Mel, *Exploring the partial use of the mo.s.e. system as effective adaptation to rising*
flood frequency of venice, n.a. (2021).

10. BOUNDARY CONDITIONS

A

This chapter sets all of the boundary conditions and commonly used parameters for the project.

A.1. Hydraulic systems

First we will go into the boundary conditions for the hydraulic systems.

A.1.1. River Systems

Figure A.1 shows a map of the Venice lagoon and its drainage basin. As can be seen there are twelve small main rivers debouching in or near the lagoon. Considering the scale of this project, it was chosen to take into account the two largest most impactful rivers; in this case the Piave and the Brenta. This because the discharges of the other rivers are simply too small to have a meaningful impact on the system in such a preliminary design.

Brenta

As shown in more detail in Figure 5.1.2, the average discharge of the Brenta river is $100m^3 s^{-1}$ [65]. This corresponds with an average annual sediment transport of $948,400m^3\ yr^{-1}$. In the current situation the Brenta river enters the Adriatic sea south of the lagoon.

Piave

The Piave river has an average discharge of 125 $m^3 \cdot s^{-1}$ [66]. This corresponds with an annual average sediment discharge of 1,538,000 $m^3 \cdot yr^{-1}$. In the current situation, the Piave enters the Adriatic sea north of the lagoon.

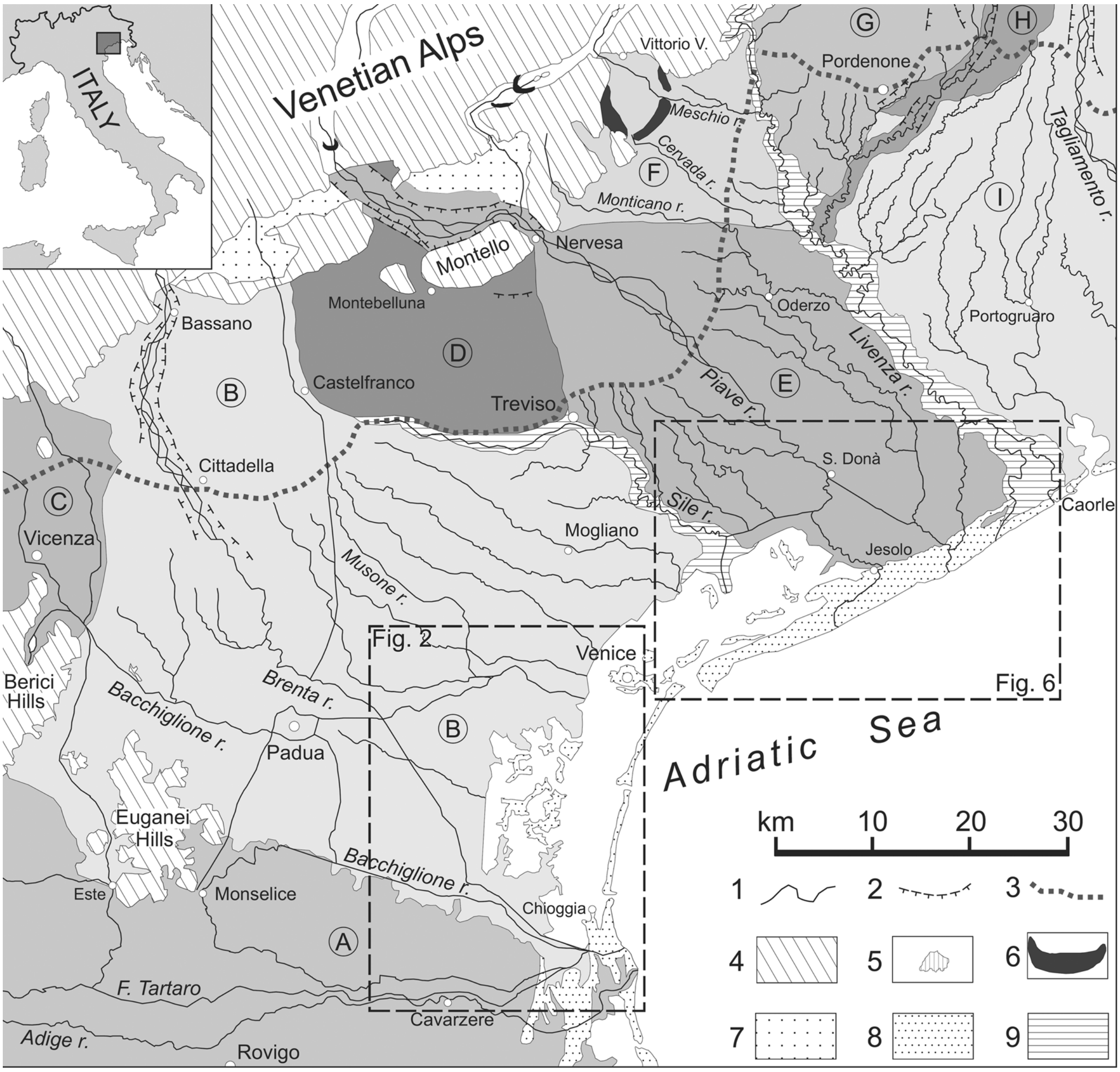


Figure A.1: Overview river system [14].

River inflow: Lagoon as a reservoir

One can see the lagoon as a reservoir with an inflow (= water coming from the rivers) and outflow (= outlets from the lagoon towards the sea). Regarding the river discharge it is important to keep in mind that only the design of the Perfect Lagoon includes diverting the Brenta and Piave rivers into the lagoon. The 1:100 year extreme discharge of the Brenta river amounts $2800 m^3 s^{-1}$ at Bassano. As can be seen in Figure A.1 the Brenta river at Bassano has almost no contribution to the lagoon at the moment. By detaching this river, like what is done after constructing the Perfect Lagoon, the assumption is made that in between $30-80\%$ of the discharge of the Brenta river is entering the lagoon. Furthermore another factor of 1.2 has been added to account for additional water out of the Brenta catchment entering downstream of Bassano.

As can be seen in Figure A.2 the 1:100 year extreme discharge of the Piave river amounts $3300 m^3 s^{-2}$ at Belluno, located in the Venetian Alps (Figure A.1). To include for the water entering in the rest of the catchment downstream a factor of 1.4 is used. Here it is also assumed that $30-60\%$ of the discharge is entering the lagoon after the detachment.

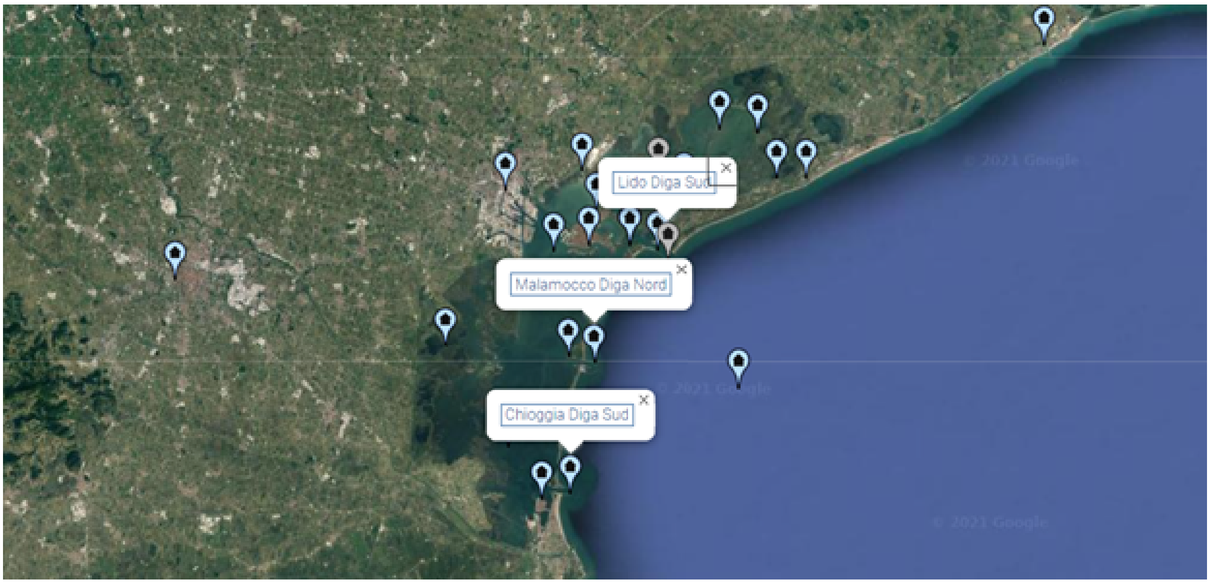


Figure A.3: Measuring stations outlets [15].

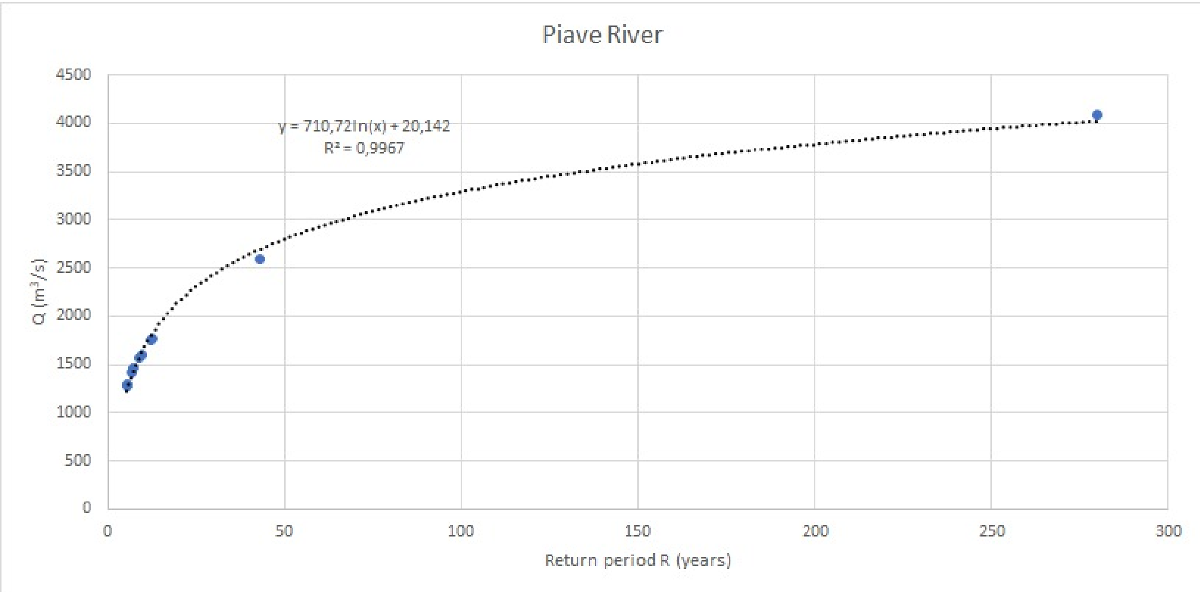


Figure A.2: Return period of the Piave river. Data recieved from L. Picco et al. [16].

As outflow, the three outlet discharges at Chioggia, Malamocco and Lido have to be determined. It is very hard to find these discharge values. Online, the website of ISPRA [15] contains open source water level data for every 5 minutes for the last 20 years. Unfortunately discharge data is not present. Discharge data is being retrieved by taking the water level difference every 5 minutes, dividing this difference by 5 minutes and rewriting this to a velocity in meters per second. As a design value for the outflow discharge, the biggest velocity in the last 5 years is being used as can be seen in Table A.1. The cross-sections of the three outlets together is determined using Google Maps. It has to be noted that this outflow velocity is highly simplified and there should be further research done on what the exact outflow velocity is. In this preliminary design only an indication is sufficient. The measuring station used are shown in Figure A.3.

Table A.1: Discharge and cross-sectional area of the river systems.

Measuring station	A_c [m^2]	u_{max} [m/s]	$Q_{outflow}$ [m^3/s]
Chioggia Diga Sud	4000	1.23E-03	
Malamocco Diga Nord	5000	1.60E-03	
Lido Diga Sud	9000	1.68E-03	
			28.1

Lastly the duration of the high discharge peak has to be given. Here as lower bound 1 hour and as upper bound 3 days is being used. For a 1:100 year discharge and a lagoon area assumed to be $550 km^2$ this gives a water level increase inside the lagoon of $0.01 - 1.77 m$ due to Scenario 1 from Subsection A.1.2.

A.1.2. Extreme Design Scenario

The design of primary and secondary flood defences have to be able to cope with extreme scenarios. Both designs have their primary flood defence lane roughly inside the lagoon, diverting the middle part of the lagoon from the southern and northern part. An extreme scenario is a scenario for which the head difference (= water level difference between both side of the flood defence) is maximum. The water level inside the middle part of the lagoon stays 'normal' and is assumed to be never lower than the current water level since the water level can be controlled by the spillways included in the flood defence.

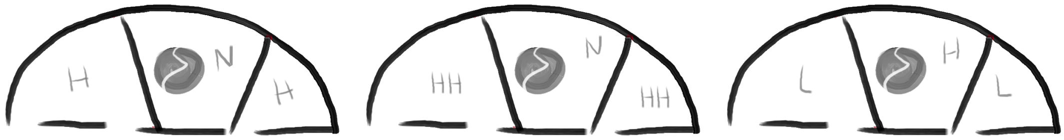
Eventually, there are four extreme scenarios which can be distinguished (Figure A.4):

1. **Extreme high discharge from the river**
   Problems regarding clogging of outflowing water from the inland and lagoon towards the Adriatic Sea due to too small outlets which can cause a water level rise inside the southern and northern part of the lagoon. The water level inside the middle part of the lagoon is normal. Here outlets refer to the three outlets from the lagoon towards the sea and spillways in the flood defence which allow water to enter from the southern and northern part of the lagoon towards the middle part.

2. **Extreme high water level Adriatic Sea**
   Problems regarding a water level rise inside the southern and northern part of the lagoon due to an extreme water level of the Adriatic Sea. The water level inside the middle part of the lagoon is normal. An extreme water level of the Adriatic Sea happens when having an extreme storm combined with a SLR.

3. **Extreme high discharge from the rivers & extreme high water level Adriatic Sea**
   Problems regarding a water level rise inside the southern and northern part of the lagoon due to extreme peak discharges from the rivers which occurring simultaneously with an extreme water level of the Adriatic Sea. This scenario is much more unlikely to happen than Scenario 1 and 2 and is therefore taken out of the analysis.

4. **Extreme high water level middle part lagoon**
   Problems regarding an extreme high water level inside the middle part of the lagoon, with the southern and northern part of the lagoon having a low water level. This can be the case for rivers flowing into the lagoon. However, since all designs do not include this and guarantee the controllability of the water level inside the flood defence, this scenario can be taken out.



(a) Scenario 1 or 2 (b) Scenario 3 (c) Scenario 4

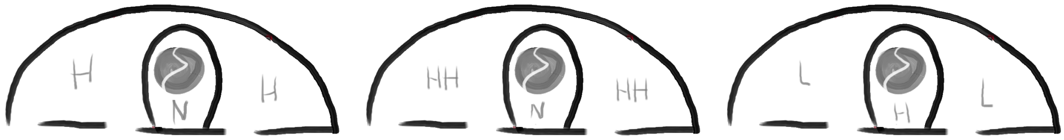


Figure A.4: Schematic sketches of the extreme scenarios. L = low, N = normal and H = high. Top 3: Perfect Lagoon. Bottom 3: Symbiotic System.

Storms and return periods

Flood defences are built for a storm with a return period of 1:1,000 year or even higher. In The Netherlands for example, primary flood defences are built for a storm with a return period of even 1:10,000 years. Italian authorities assume a return period of 1:100 year. Higher return periods are assumed insignificant in relation to the topographical and meteorological local conditions [67]. For this reason it is very hard to find usable data about the extreme water scenarios. It is therefore chosen to use a 1:1,000 year return period for the design water conditions at sea and a 1:100 year return period for the design water conditions coming from the rivers.

Sea level rise (SLR)

According to Allan *et al.* [29], sea level rise in 2100 will be between $0.63-1.01m$ under the very high GHG emissions scenario (SSP5-8.5). Assuming the upper bound, as we will design for the worst case scenario, this means a sea level rise of $1.01m$ at the end of this century.

Storm surge

Information about sea levels which occur once every 1,000 years is found on the website of OpenEdition Journals [17]. On these figures it is clear to see that the water level increase inside the lagoon will rise until MSL $+220cm$ and nearby Lido until MSL $+175cm$.

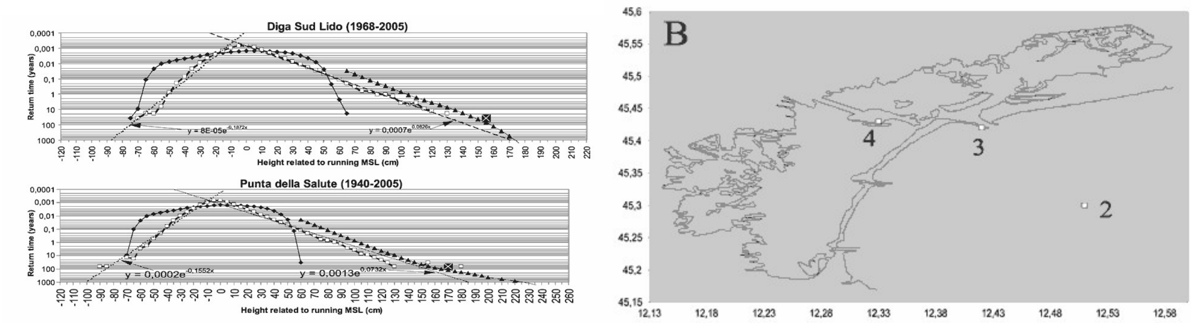


Figure A.5: Return period Adriatic Sea at Lido Diga Sud (right plot: 3) and Punta della Salute (right plot: 4) [17].

A.1.3. Design scenario

The design scenario is the most extreme scenario. There are two scenarios left as given in Subsection A.1.2. Just like elaborated above, Scenario 1 results in a maximum water level difference inside the lagoon of $< 2m$ $(0.01-1.77m)$. Scenario 2 results in a maximum water level difference inside the lagoon of $1.01+2.20=3.21m$. Comparing these extreme conditions, Scenario 2 gives the most extreme water levels thus becomes the design scenario. This also means that the influence of (extreme) river discharges is being neglected for the design of the flood defence structures.

A.2. Subsoil

Of importance is the subsoil profile up to a couple of meters beneath MSL. Such a shallow subsoil section is given in Figure A.6 with distances up to $30m$ depth. The dredged canals and different subsoils can be seen clearly. The middle part of the Venice lagoon consists of roughly clayey lagoon deposits which are layers characterized by a very bad bearing capacity. Furthermore the more sandy parts in yellow contain peat deposits which makes this subsoil unsuitable for shallow foundations. Pile foundations have to be driven up to a depth of about MSL $-12m$ at least.

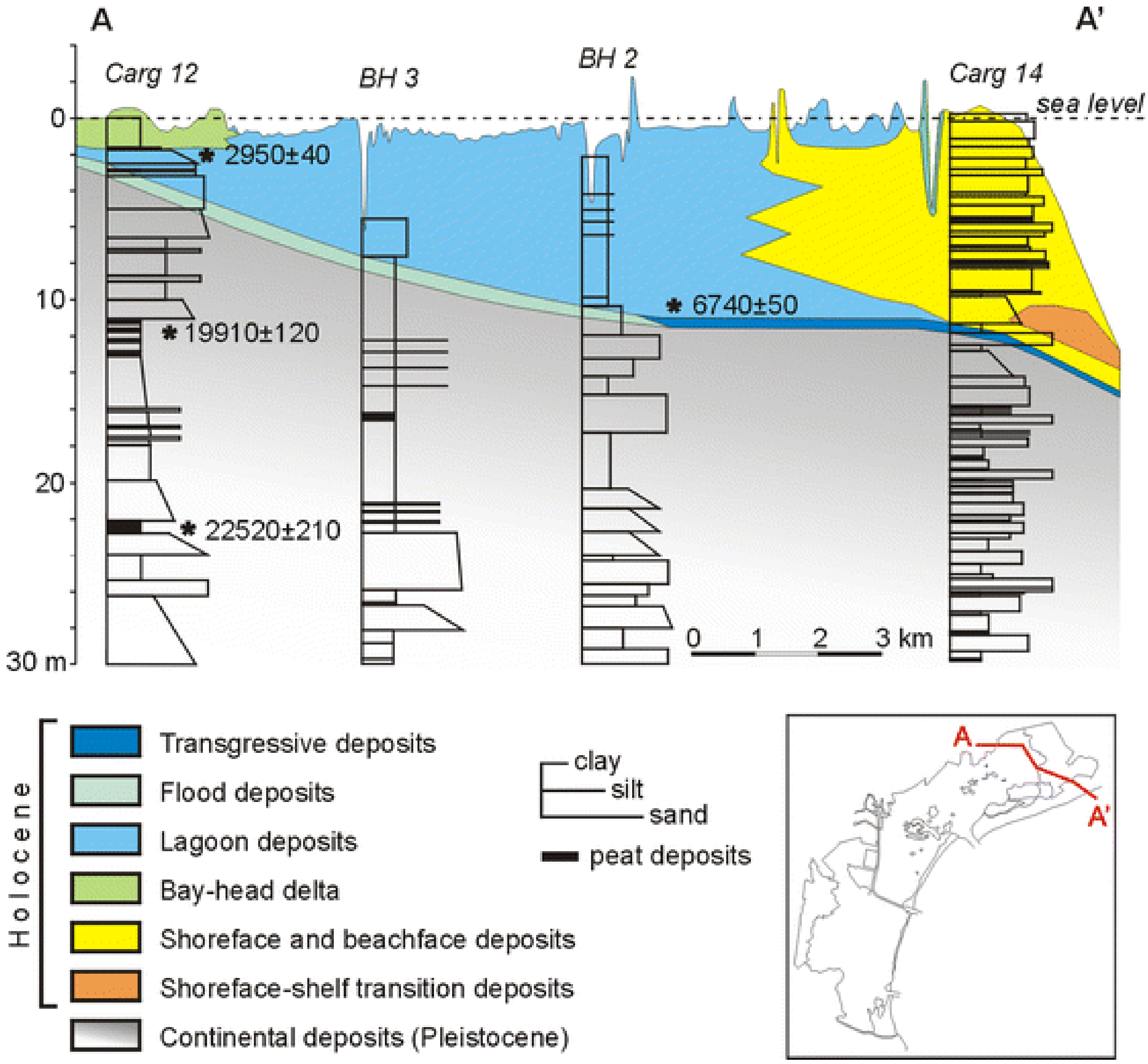


Figure A.6: Shallow subsoil section Venice lagoon (north) [18].

B

NATURE BASED SOLUTIONS

B.1. WHAT ARE NATURE BASED SOLUTIONS (NBS)

Nature based solutions is a new concept introduced in the beginning of the 21th century. It is explained by the International Union for Conservation of Nature[68] as:

> "Nature-based Solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."

Figure B.1: Pictogram of NBS approach [19].

NBS can be categorized into four subcategories: Fully natural solution, Managed natural solutions, Hybrid solutions and Environmentally solutions.

Fully natural solutions are naturally occurring coastal protections, some examples are coral, mangroves, marshes and wetlands. Each contribute in a different way to the protection of a coastal system. Managed natural solutions consist of artificial 'natural' protections like artificial coral reefs and oysters beds, (re-)nourished beaches and dunes and planted marshes or wetlands. Hybrid solutions is combination between *gray/hard* constructions and nature, examples include the marsh-levee system, dune-dike systems, double-dike system, offshore breakwater (as basis for coral transplants). Lastly there are environmentally friendly solutions, in this category falls vegetated engineering, bamboo sediment fencing and eco-tourism.

From Figure B.2 we can conclude that the plan of the perfect lagoon falls in a type 3 NBS, while the measures of the symbiotic system would fall into a type 1 NBS with none/minimal ecosystem intervention.

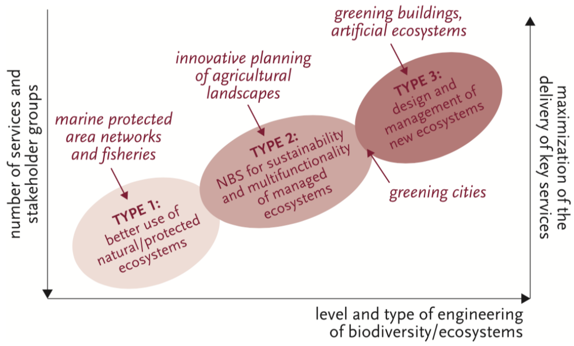


Figure B.2: Schematic representation of the range of nature-based solutions (NBS) approaches. Three main types of NBS are defined, differing in the level of engineering or management applied to biodiversity and ecosystems (x-axis), and in the number of services to be delivered, the number of stakeholder groups targeted, and the likely level of maximization of the delivery of targeted services (y-axis). Some examples of NBS are located in this schematic representation. Note that the y-axes could be shifted, and that type 3 cannot be viewed as "better" than type 1, the three types being complementary.[20]

The eight proposed principles of NBS are [68]:

1. NBS embrace nature conservation norms (and principles)
2. NBS can be implemented alone or in an integrated manner with other solutions to societal challenges (e.g. technological and engineering solutions);
3. NBS are determined by site-specific natural and cultural contexts that include traditional, local and scientific knowledge
4. NBS produce societal benefits in a fair and equitable way, in a manner that promotes transparency and broad participation.
5. NBS maintain biological and cultural diversity and the ability of ecosystems to evolve over time.
6. NBS are applied at the scale at a landscape.
7. NBS recognise and address the trade-offs between the production of a few immediate economic benefits for development, and future options for the production of the full range of ecosystems services.
8. NBS are an integral part of the overall design of policies, and measures or actions, to address a specific challenge.

In the plan of the perfect lagoon, these proposed core principles of NBS are incorporated where possible.

C

Stability Calculations Perfect Lagoon

The primary flood defence structure of the Perfect Lagoon will consists of a sand dike covered as much as possible with vegetation.

C.1. Waves and set-up

For waves, data for extreme scenarios (like a storm occurring every 1,000 years) could not be found. However, [69] give data for a situation in which the water level is elevated up to $1.20m$ above MSL and a wind of $15m/s$ is blowing $10m$ above the water level. For this stormy situation, the significant wave height amounts $0.42m$ and the significant wave period $2s$ (for a wind blowing at $15m/s$ over an initial water level equal to MSL $+1.20m$ [69].

(container)Vessels inside of the lagoon generate waves which cause set-up. When in Venice, it was seen that the biggest waves come from the water buses, having a relatively large speed. The formula of Hochstein is used to find the influence of these vessel-induced waves.

$$H_{vessel} = 0.1470 \cdot v_{vessel}^2 \frac{D}{L_{vessel}}^{0.5} \left(1 - \frac{A_m}{A_c}\right)^{-2.5} \tag{C.1}$$

For this formula, a commonly used water bus found at Navionics [70] is used, having the dimensions:

- $v_{vessel} = 4m/s$
- $L_{vessel} = 78.32m$
- $b_{vessel} = 16m$
- $D = \text{draught} = 2m$
- $A_m = b_{vessel} \cdot D = 32m^2$
- $A_c = h_1 \cdot b_{channel} = 1200$

$$H_{vessel} = 0.1470 \cdot 4^2 \frac{2}{78.32}^{0.5} \left(1 - \frac{32}{1200}\right)^{-2.5} = 0.40m$$

Because of the shallow depth inside the lagoon, wind set-up can account for a significant increase of the water level. Wind set-up is depending on a coefficient (here an assumed value of $4 \cdot 10^{-6}$ is being used, note: empirically retrieved for The Netherlands). Furthermore, a fetch of $20km$ is about the longest distance present inside of the lagoon [70].

$$S_{wind} = C \cdot \frac{u^2}{g \cdot h_1} F = 4 \cdot 10^{-6} \cdot \frac{15^2}{9.81 \cdot 7.21} = 0.25m \tag{C.2}$$

The total set-up in this case is therefore a summation of the vessel-induced set-up and the wind set-up:

$$S = \frac{1}{2} H_{vessel} + S_{wind} = \frac{1}{2} 0.40 + 0.25 = 0.46m \tag{C.3}$$

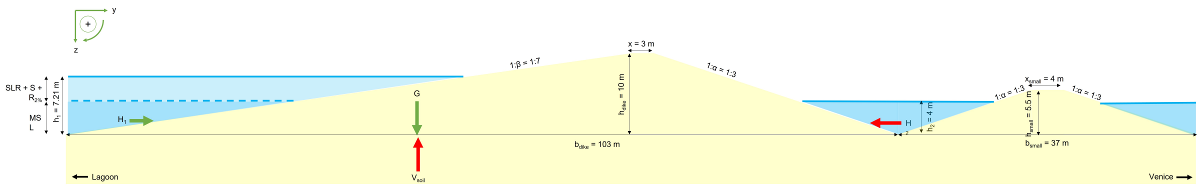


Figure C.1: Cross-section and dimensions dike surrounding middle part of Venice.

Wave run-up

Since the sand dike has a slope, waves can run up to the dike, resulting the need for a higher dike height. This wave run-up is being calculated by the 'old Delft formula' [7]:

$$R_{2\%} = 8 \cdot H_s \cdot tan(\alpha) \cdot \gamma_f \cdot \gamma_b \cdot \gamma_\beta \tag{C.4}$$

In which the gamma factors respond to the dike friction, presence of a berm and the wave angle of incidence. For the design the friction factor is assumed to be 0.6 implying the same roughness as quarry stone. All other factors are assumed to be 1.0 implying that there is no berm present on the high water side of the dike and a normal incident wave. The slope of the Venetian side of the dike (1:α) is taken to be 1:3. The slope on the lagoon side of the dike (1:β) is taken to be 1:7 just like the concept of the wide green dike (Appendix H).

$$R_{2\%} = 8 \cdot 0.42 \cdot \frac{1}{3} \cdot 0.6 \cdot 1 \cdot 1 = 0.29m$$

C.2. Static Stability

Since the dike will be quite wide the expectation is that overturning is not likely to happen. Therefore the governing water levels will be based on the sliding calculations, which are for a water depth of $4m$ (Appendix A). These design dimensions give a stable preliminary design for all mentioned failure mechanisms, proofing that the dike is stable for the whole barrier circumference provided that the bottom of the lagoon is at MSL $-4m$ or shallower. In the subsections of this chapter the elaboration for these dimensions is given.

	4 m (design WL)
h_{dike} [m]	10
b_{dike} [m]	103
x [m]	3

Table C.1: Safe dike dimensions according to a water depth of $4m$.

Sliding

For sliding the equilibrium of horizontal forces should be guaranteed taking into account the vertical forces by a friction coefficient retrieved from Table 37-1 of the Manual Hydraulic Structures [7] (= 0.4 for clayey sand) in the following manner:

$$H_1 - H_2 < 0.4 \cdot (G - V_{soil}) \tag{C.5}$$

In which H_1 and H_2 are the hydrostatic forces acting on the barrier, being calculated by the following equation [in kN per running meter]:

$$H_i = \frac{\frac{1}{2} \cdot \rho \cdot g \cdot {h_i}^2}{1000} \tag{C.6}$$

With i = 1, 2. The gravitational force acting on the soil is being calculated by:

$$G = V_{dike} \cdot \gamma_{sand} \tag{C.7}$$

With $\gamma_{sand} = 20kN/m^2$ per running meter and the volume of the dike per running meter as:

$$V_{dike} = \frac{1}{2} \cdot h_{dike} \cdot \beta h_{dike} + h_{dike} \cdot x + \frac{1}{2} \cdot h_{dike} \cdot \alpha h_{dike} \tag{C.8}$$

And the reaction force acting upwards by the bearing capacity of the subsoil is being calculated by:

$$V_{soil} = \sigma_{subsoil} \cdot b_{dike} \tag{C.9}$$

With $\sigma_{subsoil} = 144kN/m$ per running meter.

Using the above mentioned equations one can iterate Equation C.5 until the right dimensions are found. Here the dimensions shown in Table C.1 were found to give a stable preliminary caisson design. The elaboration is as follows:

$$H_1 = \frac{\frac{1}{2} \cdot 1025 \cdot 9.81 \cdot 7.21^2}{1000} = 261.4kN/m^1$$

$$H_2 = \frac{\frac{1}{2} \cdot 1025 \cdot 9.81 \cdot 4^2}{1000} = 80.4kN/m^1$$

$$V_{dike} = \frac{1}{2} \cdot 10 \cdot 7 \cdot 10 + 10 \cdot 3 + \frac{1}{2} \cdot 10 \cdot 3 \cdot 10 = 530m^2/m^1$$

$$G = 530 \cdot 20 = 10600kN/m^1$$

$$V_{soil} = 103 \cdot 74 = 9863.33kN/m^1$$

Equation C.5 becomes:

$$261.4 - 80.4 < 0.4 \cdot (10600 - 9863.33)$$

$$180.9kN/m^1 < 294.7kN/m^1$$

Overturning

For overturning one has to be sure that the core of the structure (per running meter) is smaller than 1/6 of the width of the structure (per running meter):

$$e_R < \frac{1}{6} \cdot b_{dike} \tag{C.10}$$

With

$$e_R = \frac{H_1 \cdot \frac{1}{3} h_1 - H_2 \cdot \frac{1}{3} h_2}{G - V} \tag{C.11}$$

Due to great width of the dike the expectation of no overturning turned indeed out to be valid:

$$e_R = \frac{261.4 \cdot \frac{1}{3} 7.21 - 4 \cdot \frac{1}{3} 4}{10600 - 9863.33} = 0.71m/m^1$$

$$0.71m < \frac{1}{6} \cdot 103 = 17.17m/m^1$$

C.3. Wave overtopping

Wave overtopping is defined as the amount of water flowing over the crest of a flood defence, induced by wave interacting with the flood defence due to for example set-up (Equation C.3). The overtopping discharge is being calculated by means of the European Overtopping Manual [7] and should be lower than the maximum allowed overtopping discharge:

$$\frac{q}{\sqrt{g \cdot H_{m0}^3}} = a \cdot e^{\left(\frac{-b \cdot R_c}{H_{m0}}\right)} \tag{C.12}$$

With (for a $4m$ water depth being the governing situation for overtopping (Figure C.1)):

- R_c = crest freeboard = $h_{dike} - 7.21 = 2.79m$
- H_{m0} = significant wave height = $0.42m$ [69]
- T_{m0} = significant wave period = $2.0s$
- $\xi_{m-1,0}$ = breaker parameter = $\frac{tan(\beta)}{\sqrt{\frac{H_{m0}}{1.56 \cdot T_{m-1,0}^2}}} = \frac{1:7}{\sqrt{\frac{0.42}{1.56 \cdot 2.0^2}}} = 0.55$
- $a = \frac{0.067}{\sqrt{tan(\beta)}} \cdot \gamma_b \cdot \xi_{m-1,0} = 0.98$
- $b = \frac{4.3}{\xi_{m-1,0} \cdot \gamma_b \gamma_f \gamma_\beta \gamma_v} = 13$

Solving Equation C.12 for the overtopping discharge (using the design dike dimensions) gives $q = 0 l/s/m$. This value is in accordance with what to expect since the freeboard is high ($2.79m$). Changing the dike height for example to $7m$ (below the water level of $h_1 = 7.21m$ so a freeboard of $-0.21m$) the overtopping discharge becomes over the $55770 l/s/m$. Equally, a dike height of $8m$ (freeboard = $0.79m$) gives $q = 1.94 \cdot 10^{-9} l/s/m$. These findings are shown clear in Table C.2. It should be noted that only the first row shows the correct overtopping discharge since that one represents the design height of the dike.

h_{dike} [m]	crest freeboard [m]	q [l/s/m]
10	2.79	0
8	0.79	$1.94 \cdot 10^{-9}$
7	-0.21	55770

Table C.2: Overtopping discharges for various dike heights.

C.4. Piping

Piping is the phenomenon of a water flow beneath a dike mainly caused by a too small seepage length. For piping the theory of Lane is being used [7]. This is an inequality which has to be satisfied.

$$L \geq \gamma \cdot C_L \cdot \Delta H \tag{C.13}$$

The seepage length L is in this case dependent only on the horizontal dike width, since no further (vertical) foundation structures are present in the design.

$$L = \frac{1}{3} L_{hor} = \frac{1}{3} b_{dike} = \frac{1}{3} \cdot 103 = 34.33m$$

γ is a safety factor and set to 1.5 [7]. The constant C_L depends on the soil characteristics. In this case the soil can be identified as clayey sand (generalized to very fine sand or silk: $C_L = 8.5$). ΔH refers to the head difference of the two water levels h_1 and h_2 on both sides of the dike and amounts to $3.21m$ (for a water depth of $4m$).

Equation C.13 gives that the total seepage length should be equal or bigger than $40.93m$. The inequality of Lane is satisfied and therefore piping is prevented.

C.5. Small dike

The same calculations were done for the small dike.

Wave set-up (same as for the primary dike)

$$H_{vessel} = 0.1470 \cdot v_{vessel}^2 \frac{D}{L_{vessel}}^{0.5} \left(1 - \frac{A_m}{A_c}\right)^{-2.5} = 0.40m$$

$$S_{wind} = C \cdot \frac{u^2}{g \cdot h_1} F = 0m$$

$$S = \frac{1}{2} H_{vessel} + S_{wind} = 0.20m$$

Wave run-up

$$R_{2\%} = 8 \cdot 0.42 \cdot \frac{1}{3} \cdot 1 \cdot 1 \cdot 1 = 1.12m \tag{C.14}$$

Sliding Not present due to same water levels on both sides of the small dike.

Overturning Not present due to same water levels on both sides of the small dike.

Overtopping The parameters used in the overtopping calculation for the small dike are:

- R_c = crest freeboard = $h_{dike} - 4 = 1.5m$
- H_{m0} = significant wave height = $0.42m$ [69]
- T_{m0} = significant wave period = $2.0s$
- $\xi_{m-1,0}$ = breaker parameter = $\frac{tan(\alpha)}{\sqrt{\frac{H_{m0}}{1.56 \cdot T^2_{m-1,0}}}} = \frac{1:3}{\sqrt{\frac{0.42}{1.56 \cdot 2.0^2}}} = 1.28$
- $a = \frac{0.067}{\sqrt{tan(\alpha)}} \cdot \gamma_b \cdot \xi_{m-1,0} = 0.15$
- $b = \frac{4.3}{\xi_{m-1,0} \cdot \gamma_b \gamma_f \gamma_\beta \gamma_v} = 3.35$

And therefore the overtopping discharge becomes the acceptable value of:

$$q = 0.15 \cdot e^{\left(\frac{-3.35 \cdot 1.5}{0.42}\right)} \cdot \left(\sqrt{9.81 \cdot 0.42^3}\right) = 8.19 \cdot 10^{-4} l/s/m$$

Piping Not present due to same water levels on both sides of the small dike.

C.6. Spillways

The required discharge due to evaporation of the middle part of the lagoon amounts:

$$Q_{pipe} = \frac{\frac{V_{evaporation}}{n}}{t_{active}} \tag{C.15}$$

This required discharge has to be equal to the discharge going through one pipe: Equation C.16.

$$Q_{pipe} = \frac{v_{pipe} \cdot \Pi \cdot D^2_{pipe}}{4} \tag{C.16}$$

in which the velocity through the pipe is found by solving the formula beneath:

$$z_1 - z_2 = \frac{1.5 \cdot v^2_{pipe}}{2 \cdot g} + \frac{f}{D_{pipe}} \cdot \frac{v^2_{pipe}}{2 \cdot g} \cdot L_{pipe} \tag{C.17}$$

in which:
$f = 0.02$
$z_{pipe} = 2m$
$z_1 = 7.21 - z_{pipe} = 5.21m$
$z_2 = 4 - z_{pipe} = 2m$
$g = 9.81 ms^{-2}$
$D_{pipe} = 2m$
$L_{pipe} = 83m$ (dependent on dike width)

D

NORTHERN PART LIDO AS FLOOD DEFENCE

The water level at this part of Lido for a storm with a return period of 1000 years is the MSL $+1.75m$ [17]. Taking into account the sea level rise of $+1.01m$ (Appendix A) this gives a water level on the Adriatic Sea side of MSL $+2.76m$. This means that every part of Lido which will be used as flood defence should be higher than MSL $+2.76m$. Making use of the topographic height map of Italy [4] one can determine if this is possible.

Parallel to the shoreline, from south to north, the roads Lungomare Guglielmo Marconi, Via dell'Ospizio Marino and Via Klinger are present, dividing the residential part of Lido from the beach. According to a topographic map of Italy [4] the first part of Lungomare Guglielmo Marconi (MSL $+1m$ for a length of about 400 m) and Via Klinger (MSL $+2m$ for a length of about $1200m$) are below the MSL $+2.76m$ and should therefore be heightened when using them in the flood defence system, see Figure D.1. Heightening can be done by increasing the dunes or constructing another flood defence structure.

(a) Lungomare Guglielmo Marconi - Lido south

(b) Via Klinger - Lido north

Figure D.2: Two pictures showing the different landscapes of the Lido flood defence system [21].

(a) Envisioned vertical wall of 1.5m at the southern parts of Lido

(b) Envisioned dunes towards the north of Lido

Figure D.3: Figure showing the vision for the Lido flood defense.

As can be seen in Figure D.2 Lungomare Guglielmo Marconi does not allow for heightening dunes. The land-

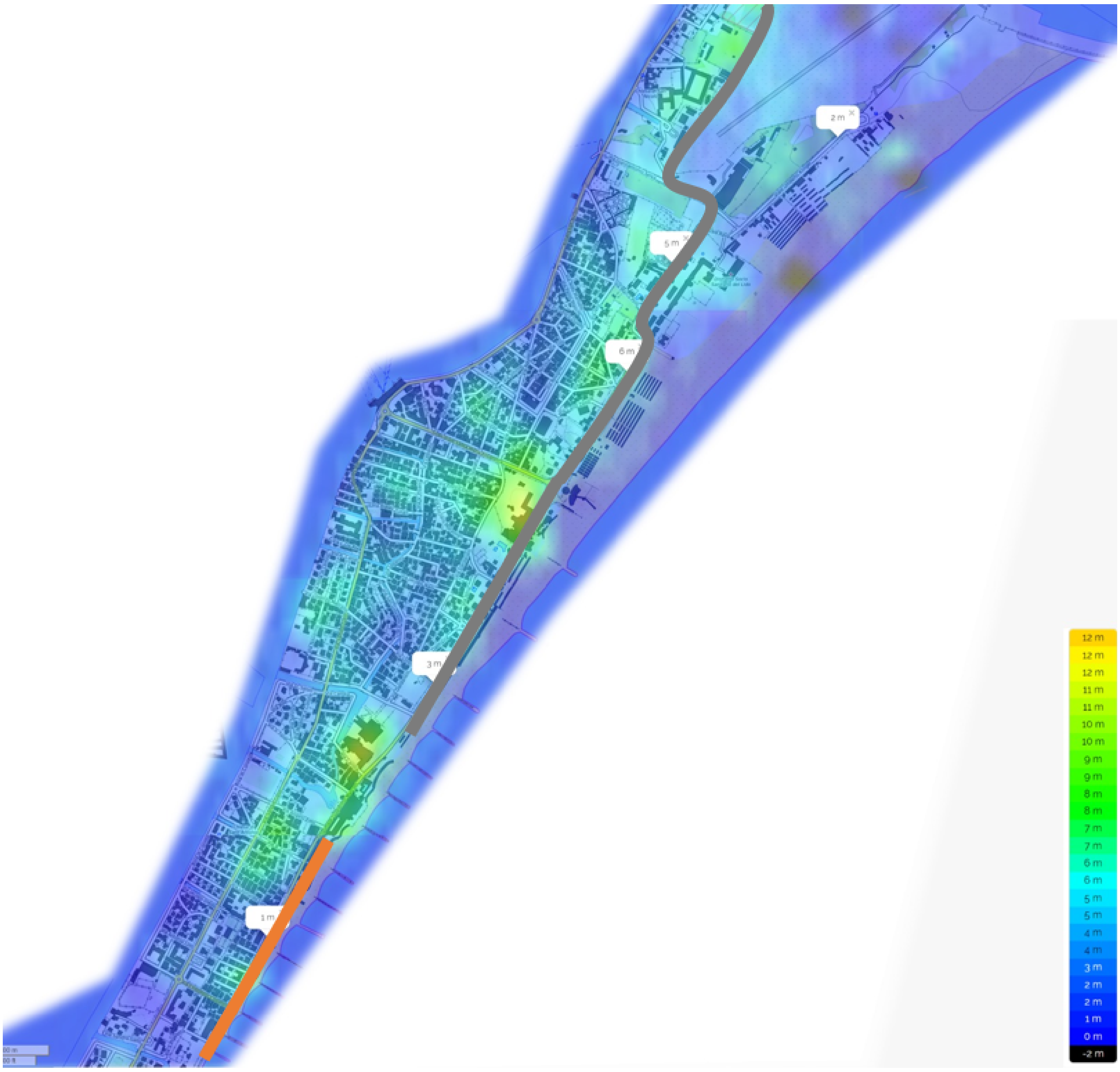


Figure D.1: Lido as a barrier[4].

scape consists of high-rise buildings with a seaside view. At the lowest points of this street a flood defence structure would be the most suitable solution, for example to use a newbuilt wall the current apartment complexes as flood defence lane. The built environment of Via Klinger is much less than that of Lungomare Guglielmo Marconi. Most of the present buildings are small, outdated or built to cope high water levels. Here a dune increase of about $1m$ may be a possibility to investigate. The amount of sand needed for a $1m$ dune increase becomes $150m^2 \cdot 1200m = 180.000m^3$, equal to about 5,000 trucks. This seems an unreasonable amount. More preferable would be to use the higher part of the north of Lido which is high enough to function as a primary flood defence (Figure D.1). The consequence may be that all buildings and the airport in front become useless within 100 years because of the sea level rise. However, since these buildings seem already quite old the prognosis is that they will be rebuilt within 100 years anyway.

Eventually, Figure D.1 presents the primary flood defence lane as suggested. Parts in orange are the additional elevated parts by for example a wall as explained above. Parts in black are the present, untouched Lido dune system. In this way the current Lido dune system can be incorporated into the primary flood defence system and stay intact as much as possible.

E

STABILITY CALCULATIONS SYMBIOTIC SYSTEM

The primary flood defence structure of the Symbiotic System will consists out of a dam, with on the inside two metro tracks. The cross-section of the dam will be bigger when a metro platform is present. For this Appendix the lecture notes about caissons of the TU Delft [71], the lecture notes about bored and immersed tunnels of the TU Delft [60] and the lecture notes about the geometric design of roads and railways of the TU Delft [61] have been consulted. From the latter the design velocity of a metro ($80km/h$), the minimum horizontal curve radius ($400m$) and the maximum vertical slope (7%) for metro tracks are being retrieved. It should be noted that this report only contains preliminary static stability calculations. More detailed dynamical calculations regarding fluid-structure interaction (FSI) and soil-structure interaction (SSI) are also of importance but not included here.

E.1. FLOATING

The caisson design for the Symbiotic System preferably allows the structure to float during transportation. The buoyant force should therefore be balanced with the weight of the caisson.

$$F_b = l \cdot b \cdot d \cdot \gamma_w \tag{E.1}$$

$$F_w = l \cdot b \cdot h - (l - 2t_{wall}) \cdot (b - 2t_{wall}) \cdot (h - t_{wall}) \tag{E.2}$$

With l, b, d and h being the length, width, draught and height of the caisson. A length-width ratio of $l = 3b$ has proved reasonable with respect to navigability. Taking E.1 and E.2 equal and iterating t_w, width b and therefore length l can be found. Unfortunately the shallow water depth inside the lagoon combined with the minimum dam height does not allow for a balance between the caisson weight and the buoyant force, so a floating caisson is not possible. The caisson therefore has to be constructed in situ. Prefab segments can still be used but have to be transported by boat towards the exact location. For the construction steps of the in situ construction method the reader is referred to Figure 5.20.

E.2. STATIC STABILITY

After construction the caisson is ready to be used. In this paragraph the caisson is being checked on sliding and overturning. The following dimensions turned out to be safe for these failure mechanisms:

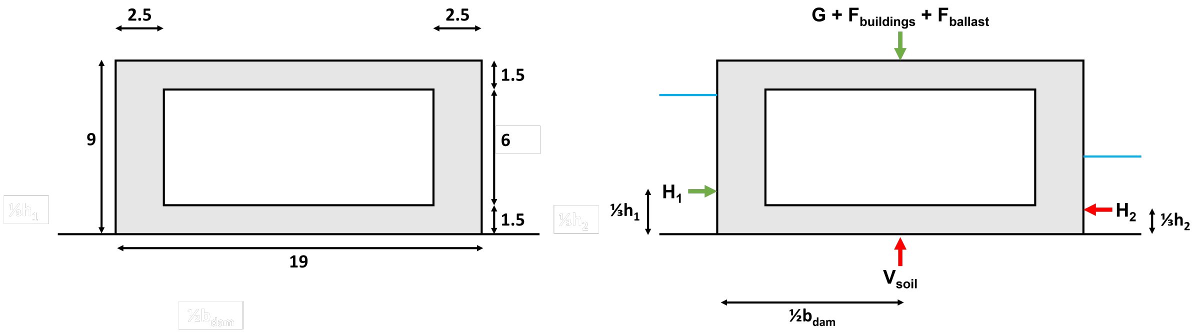


Figure E.1: Dimensions and forces acting on the dam.

Sliding

Checking the sliding stability of this fully installed caisson is done by taking into account the vertical forces by a friction coefficient retrieved from Table 37-1 of the Manual Hydraulic Structures [7] (= 0.4 for clayey sand) in the following manner:

$$H_1 - H_2 < 0.4 \cdot (G + F_{ballast} + F_{buildings} - V) \tag{E.3}$$

In which H_1 and H_2 are the hydrostatic forces acting on the barrier, being calculated by the following equation [in kN per running meter]:

$$H_i = \frac{\frac{1}{2} \cdot \rho \cdot g \cdot {h_i}^2}{1000} \tag{E.4}$$

With i = 1, 2 The gravitational force acting on the soil is being calculated by:

$$G = (b \cdot h - (b - 2t_{wall}) \cdot (h - 2t_{wall})) \cdot \gamma_{concrete} \tag{E.5}$$

With $\gamma_{concrete} = 25kN/m^2$ per running meter. Also an additional ballast force is added to account for finishing and installation works within the caisson. This force is assumed to be $F_{ballast} = 6kN \cdot b_{dam}$. The force $F_{buildings}$ takes into account the forces for eventual buildings on top of the caisson. This force is assumed to be $5kN/m$ per building floor [72]. The reaction force acting upwards by the bearing capacity of the subsoil is being calculated by:

$$V = \sigma_{subsoil} \cdot b \tag{E.6}$$

With $\sigma_{subsoil} = 95.8kN/m$ per running meter.

The governing situation for sliding and overturning is the situation with the least vertical forces, so when there are no buildings on top of the dam ($F_{buildings} = 0kN/m$) and no metro present. Using the above mentioned equations one can iterate Equation E.3 until the right dimensions are found. Here the dimensions shown in Table 5.2 were found to give a stable preliminary caisson design. The elaboration is as follows:

$$H_1 = \frac{\frac{1}{2} \cdot 1025 \cdot 9.81 \cdot 7.21^2}{1000} = 261.4kN/m^1$$

$$H_2 = \frac{\frac{1}{2} \cdot 1025 \cdot 9.81 \cdot 4^2}{1000} = 80.4kN/m^1$$

$$G = (19 \cdot 9 - (19 - 2 \cdot 2.5) \cdot (9 - 2 \cdot 1.5)) \cdot 25 = 2175kN/m^1$$

$$V = 95.8 \cdot 19 = 1819.4kN/m^1$$

Equation E.3 becomes:

$$261.4 - 80.4 < 0.4 \cdot (2175 + (6 \cdot 19) + 0 - 1819.4)$$

$$180.9kN/m^1 < 187.8kN/m^1$$

Overturning

For overturning one has to be sure that the core of the structure (per running meter) is smaller than 1/6 of the width of the structure (per running meter):

$$e_R < \frac{1}{6} \cdot b \tag{E.7}$$

With:

$$e_R = \frac{H_1 \cdot \frac{1}{3} h_1 - H_2 \cdot \frac{1}{3} h_2}{G - V} \tag{E.8}$$

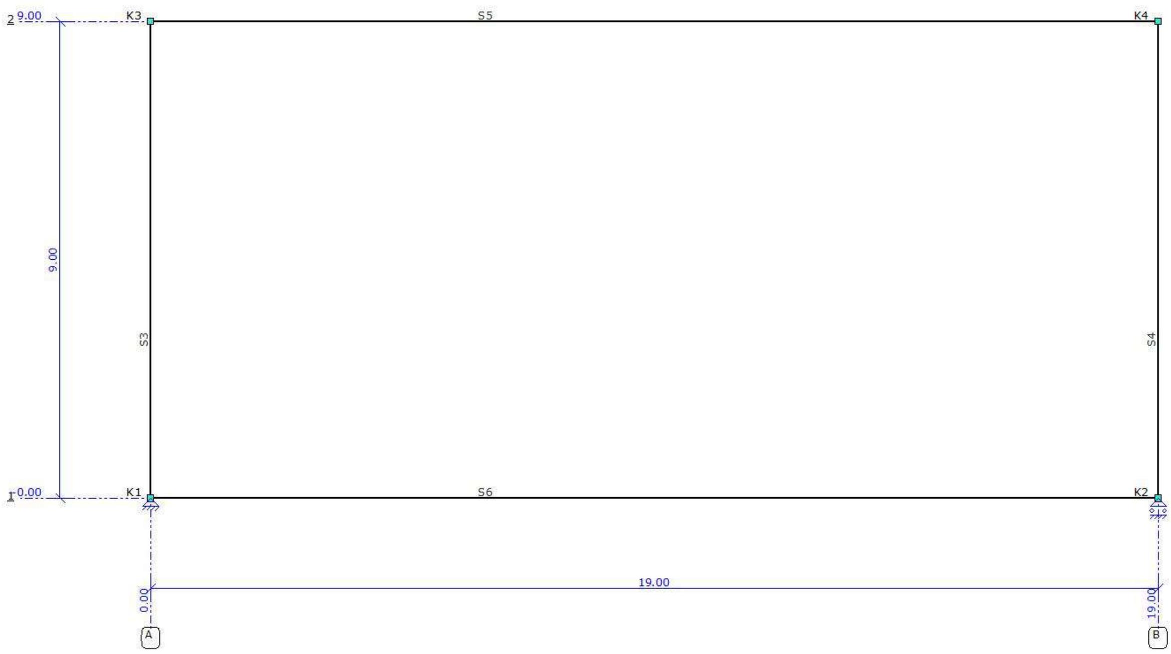
Due to great width of the dam the expectation of no overturning turned indeed out to be valid:

$$e_R = \frac{261.4 \cdot \frac{1}{3} 7.21 - 4 \cdot \frac{1}{3} 4}{2175 - 1819.4} = 1.1 m/m^1$$

$$1.1m < \frac{1}{6} \cdot 19 = 3.33 m/m^1$$

Roof deflection due to buildings on top

To examine if the deflection of the roof is acceptable the program MatrixFrame 5.5 is being used in which the dam structure is modeled and tested on various loading conditions. The most extreme load condition regarding deflection is when the Q-load is spread over the whole width of the dam. As said before, for this Q-load of the buildings a value of $F_{buildings} = 5kN/m^1$ is taken per quantity of floors. On the following pages the results of three different loading conditions and there maximum rod deflections (= **Z'glb**) are shown: $5kN/m/m^1$ (one floor), $20kN/m/m^1$ (4 floors) and $100,000kN/m/m^1$ (load on which the deflection amounts about $25cm$). It should be noted that the MatrixFrame model does not include reinforced concrete so maybe different results will follow after implementing this. However, reinforced concrete is even stronger than plane concrete and therefore the hypothesis is that the reliability of these given results in the coming pages is sufficient.



MEMBERS

Member	Node B	Node E	X-B	Z-B	X-E	Z-E	Length	Section	Position
S3	K1	K3	0.000	0.000	0.000	-9.000	9.000	P1	0.000 - L(9.000)
S4	K2	K4	19.000	0.000	19.000	-9.000	9.000	P1	0.000 - L(9.000)
S5	K3	K4	0.000	-9.000	19.000	-9.000	19.000	P2	0.000 - L(19.000)
S6	K1	K2	0.000	0.000	19.000	0.000	19.000	P2	0.000 - L(19.000)
-	**-**	**-**	**m**	**m**	**m**	**m**	**m**	**-**	**-**

SECTIONS

Section	Section Name	Area	Iy	Material	Angle
P1	R22000x2000	4.4000e+01	1.4667e+01	C35/45	0.0
P2	R22000x1500	3.3000e+01	6.1875e+00	C35/45	0.0
-	**-**	**m2**	**m4**	**-**	**°**

SECTION SHAPES

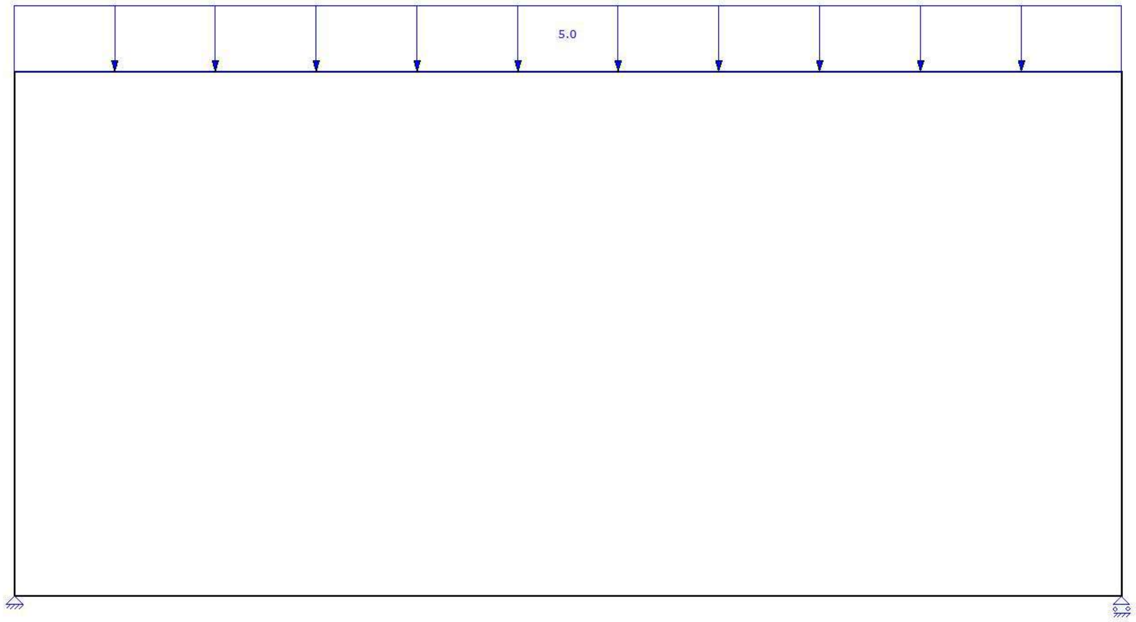
Section	Tapered	hB	hE	tf	tw	tf2	B	b1	b2	Castellate	Height
P1	No	2,000	2,000	0,0000	0,0000	0,0000	22,000	0,000	0,000	No	0,000
P2	No	1,500	1,500	0,0000	0,0000	0,0000	22,000	0,000	0,000	No	0,000
-	**-**	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**-**	**m**

MATERIALS

Material	Density	Youngs mod.	Lin. Exp.
C35/45	25.00	3.4000e+07	10.0000e-06
-	**kN/m3**	**kN/m2**	**C°m**

Student version

PIC. LASTEN B.G.1



L.C. SUPPORT REACTIONS

LComb	Support	Node	X	Z	My
B.G.1	O3	K1	0.00	-47.50	0.00
	O4	K2	0.00	-47.50	0.00
	Sum Reactions		**0.00**	**-95.00**	
	Sum Loads		**0.00**	**95.00**	
-	-	-	**kN**	**kN**	**kNm**

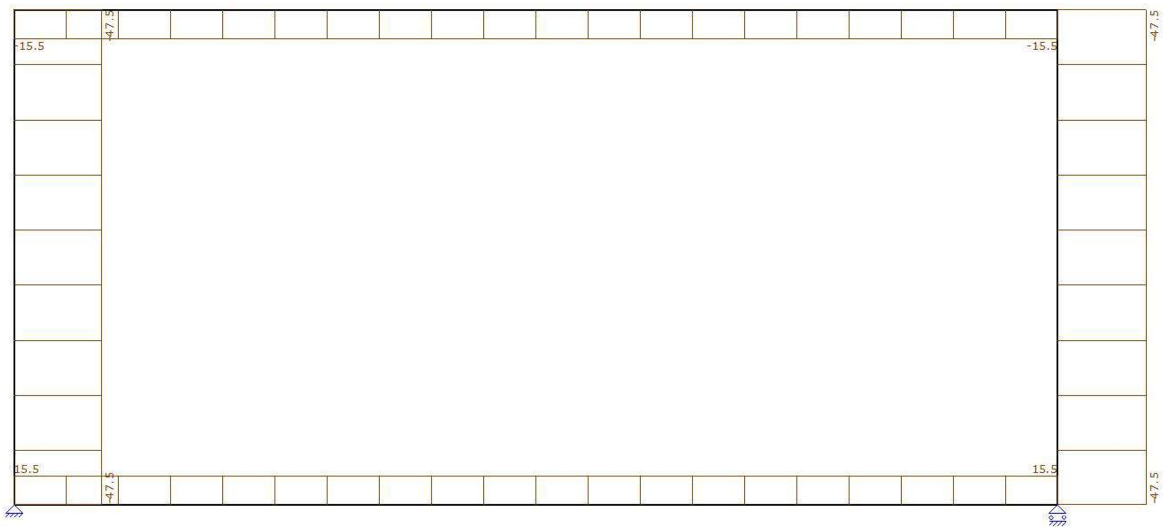
L.C. DEFLECTIONS

Member	L.C.	Node Begin		Member				Node End	
		X	Z	Z' dist	Z'	Z' glb dist	Z' glb	X	Z
S3	B.G.1	0.000	0.000	5.264	0.0000	5.064	0.0000	0.000	0.000
S4	B.G.1	0.000	0.000	5.264	0.0000	5.064	0.0000	0.000	0.000
S5	B.G.1	0.000	0.000	9.500	0.0000	9.500	0.0000	0.000	0.000
S6	B.G.1	0.000	0.000	9.500	0.0000	9.500	0.0000	0.000	0.000
-	-	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**m**

L.C. NODAL FORCES

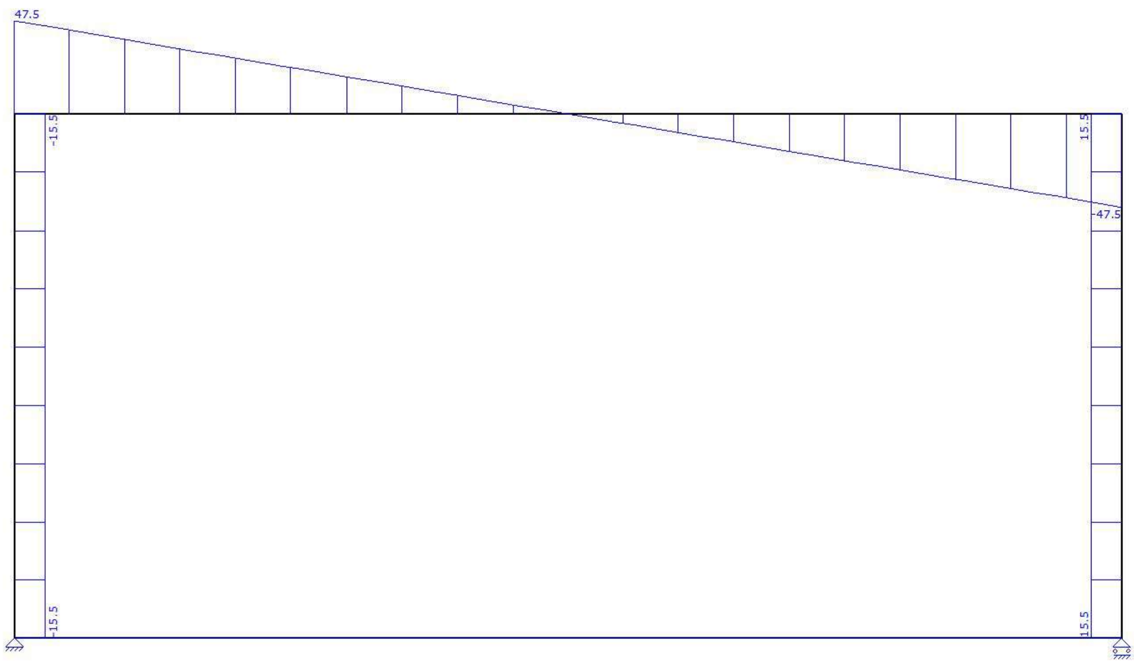
Member	L.C.		Node	TC	Nx	Vz	My
S3	B.G.1	B	K1	C	47.50	15.53	-7.22
		E	K3	C	-47.50	-15.53	-132.59
S4	B.G.1	B	K2	C	47.50	-15.53	7.22
		E	K4	C	-47.50	15.53	132.59
S5	B.G.1	B	K3	C	15.53	-47.50	132.59
		E	K4	C	-15.53	-47.50	-132.59
S6	B.G.1	B	K1	T	-15.53	0.00	7.22
		E	K2	T	15.53	0.00	-7.22
-	-		-	-	**kN**	**kN**	**kNm**

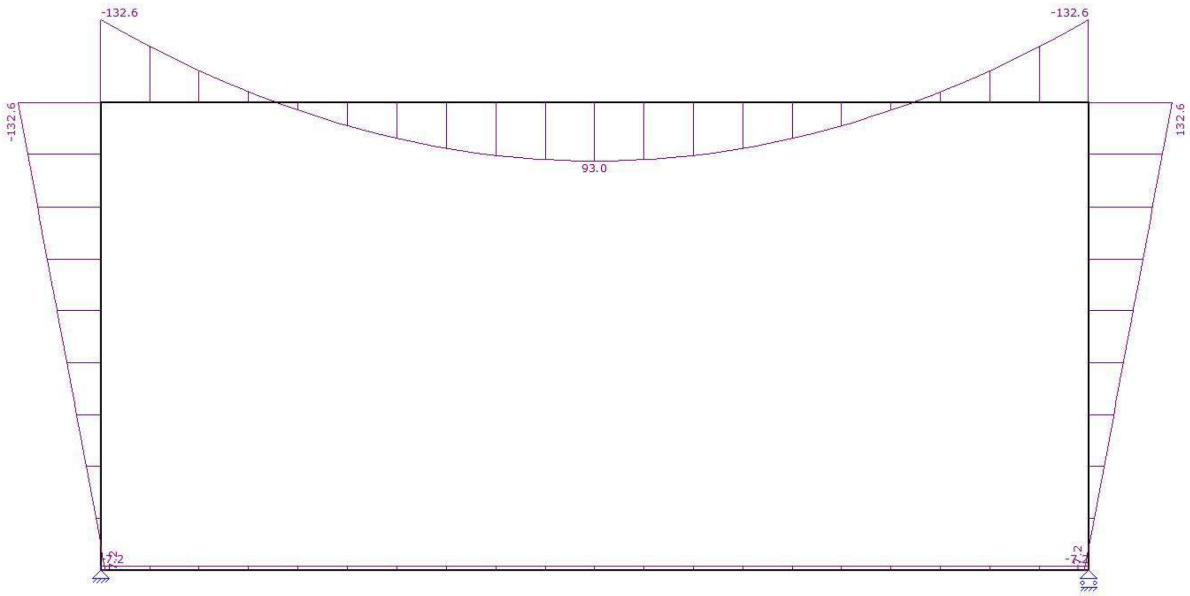
PIC. B.G.1 NORMAALKRACHT (NX)



Belastingsgevallen

PIC. B.G.1 DWARSKRACHT (VZ)





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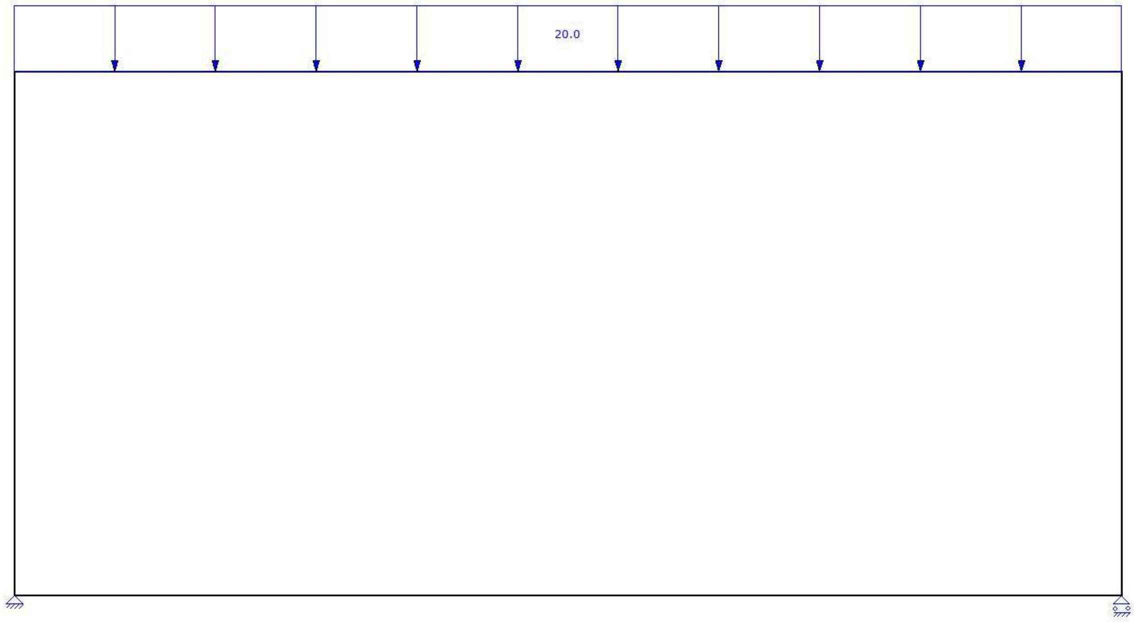


Student version

L.C. SUPPORT REACTIONS

LComb	Support	Node	X	Z	My
B.G.1	O3	K1	0.00	-190.00	0.00
	O4	K2	0.00	-190.00	0.00
	Sum Reactions		**0.00**	**-380.00**	
	Sum Loads		**0.00**	**380.00**	
-	-	-	**kN**	**kN**	**kNm**

L.C. DEFLECTIONS

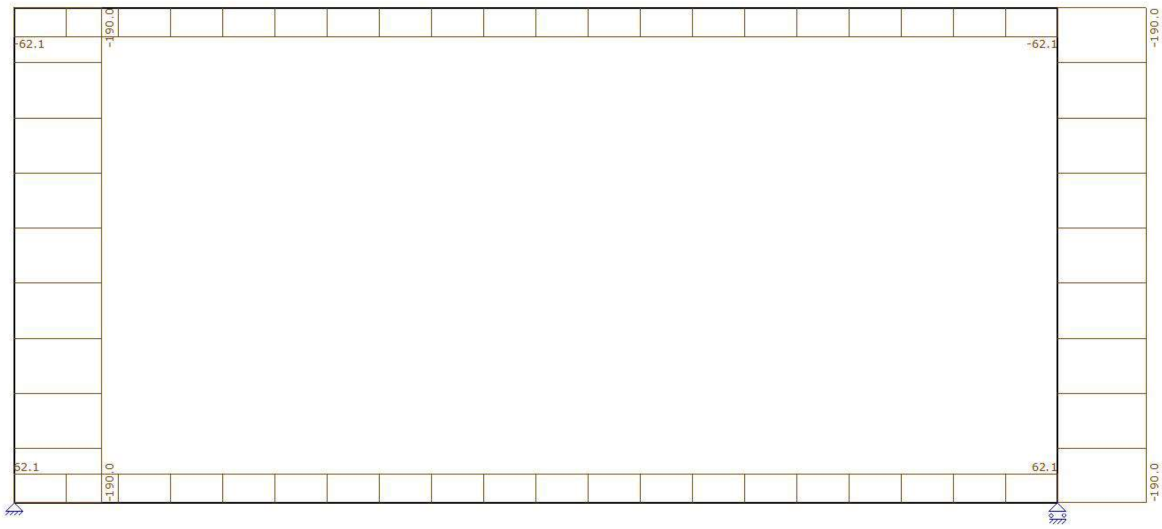
Member	L.C.	Node Begin		Member				Node End	
		X	Z	Z' dist	Z'	Z' glb dist	Z' glb	X	Z
S3	B.G.1	0.000	0.000	5.264	0.0000	5.064	0.0000	0.000	0.000
S4	B.G.1	0.000	0.000	5.264	0.0000	5.064	0.0000	0.000	0.000
S5	B.G.1	0.000	0.000	9.500	0.0000	9.500	0.0000	0.000	0.000
S6	B.G.1	0.000	0.000	9.500	0.0000	9.500	0.0000	0.000	0.000
-	-	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**m**

L.C. NODAL FORCES

Member	L.C.		Node	TC	Nx	Vz	My
S3	B.G.1	B	K1	C	190.00	62.14	-28.89
		E	K3	C	-190.00	-62.14	-530.35
S4	B.G.1	B	K2	C	190.00	-62.14	28.89
		E	K4	C	-190.00	62.14	530.35
S5	B.G.1	B	K3	C	62.14	-190.00	530.35
		E	K4	C	-62.14	-190.00	-530.35
S6	B.G.1	B	K1	T	-62.14	0.00	28.89
		E	K2	T	62.14	0.00	-28.89
-	-		-	-	**kN**	**kN**	**kNm**

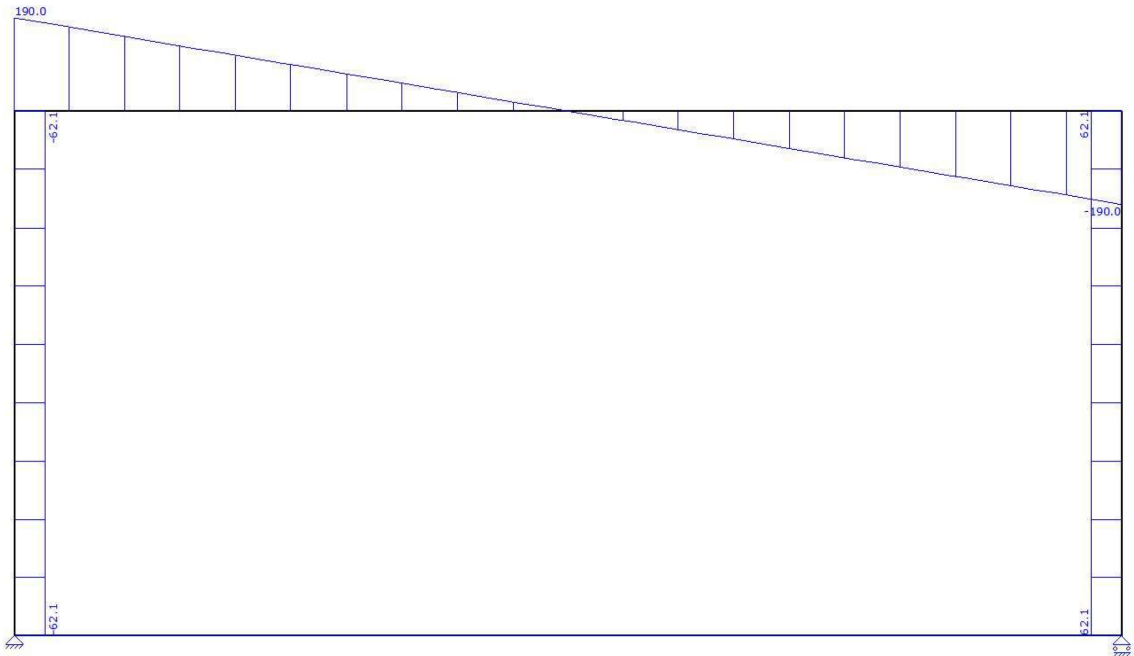
PIC. B.G.1 NORMAALKRACHT (NX)

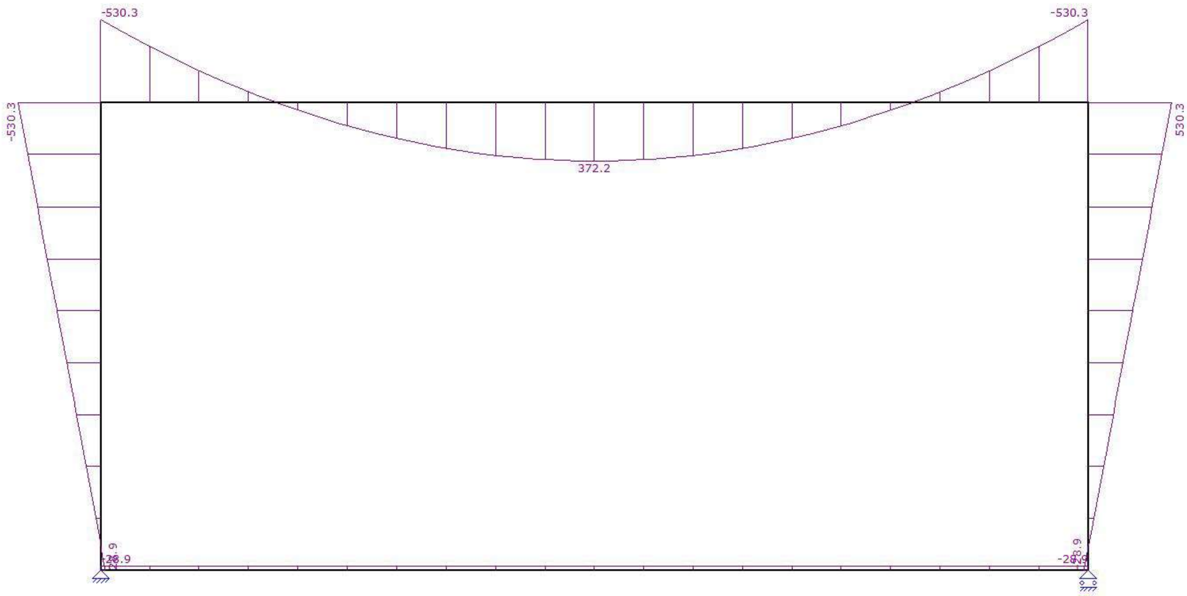
Belastingsgevallen



PIC. B.G.1 DWARSKRACHT (VZ)

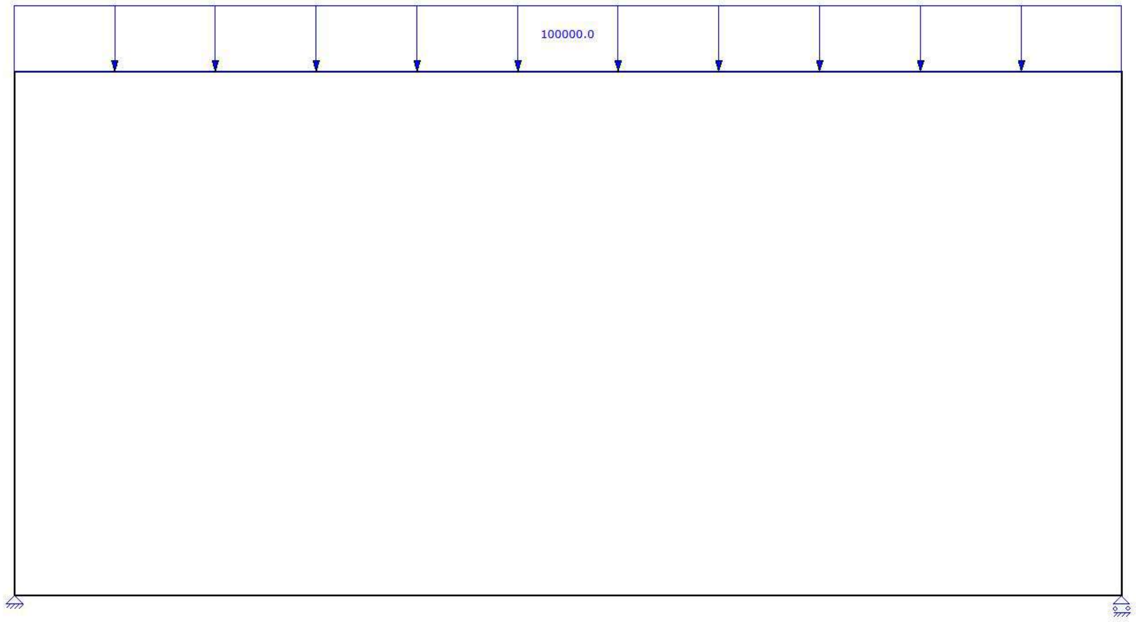
Belastingsgevallen





Student version

PIC. LASTEN B.G.1



L.C. SUPPORT REACTIONS

LComb	Support	Node	X	Z	My
B.G.1	O3	K1	0.00	-950000.00	0.00
	O4	K2	0.00	-950000.00	0.00
	Sum Reactions		**0.00**	**##########**	
	Sum Loads		**0.00**	**1900000.00**	
-	-	-	**kN**	**kN**	**kNm**

L.C. DEFLECTIONS

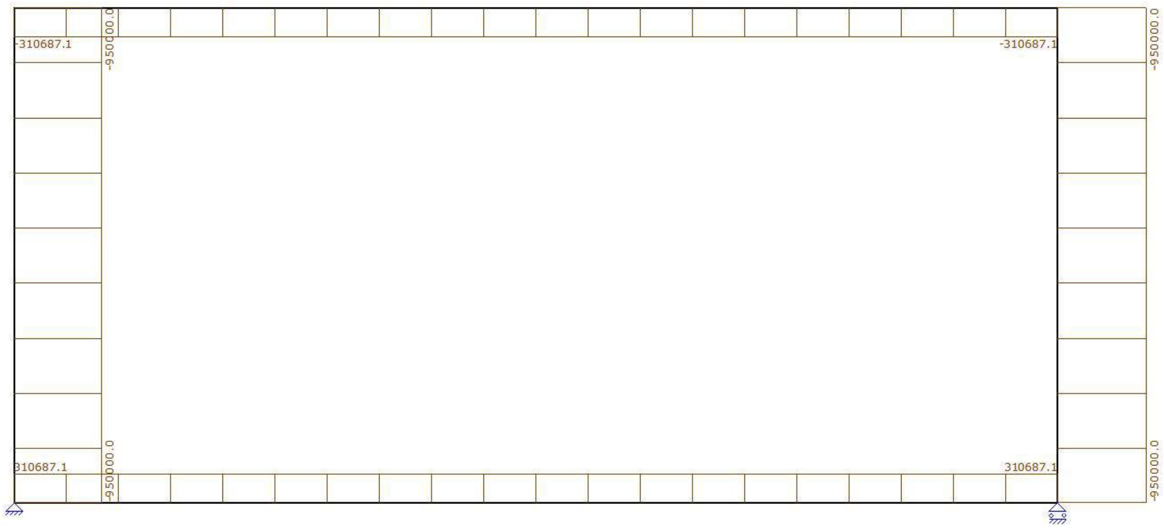
Member	L.C.	Node Begin		Member				Node End	
		X	**Z**	**Z' dist**	**Z'**	**Z' glb dist**	**Z' glb**	**X**	**Z**
S3	B.G.1	0.000	0.000	5.264	-0.0263	5.064	-0.0233	0.005	0.006
S4	B.G.1	0.005	0.000	5.264	0.0263	5.064	0.0285	0.000	0.006
S5	B.G.1	0.005	0.006	9.500	0.2378	9.500	0.2435	0.000	0.006
S6	B.G.1	0.000	0.000	9.500	-0.0310	9.500	-0.0310	0.005	0.000
-	-	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**m**

L.C. NODAL FORCES

Member	L.C.		Node	TC	Nx	Vz	My
S3	B.G.1	B	K1	C	950000.00	310687.07	-144447.87
		E	K3	C	-950000.00	-310687.07	-2651735.81
S4	B.G.1	B	K2	C	950000.00	-310687.07	144447.87
		E	K4	C	-950000.00	310687.07	2651735.81
S5	B.G.1	B	K3	C	310687.07	-950000.00	2651735.81
		E	K4	C	-310687.07	-950000.00	-2651735.81
S6	B.G.1	B	K1	T	-310687.07	0.00	144447.87
		E	K2	T	310687.07	0.00	-144447.87
-	-		-	-	**kN**	**kN**	**kNm**

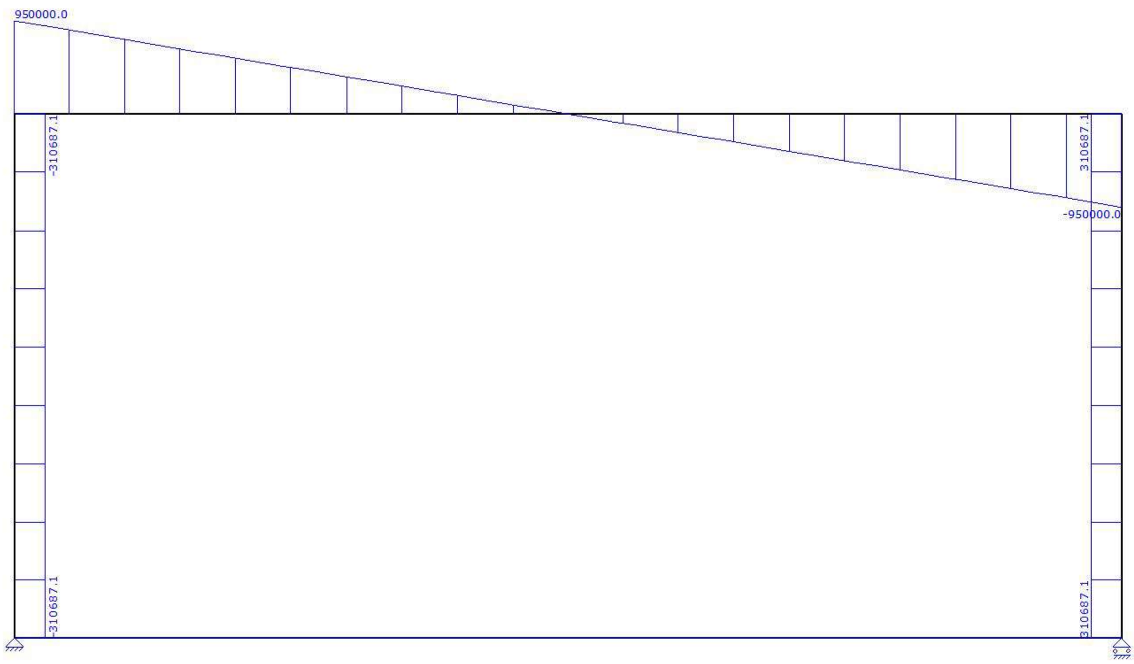
Student version

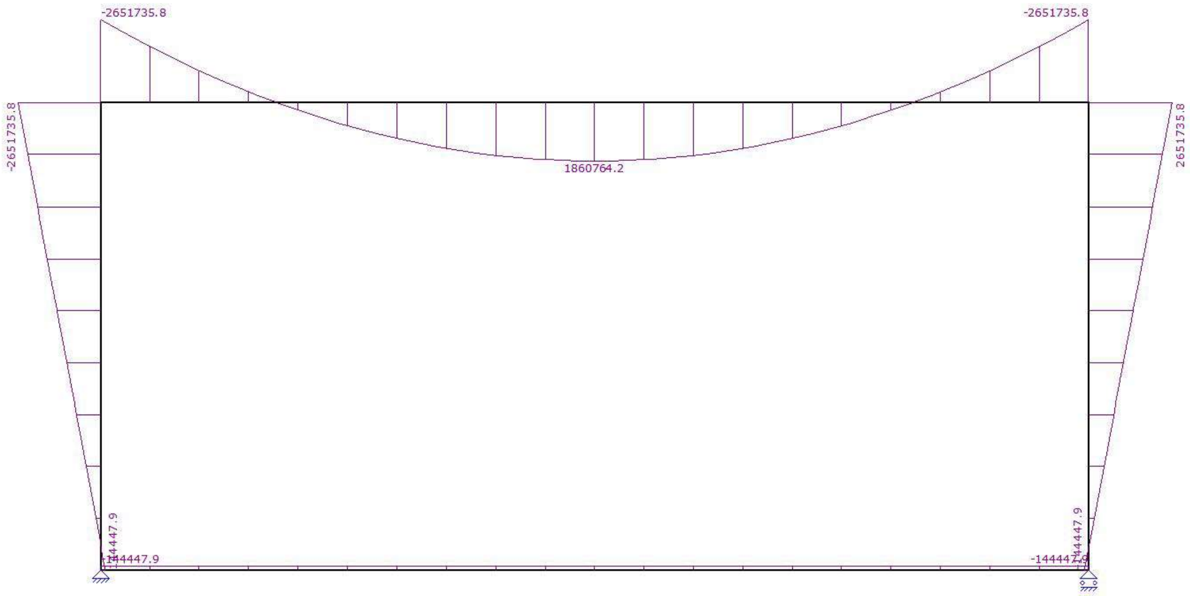
PIC. B.G.1 NORMAALKRACHT (NX)



PIC. B.G.1 DWARSKRACHT (VZ)

Belastingsgevallen





Student version

SPILLWAYS

First the velocity in the pipe is found using Equation C.17.

$$z_1 - z_2 = \frac{1.5 \cdot v_{pipe}^2}{2 \cdot g} + \frac{f}{D_{pipe}} \cdot \frac{v_{pipe}^2}{2 \cdot g} \cdot L_{pipe} \tag{E.9}$$

In which:

$$\begin{aligned}
f &= 0.02 \\
z_{pipe} &= 0.5m \\
z_1 = 7.21 - z_{pipe} &= 6.71m \\
z_2 = 4 - z_{pipe} &= 3.5m \\
g &= 9.81ms^{-2} \\
D_{pipe} &= 0.7m \\
L_{pipe} &= 19m(dependentondamwidth)
\end{aligned}$$

From the pipe velocity one can now find the discharge through the pipe.

$$Q_{pipe} = \frac{v_{pipe} \cdot \Pi \cdot D_{pipe}^2}{4}$$

This discharge should be the same as the evaporation discharge calculated in Equation C.15.

F

MOSE considerations

Using the MOSE as a submerged weir, flow to the lagoon during high tide can be controlled, and it can act as a measure of sediment control towards or from the lagoon (depending on usage during ebb/flood). An increase of sediment supply is required to keep the system constant and even more is required to increase the total dry area in order to create the perfect lagoon. By using the MOSE as weir during falling tide, erosion by the sea is significantly reduced. During rising tide, MOSE will then be lowered again the allow sediment from the sea to enter the lagoon, as well as picking up sediment that has accumulated behind the MOSE.

Additional research will need to be done on how to deal with the additional sedimentation below the MOSE during falling tide, as this will prevent the MOSE from closing during rising tide, a problem that is already occurring. This problem has been stated as well in different MOSE designs like the one of 1992 [42] where by usage of hydraulic jet pumps, they remove solids from gate recesses. However, usage of MOSE as sediment retention device will ensure high amounts of sediment accumulation just below the barrier. Hydraulic jet pumps will in this scenario not suffice and a solution will need to be found. Ideally, turning the MOSE by 180° would solve this problem.

Additional research must be done on scour-hole development around the construction when MOSE is used as submerged weir. Lastly, a cost benefit analysis should be done in order to find out if using the MOSE for sediment retention is better than using sand nourishments to deal with the eroding system.

A solution might be found in rebuilding MOSE and placing the barrier 180°. This seems like a simple solution but there is more to it as it seems. The operation would come at great cost and replacement of the construction below the gates as well. As dredging is very expensive, this would in the long term be a more affordable solution. During rebuilding, hydraulic jet pumps can be installed to deal with small amounts of sediment accumulating behind the construction during falling tide.

Another way would be to install a lift gate on the locations of the MOSE and adapting the current infrastructure. However, the lift gates would have to be removed and it is uncertain if a lift gate would be feasible over a large depth.

A different approach would be to make slats or doors in the MOSE gates which would be able to hermetically close. Being able to hermetically close is of utmost important as this is the main mechanism driving the MOSE upwards during operation as it rises when filled with air according to Archimedes' principle. In this scenario, in case of large sediment deposits on the lagoon side after operation during falling tide, these slats or doors can be opened on the seaward side to let water *trough* the MOSE gates, carrying the accumulated sand back into the lagoon.

Lastly, a solution might be to allow the MOSE to turn beyond its most vertical position. For this to happen, additional space will need to be made behind the MOSE (towards the seaward side) to allow the MOSE to drop down here. An extra driving force may be required to push the barriers beyond their turning point. Afterwards, if used during falling tide as designed, the flow will help push the barriers down (if combined with filling the barriers with water).

In Table F.1, a basic assessment is done for different MOSE design ideas which are then compared to each other.

Table F.1: MOSE considerations in terms of costs and functionality.

Criteria: Design	Estimated cost -:€€€ and +:€	Functionality	Feasibility
Existing MOSE as weir	+ +	- -	-
180°Turned MOSE	+/-	+/-	+/-
Slats or doors	-	+	+/-
Lift gate	- -	+ +	+/-
Allow turning towards seaside	-	+	+

The most feasible in terms of cost versus functionality is to allow the MOSE gates to turn towards the seaside. An additional storage area for the lift gates would have to made made on the other side of the joints. Additionally, there would need to be a mechanism forcing the turning of the gates towards the seaside. Figure F.1 shows a simple image of this concept.

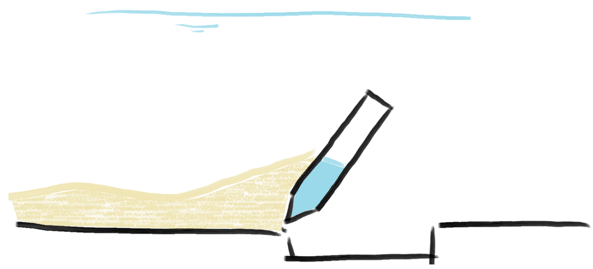


Figure F.1: MOSE turning towards seaside.

G

TIDAL PRISM

The tidal prism is the water that flows in and out in one tidal cycle. Equation 5.2 shows the relation between the channel volume of the crossection and the tidal prism.

$$A_c = xP^n \tag{G.1}$$

Where A_c is the cross-section of the channel, $x = 7,489 \cdot 10^{-4}$ (for jettied inlets), P is tidal prism (H (tidal range)$\cdot$ A(surface area)), and $n = 0.86$ (for jettied inlets), Equation 5.2.

In the Symbiotic System the decrease in surface area is estimated from $70km^2$ to $53km^2$, the tidal range (H) remains the same. To calculate the effect on the channels the formula can be rewritten as follows:

$$A_{c1} = 7.489 \cdot 10^{-4}(70 \cdot H)^{0.86} \tag{G.2}$$

$$A_{c2} = 7.489 \cdot 10^{-4}(53 \cdot H)^{0.86} \tag{G.3}$$

$$\frac{A_{c1}}{A_{c2}} = \frac{70^{0.86}}{53^{0.86}} \tag{G.4}$$

$$A_{c2} = 0.79 \cdot A_{c1} \tag{G.5}$$

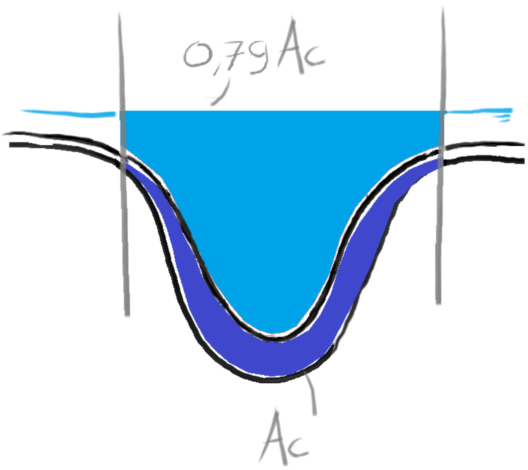


Figure G.1: Channel cross-section.

H

SOLUTIONS FOR THE PERFECT LAGOON

In this chapter, possible solutions and designs are discussed fitting the Perfect Lagoon. First of all, the importance and effects of salt marshes are discussed.

H.1. GREEN SOLUTIONS

In the Perfect Lagoon, the focus lies on nature and nature based solutions (see also Appendix B). At the center of this vision is the philosophy of building with nature. Concepts used and implemented are explained below, as well as their beneficial effects/impacts on the Perfect Lagoon.

SALT MARSHES

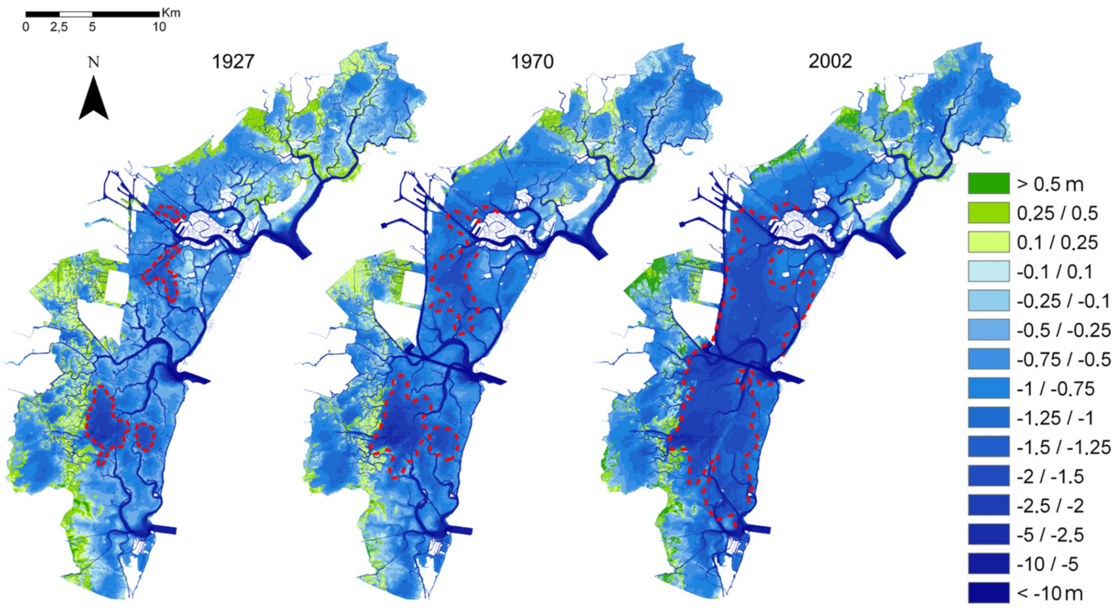


Figure H.1: Figure depicting the retreat of dry area over the last century [22].

Salt marshes allow for a unique and thriving ecosystem because of their ability to supply nutrients to the system [40]. They also play a role in water quality protection and flood protection by absorption of rainwater and may play a crucial role as climate change adaptation strategy in the years to come[73].

Due to climate change[74] and anthropogenic[75] influences, salt marshes are rapidly disappearing. The plan of the perfect lagoon aims to preserve the existing salt marshes as well as create new area's for salt marshes as how it was in 1927[22]. This preservation and creation of salt marshes is great for the dike infrastructure as salt marshes benefit the to be designed flood protection by reducing load and supplying as building material[73] [76].

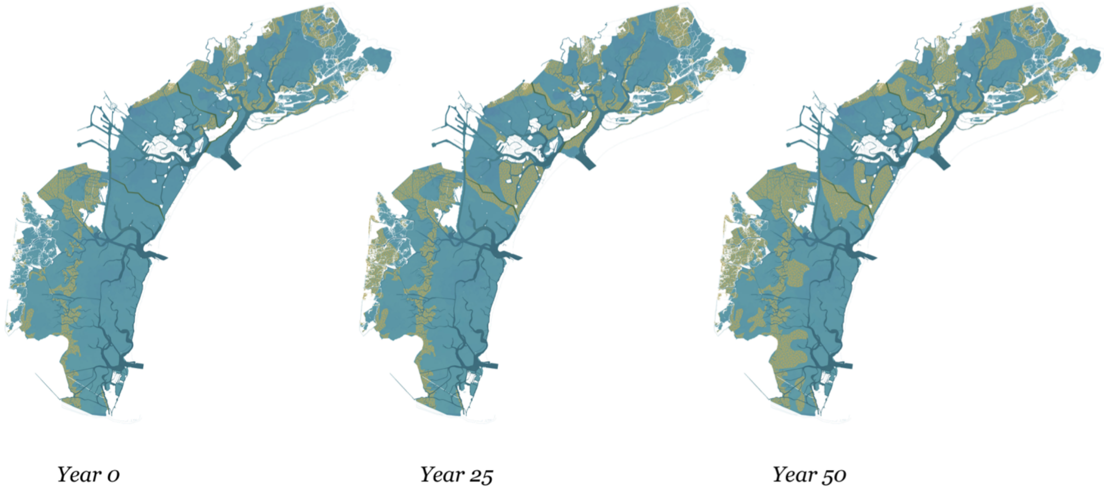


Figure H.2: Regrowth of the salt marshes over time in an ideal scenario

This makes them an essential building block in the plans for the perfect lagoon.

Dike as agriculture

Next to grass cultivation which is standard, literature does not say anything about agriculture on dikes. In Venetian style, that of doing extreme things, a pilot will be started on part of the dike, researching the possibility of agriculture on dikes. This possibly is a revolutionary idea which we want to research in this design.

If this is deemed unrealistic, we could try using the dikes as grazing/herding area's for livestock like sheep. This would benefit local farmers as well as reduce the need for dike maintenance. When overtopping or flooding is expected, livestock can easily be moved to another location.

Figure H.3: Concept of Wide Green Dike on the left side you can see the salt marshes causing additional energy dissipation.

Wide Green Dike For the creation of the Perfect Lagoon, we would like to introduce the Wide Green Dike to Italy. This is a dike covered with grass with slope less steep than the traditional dike of 1:4. The wide green dike also allows for greater ease of doing repairs, enhanced spatial quality and increased adaptability. The wide dike could potentially create more land for agriculture/grazing and would be a cheaper and greener solution[77].

Natural Rivers

Nature based solution (NBS)(see also Appendix B) will be applied in the form of Room for the River. Room for the River was a Dutch government design plan carried out during the years 2006–2015, intended to address flood protection, master landscaping and the improvement of environmental conditions in the areas surrounding the Netherlands' rivers. For this, eight interventions were devised that will also be used for the Perfect Lagoon. These are shown in Figure H.4.

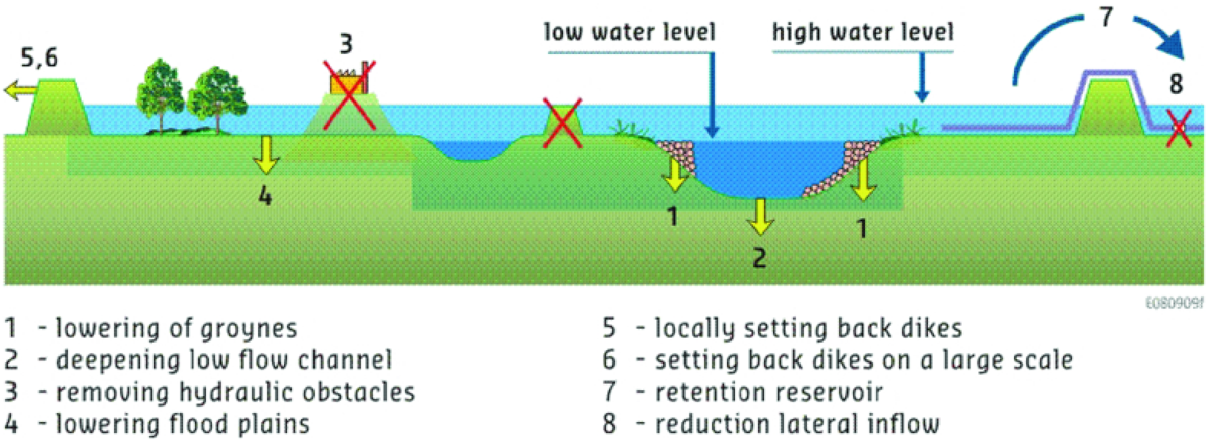


Figure H.4: The eight drastic measures that were implemented during the Room for the River plan [23].

As described in Subsection 4.1.1, the main rivers Brenta and Piave will be diverted back into the lagoon, with the above-mentioned interventions applied. These interventions will ensure that excess water due to more frequent heavy rainfall due to climate change is better handled and drained. But in addition to safety, floodplains are also very interesting in terms of ecological value, they form a great place for fish spawn and growth of young fish and a place for young plants to develop[78]. These floodplains or wetlands also help in regulating soil moisture, the ground water level in the river system and in the protection of the water quality. See also Figure H.5 as a schematic overview for ecological possibilities.

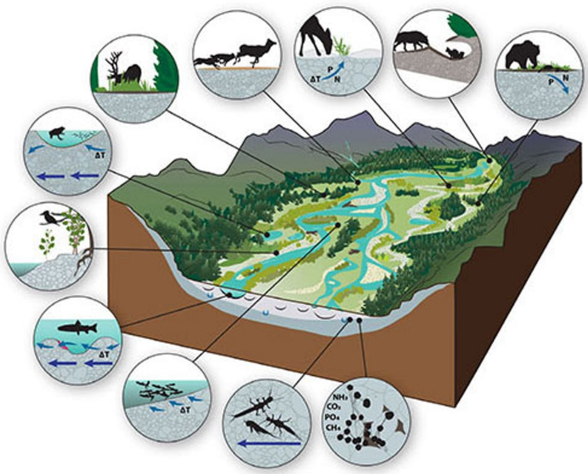


Figure H.5: Idealistic scenario for when the Brenta and Piave rivers are naturally diverted as NBS. The river floodplains provide water exchange and ecological habitat improvement [24].

Another advantage of diverting the Brenta and Piave river in the Perfect Lagoon will be the supply of freshwater for heightening the groundwater level. Excess water during flood events will be stored in a reservoir connected to the river. From there, the water can be use for restoring the groundwater level in Venice. This will put the subsiding of Venice by lack of groundwater to a hold. The reservoir will be connected to river by a side channel as to not cause sediment trapping in the main channel (the sediment supply from the Brenta and Piave is very important for the system).

I

Hydrodynamcis and Morphodynamics of the Venice Lagoon

This appendix goes into the hydrodynamics and morphology of the Venice lagoon.

The Venice lagoon has three inlets: Chioggia, Malamocco and Lido. These, and the accompanying channels can be seen in Figure H.1. These multiple inlets combined with the morphology of the basin ensure that the lagoon can be divided into four basins during calm conditions [62]. Each tidal cycle, water enters the inlet, and disperses through the lagoon, at some point, the tidal wave 'meets' the tidal wave coming from the other inlet, creating a standstill point, where the tidal velocity is near-zero. A near zero velocity also means a near zero sediment transport. A representation of such a tidal watershed can be seen in Figure I.1.

Figure I.1: An impression of a tidal watershed in the Wadden sea. Two tidal waves meet each other creating a line of (near) zero velocity.

That the lagoon has four basins, means that it has 3 tidal watersheds [79]. These can be seen in Figure I.1.

As one can see, the northern most tidal watershed cuts straight through the Lido inlet channel. Normally a tidal watershed cannot exist here, however because of the particular morphology of the lagoon, and the island directly in front of the inlet, the Lido inlet creates a two basin system [79] [80].

Because of the nature of a tidal watershed (near zero sediment transport, and velocity), a dam can be built over this line, without affecting the lagoon morphology all that much.

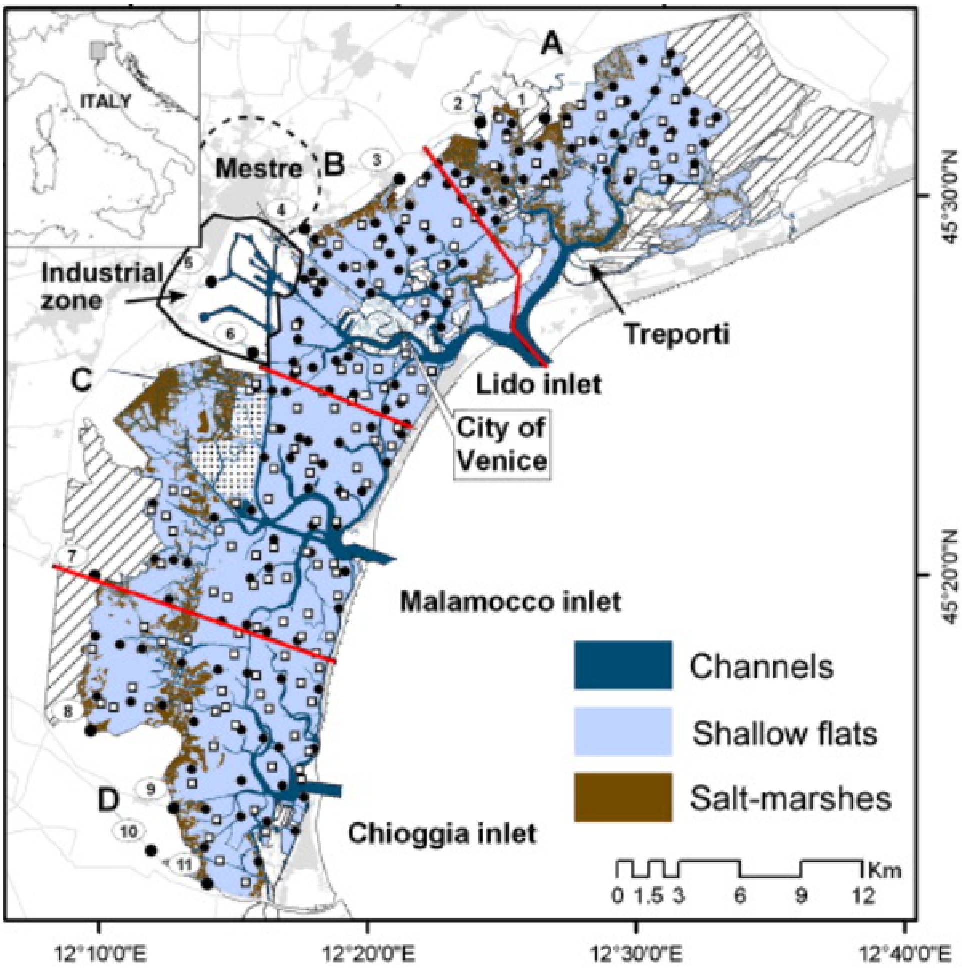
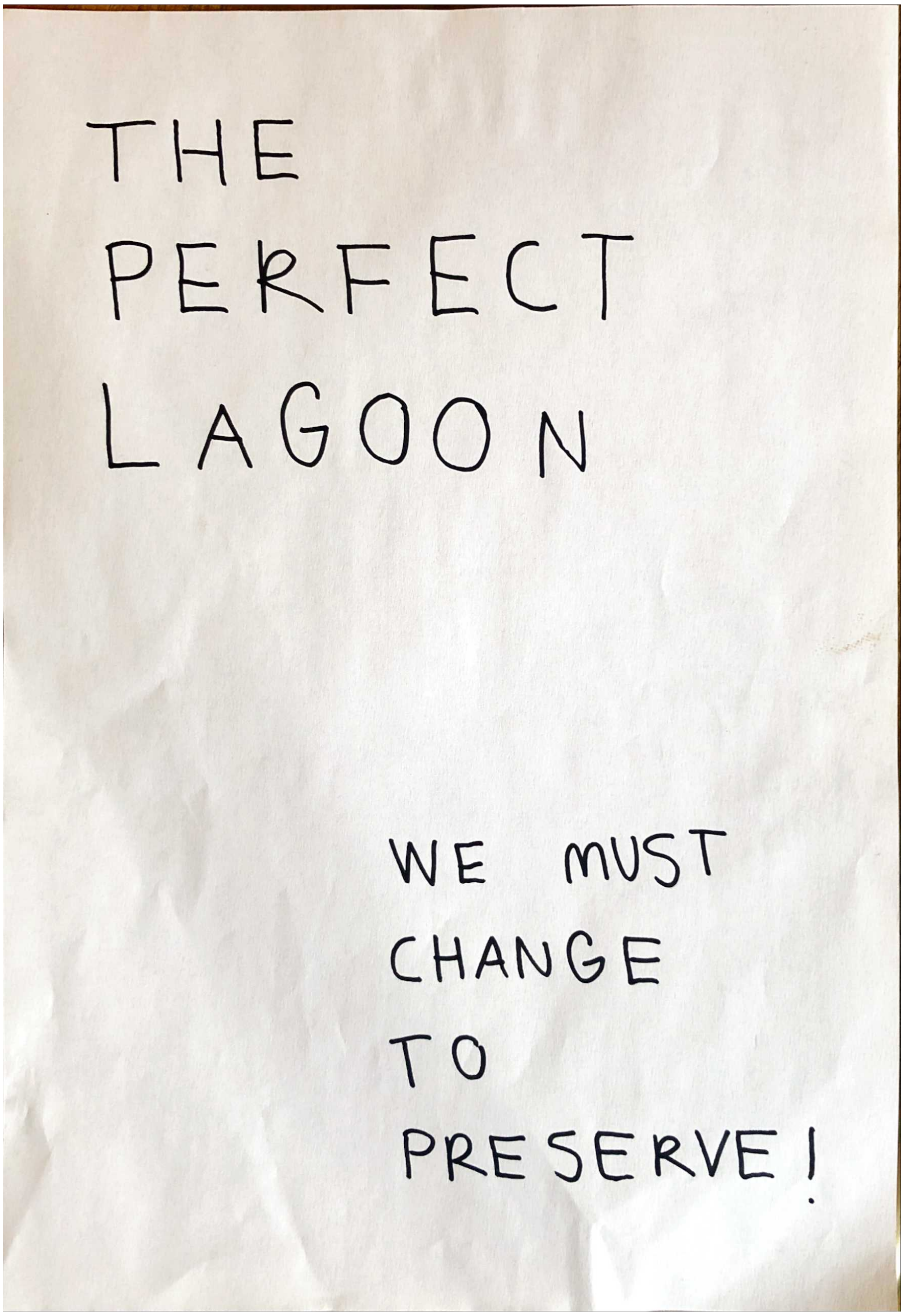


Figure I.2: The watersheds in the lagoon [25].

J

Concept 1 - The Perfect Lagoon



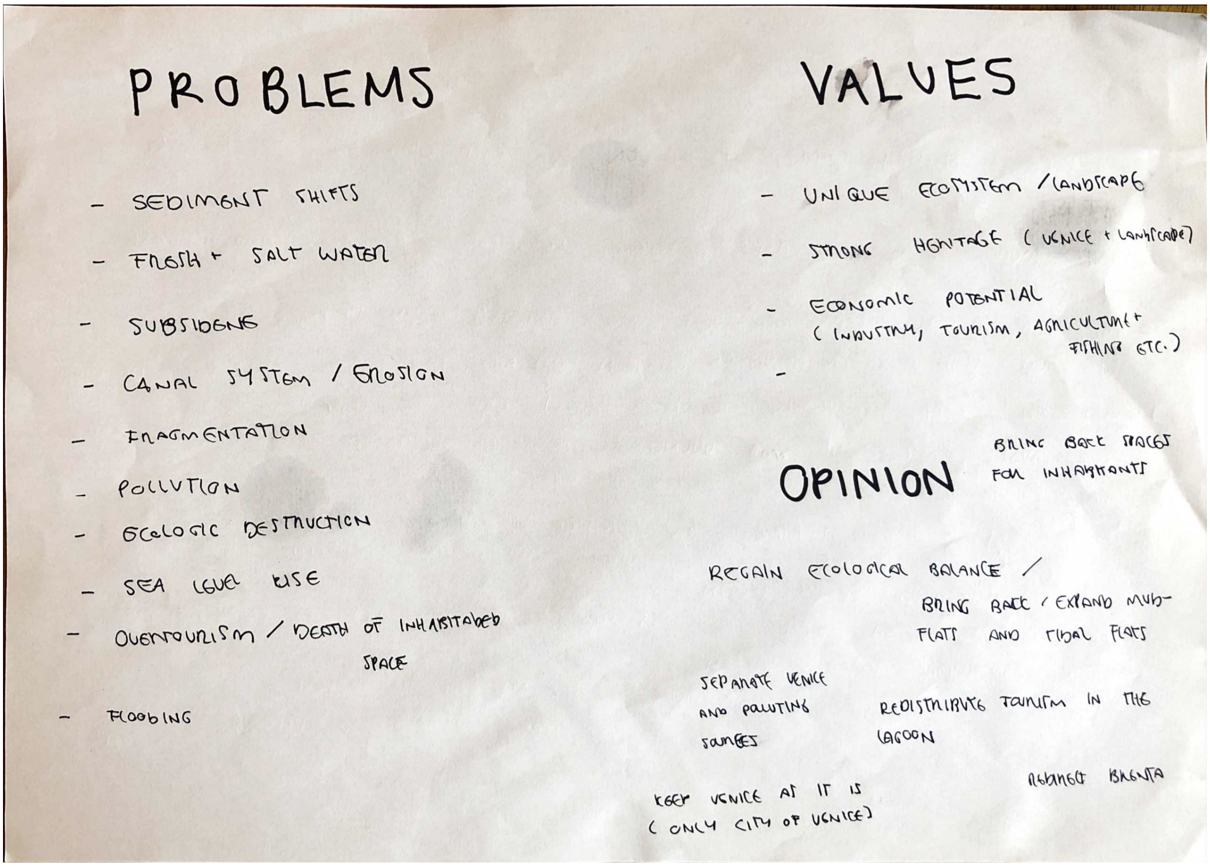
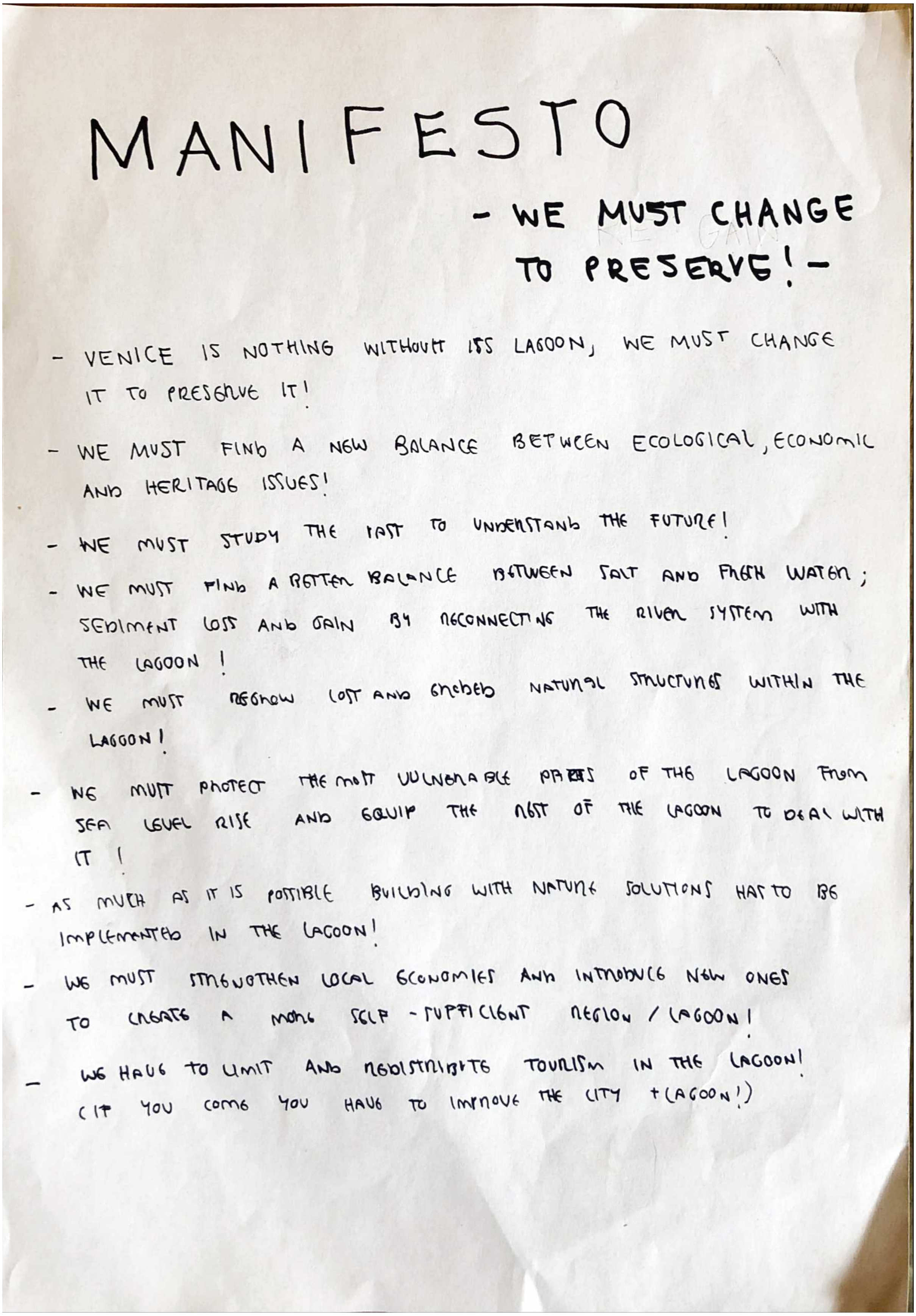


Figure J.1: Problems, values and opinion Perfect Lagoon.

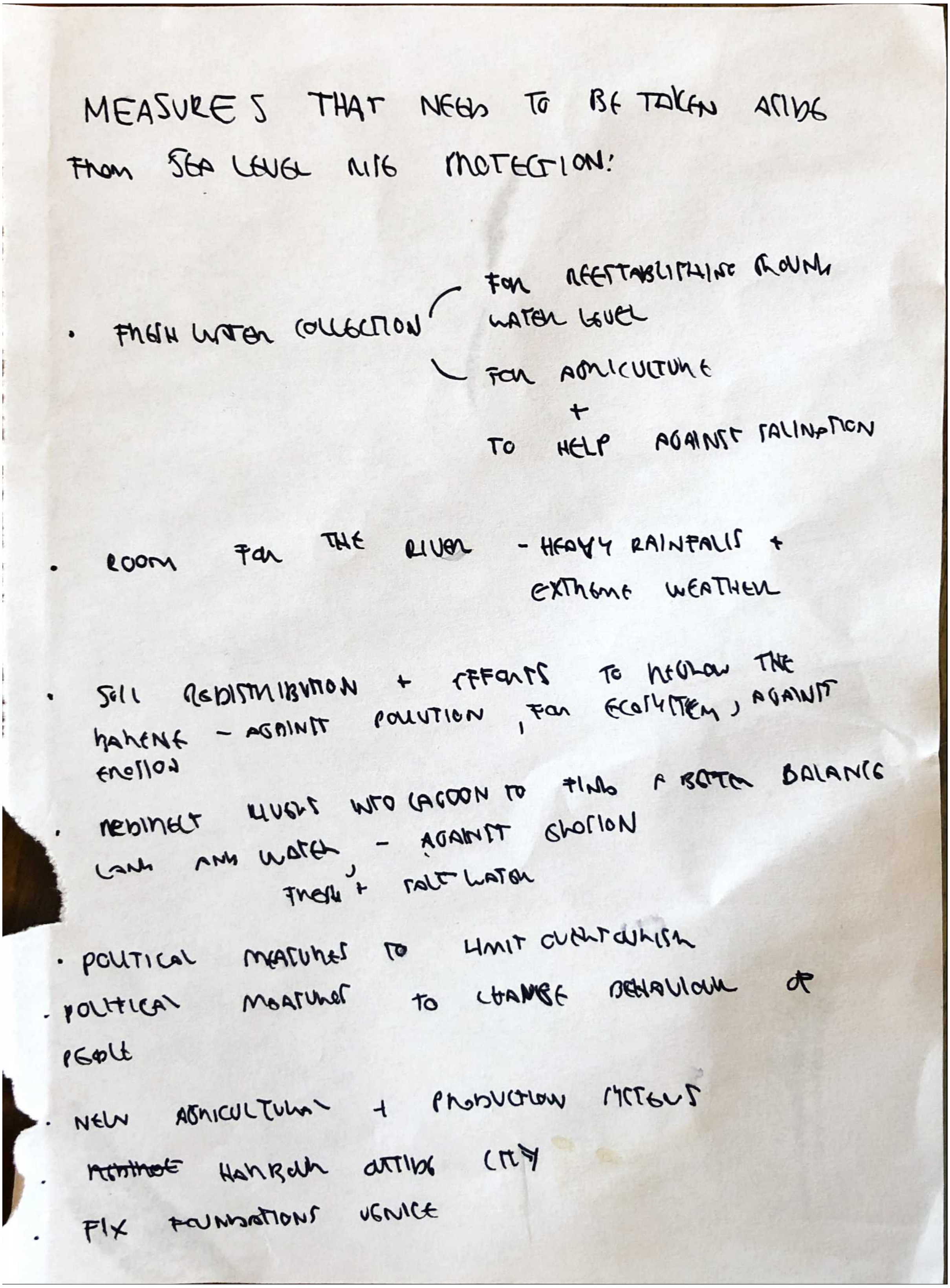


MANIFESTO

- WE MUST CHANGE TO PRESERVE! -

- VENICE IS NOTHING WITHOUT ITS LAGOON, WE MUST CHANGE IT TO PRESERVE IT!
- WE MUST FIND A NEW BALANCE BETWEEN ECOLOGICAL, ECONOMIC AND HERITAGE ISSUES!
- WE MUST STUDY THE PAST TO UNDERSTAND THE FUTURE!
- WE MUST FIND A BETTER BALANCE BETWEEN SALT AND FRESH WATER; SEDIMENT LOSS AND GAIN BY RECONNECTING THE RIVER SYSTEM WITH THE LAGOON!
- WE MUST REGROW LOST AND ERODED NATURAL STRUCTURES WITHIN THE LAGOON!
- WE MUST PROTECT THE MOST VULNERABLE PARTS OF THE LAGOON FROM SEA LEVEL RISE AND EQUIP THE REST OF THE LAGOON TO DEAL WITH IT!
- AS MUCH AS IT IS POSSIBLE BUILDING WITH NATURE SOLUTIONS HAS TO BE IMPLEMENTED IN THE LAGOON!
- WE MUST STRENGTHEN LOCAL ECONOMIES AND INTRODUCE NEW ONES TO CREATE A MORE SELF-SUFFICIENT REGION / LAGOON!
- WE HAVE TO LIMIT AND REDISTRIBUTE TOURISM IN THE LAGOON! (IF YOU COME YOU HAVE TO IMPROVE THE CITY + LAGOON!)

Figure J.2: Manifesto Perfect Lagoon.


MEASURES THAT NEED TO BE TAKEN ASIDE FROM SEA LEVEL RISE PROTECTION:

- FRESH WATER COLLECTION
  - FOR REESTABLISHING GROUND WATER LEVEL
  - FOR AGRICULTURE + TO HELP AGAINST SALINATION
- ROOM FOR THE RIVER - HEAVY RAINFALLS + EXTREME WEATHER
- SOIL REDISTRIBUTION + EFFORTS TO REGROW THE BARENE - AGAINST POLLUTION, FOR ECOSYSTEM, AGAINST EROSION
- REDIRECT RIVERS INTO LAGOON TO FIND A BETTER BALANCE LAND AND WATER, - AGAINST EROSION
  FRESH + SALT WATER
- POLITICAL MEASURES TO LIMIT OVERTOURISM
- POLITICAL MEASURES TO CHANGE BEHAVIOUR OF PEOPLE
- NEW AGRICULTURAL + PRODUCTION METHODS
- HARBOUR OUTSIDE CITY
- FIX FOUNDATIONS VENICE

Figure J.3: Measurements that need to be taken.

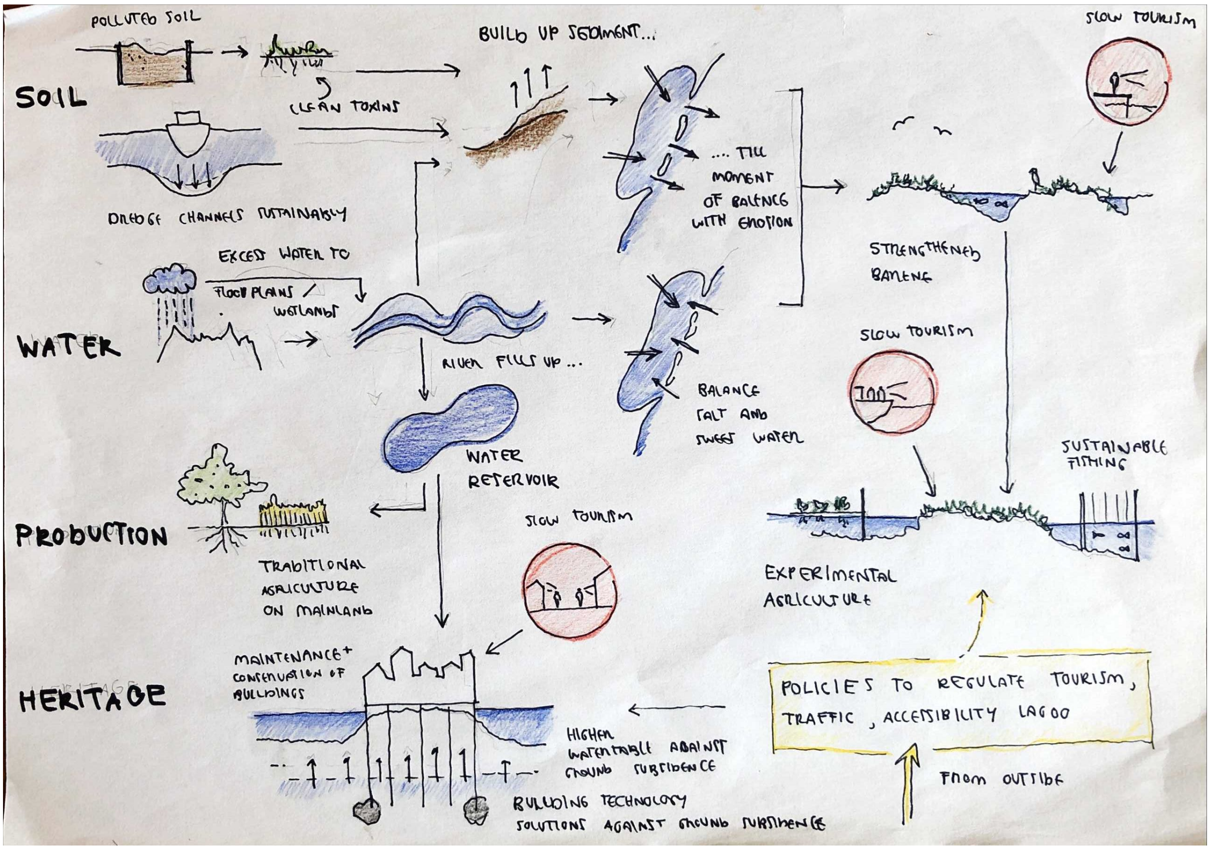


Figure J.4: Measurements taken per category.

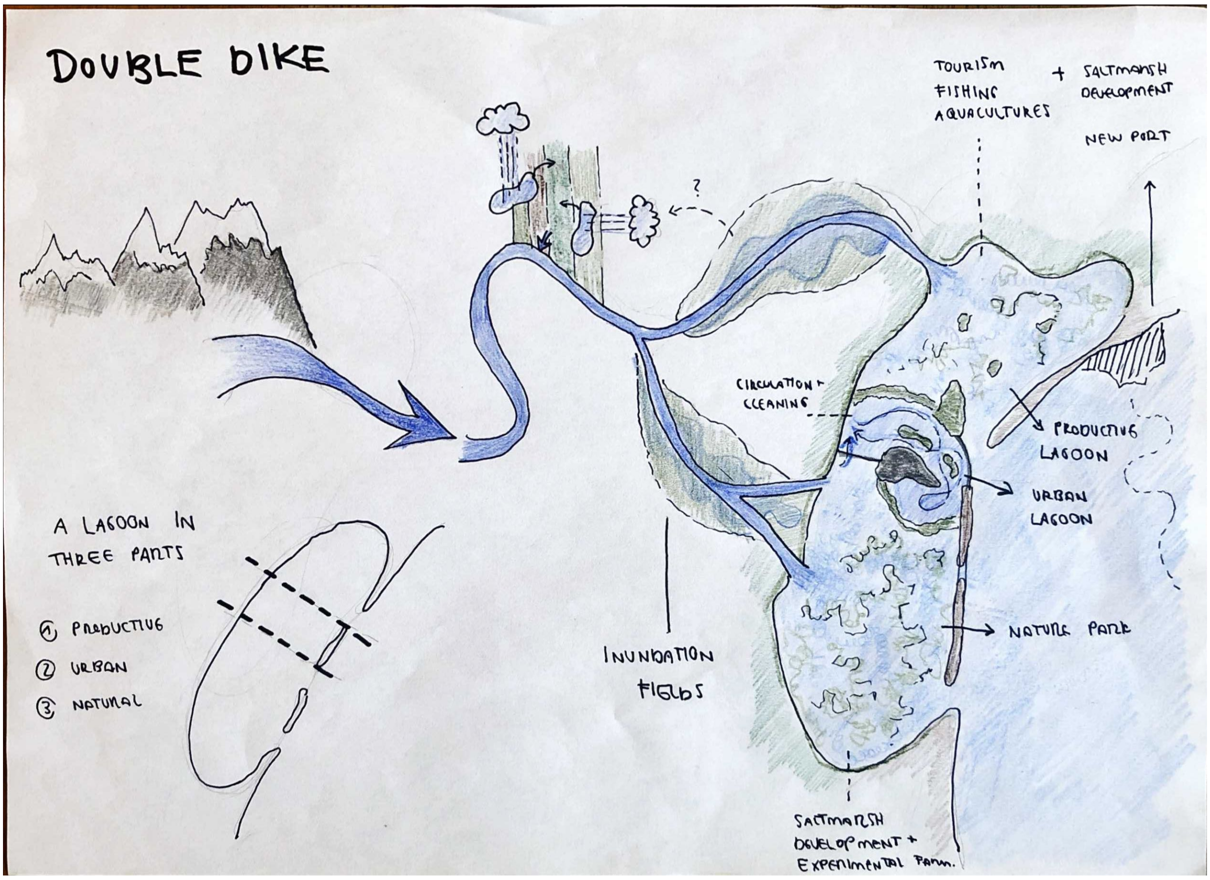


Figure J.5: Double dike sketch Perfect Lagoon.

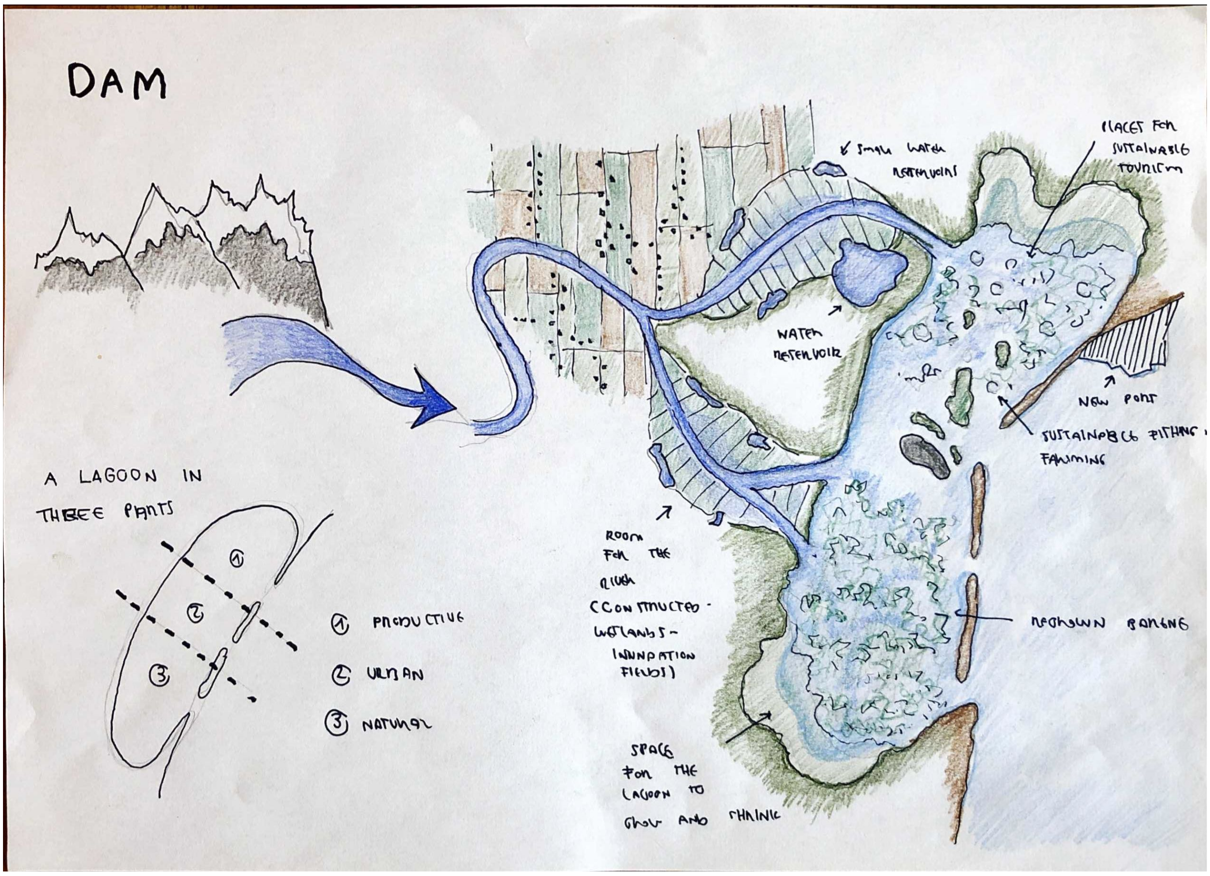


Figure J.6: Dam sketch Perfect Lagoon.

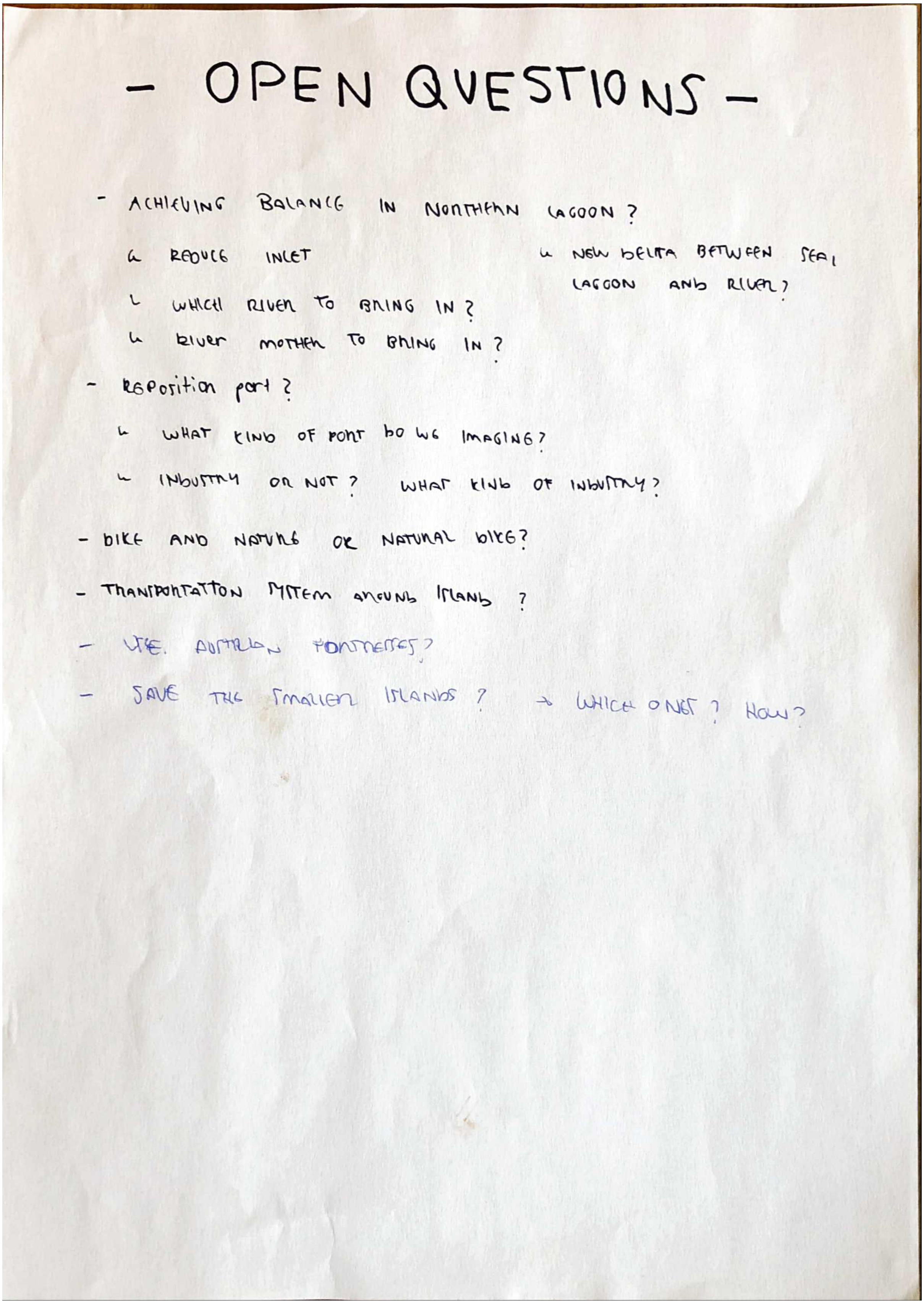
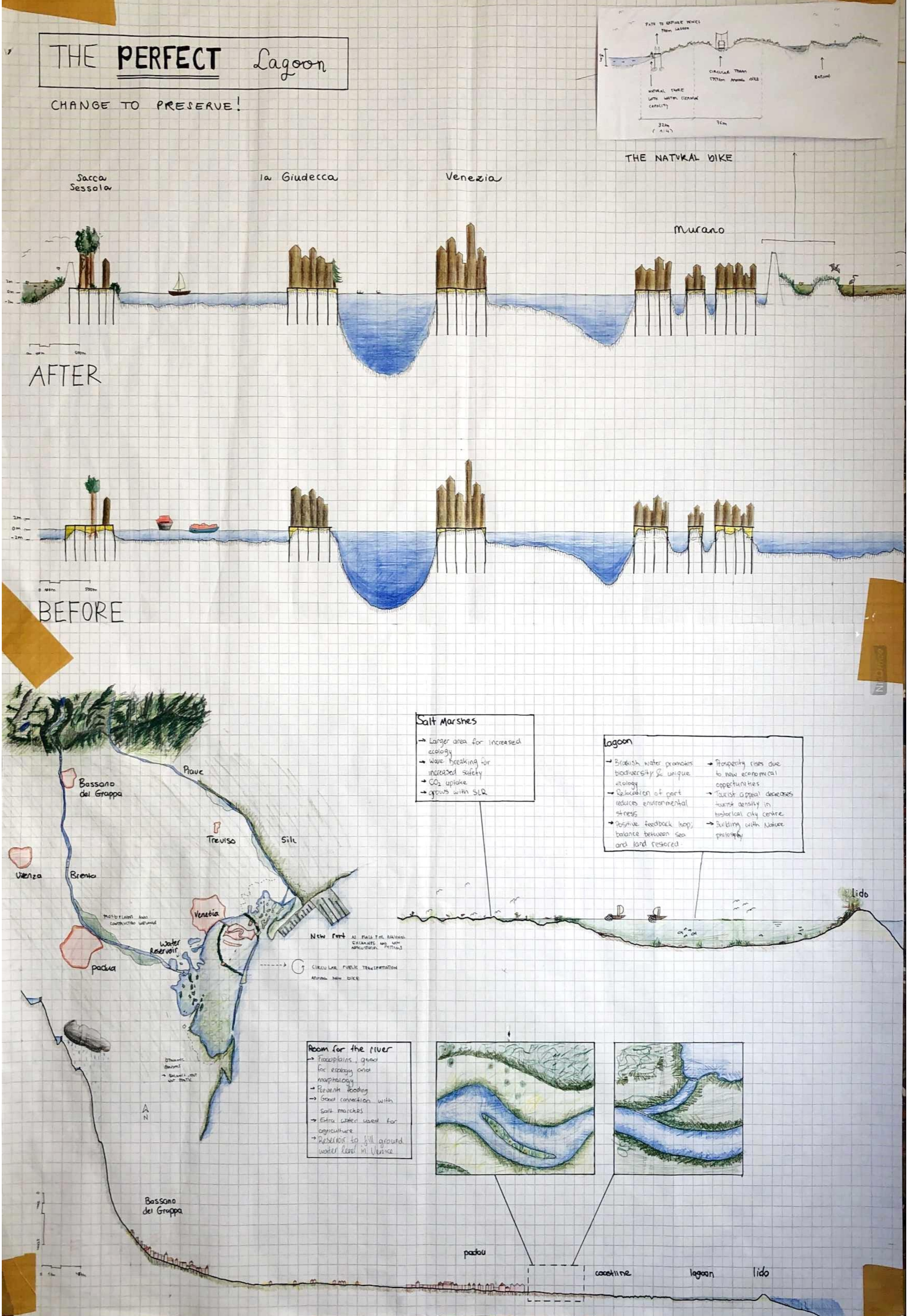


Figure J.7: Open questions regarding the Perfect Lagoon vision.


THE PERFECT Lagoon
CHANGE TO PRESERVE!
CIRCULAR TRAM SYSTEM AROUND DIKE
32m
36m
THE NATURAL DIKE
Sacca Sessola
la Giudecca
Venezia
Murano
AFTER
BEFORE
Salt Marshes
→ Larger area for increased ecology
→ Wave Breaking for increased safety
→ CO_2 uptake
→ grows with SLR
Lagoon
→ Brakish water promotes biodiversity & unique ecology
→ Relocation of port reduces environmental stress
→ Positive feedback loop; balance between sea and land restored.
→ Prosperity rises due to new economical opportunities
→ Tourist appeal decreases tourist density in historical city centre
→ Building with Nature philosophy
Piave
Bassano del Grappa
Treviso
Sile
Vienza
Brenta
Venetia
Water Reservoir
padua
New Port
Lido
Room for the river
→ Floodplains, good for ecology and morphology
→ Prevents flooding
→ Good connection with salt marches
→ Extra water used for agriculture
→ Reservoir to fill ground water level in Venice
Bassano del Grappa
padua
coastline
lagoon
Lido

K

CONCEPT 2 - A SYMBIOTIC SYSTEM

Figure K.1: The Brenta river diverted into the lagoon.

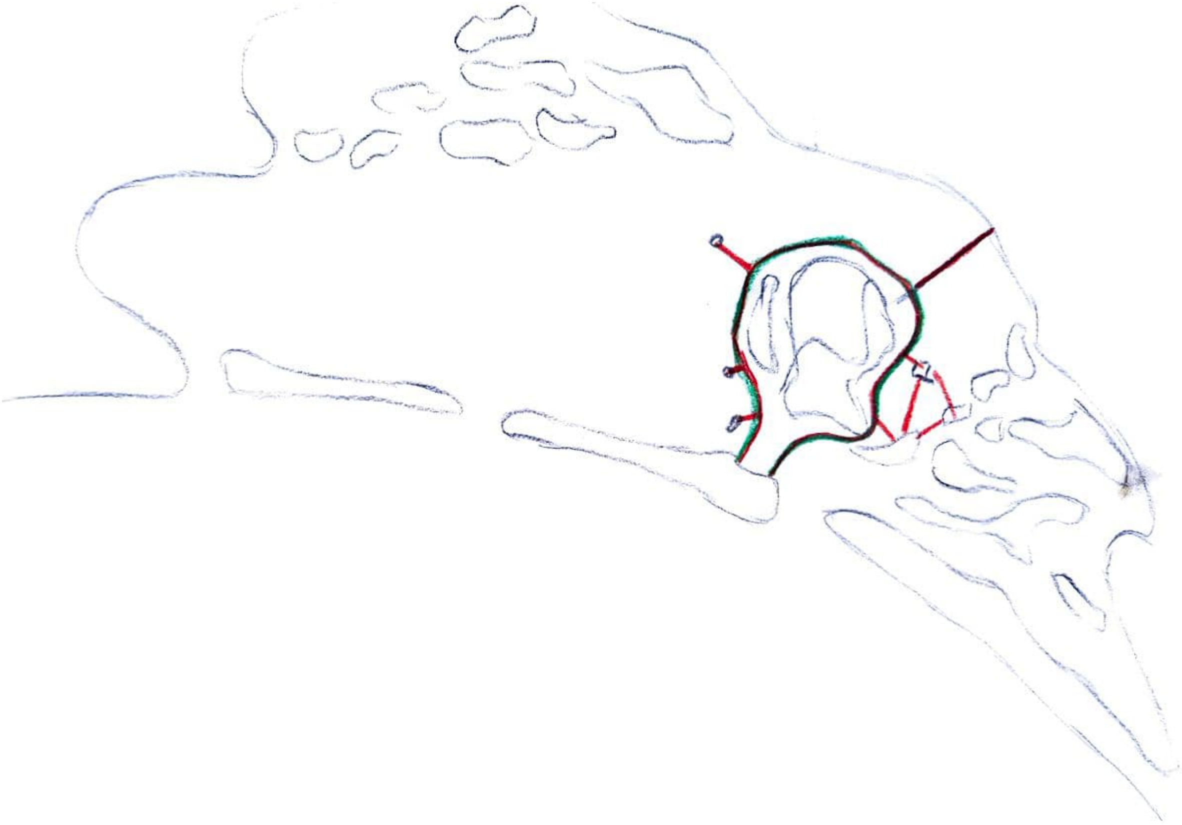


Figure K.2: The dike ring and the bridges around Venice.

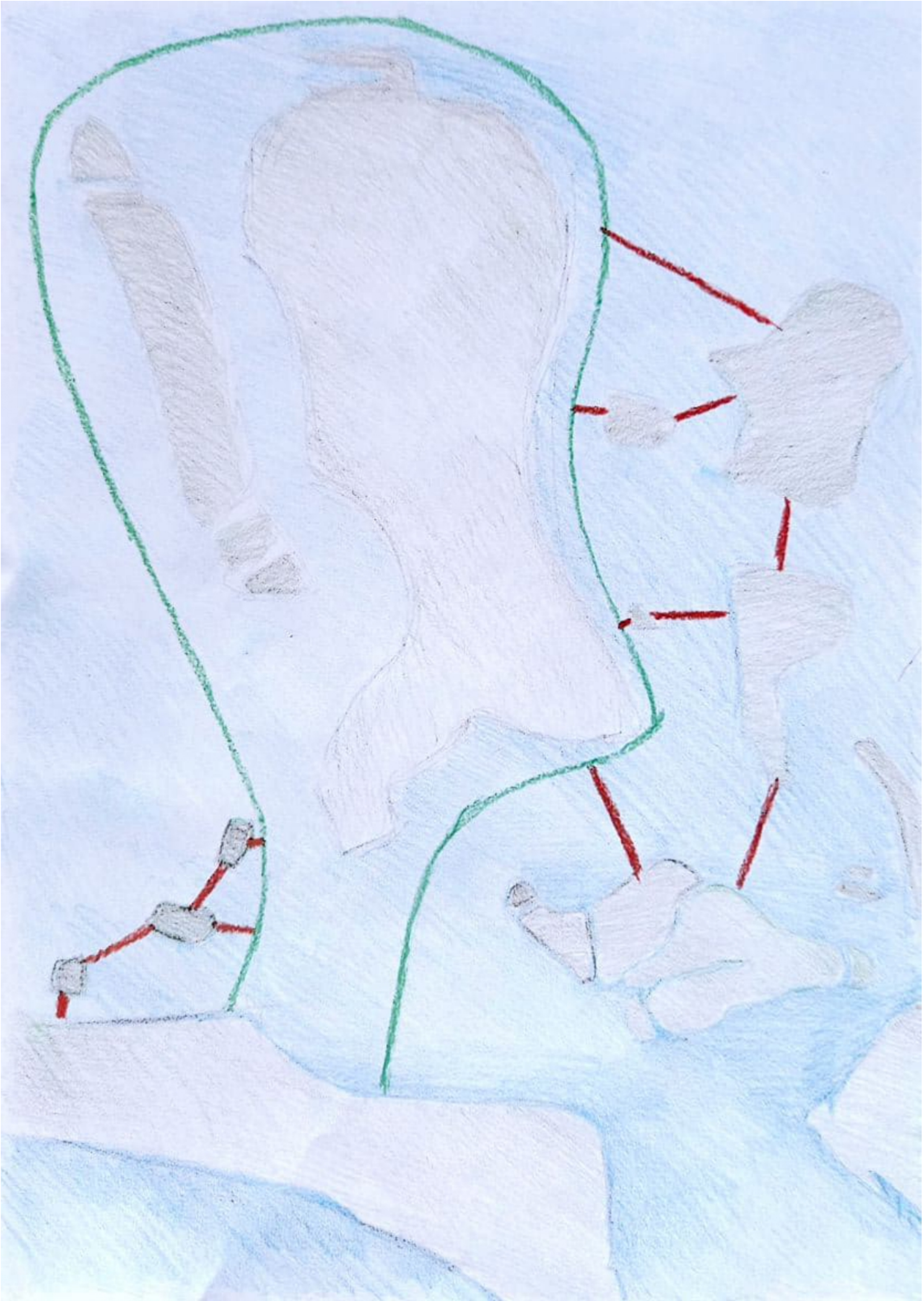


Figure K.3: The dike ring and the bridges around Venice.

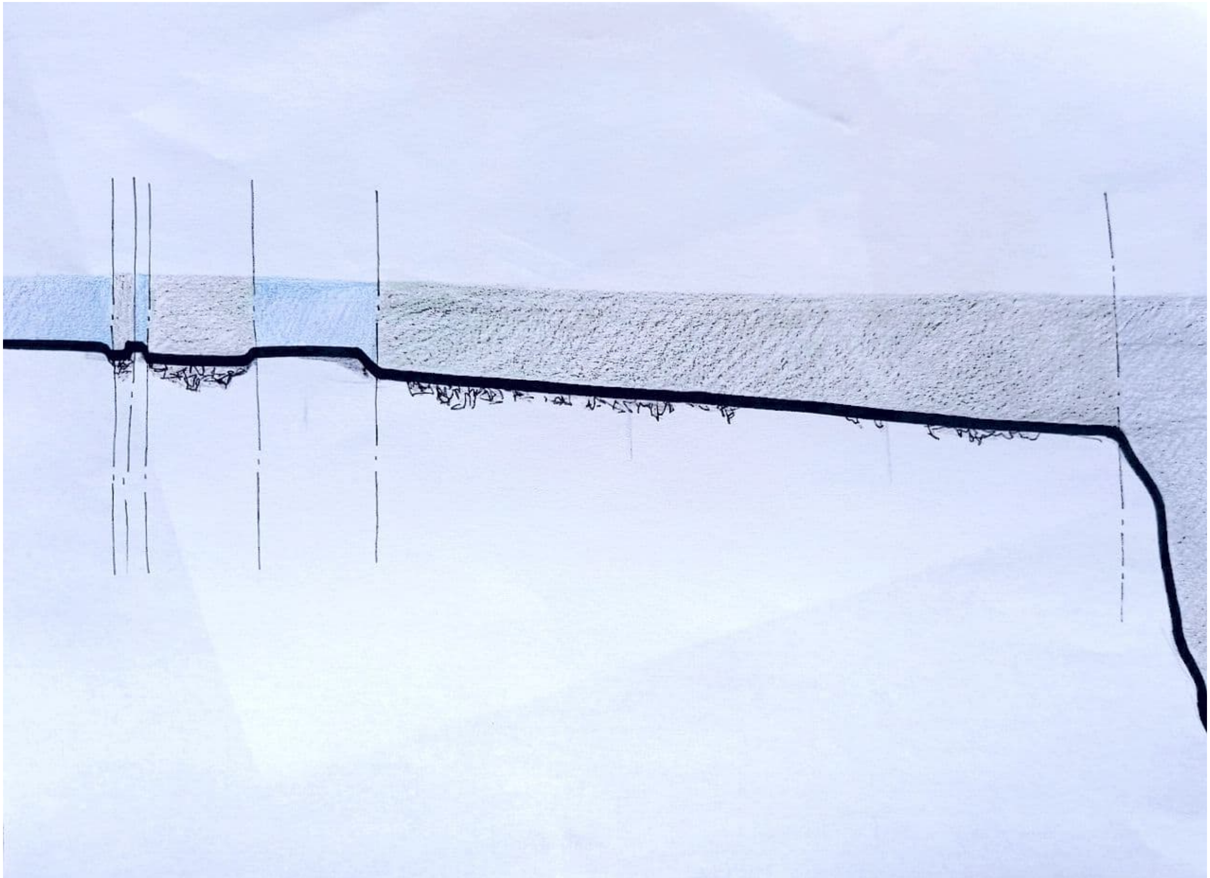


Figure K.4: Cross-section of the lagoon.

Figure K.5: Canals in the lagoon.

Figure K.6: Cross-section from the mountains.

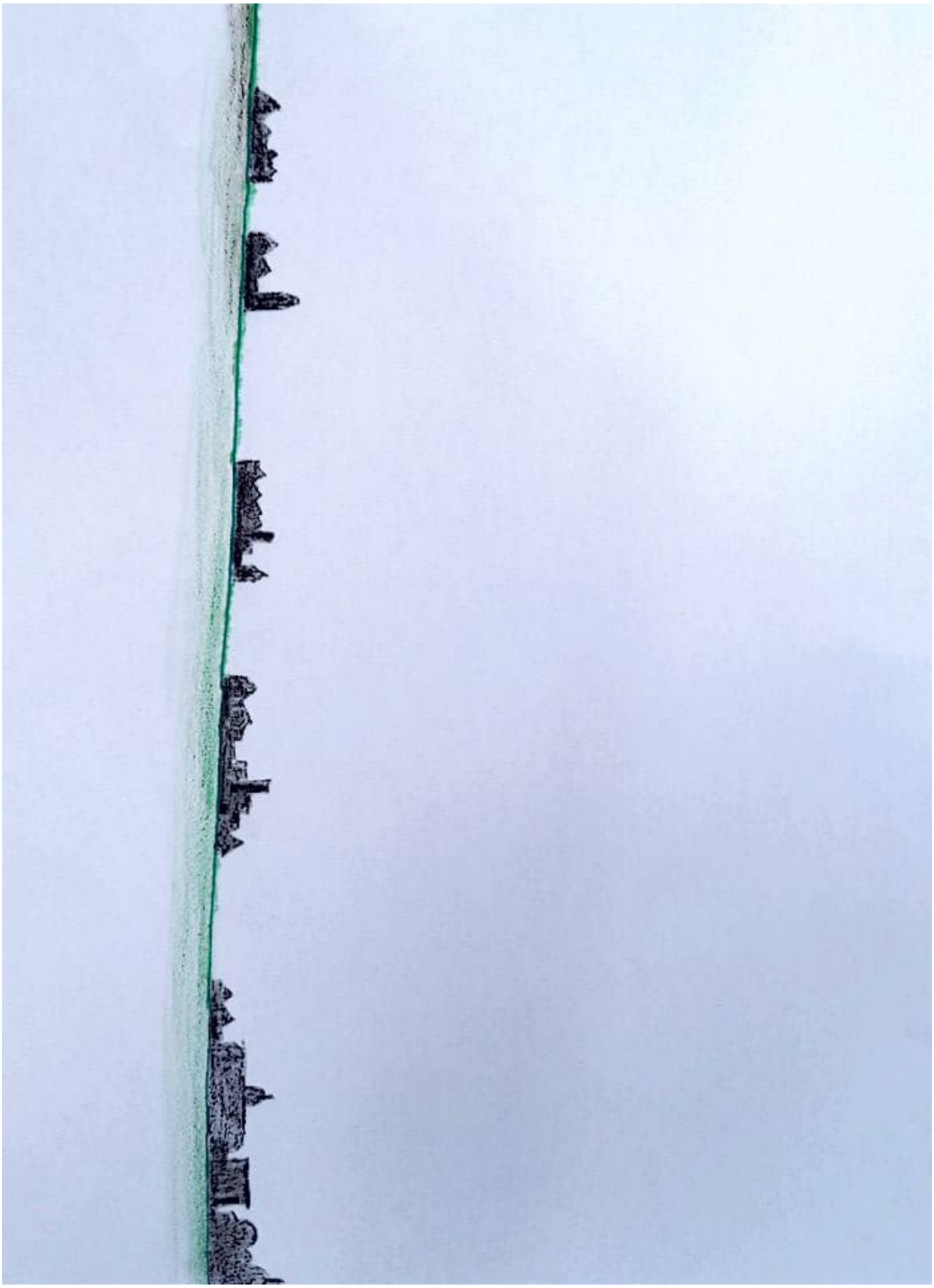


Figure K.7: Cross-section of villages and farms.

Figure K.8: Close-up on Porto Marghera.

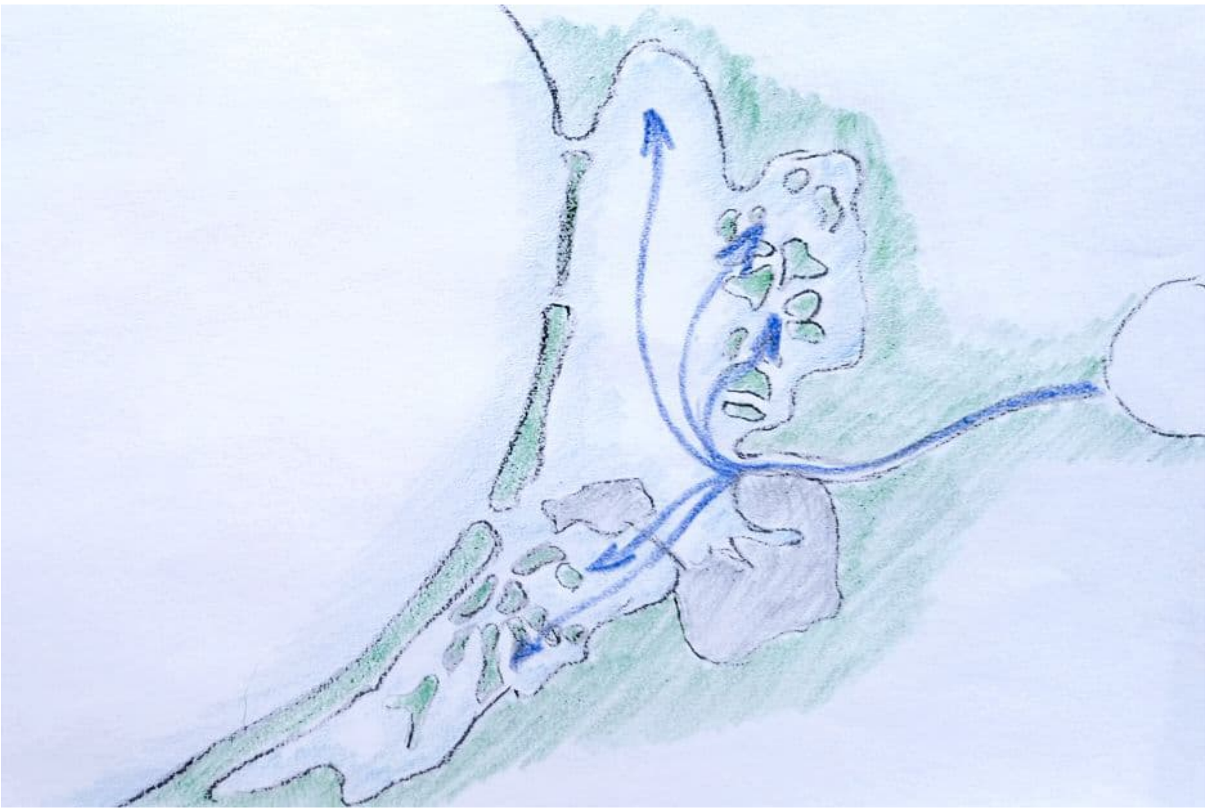


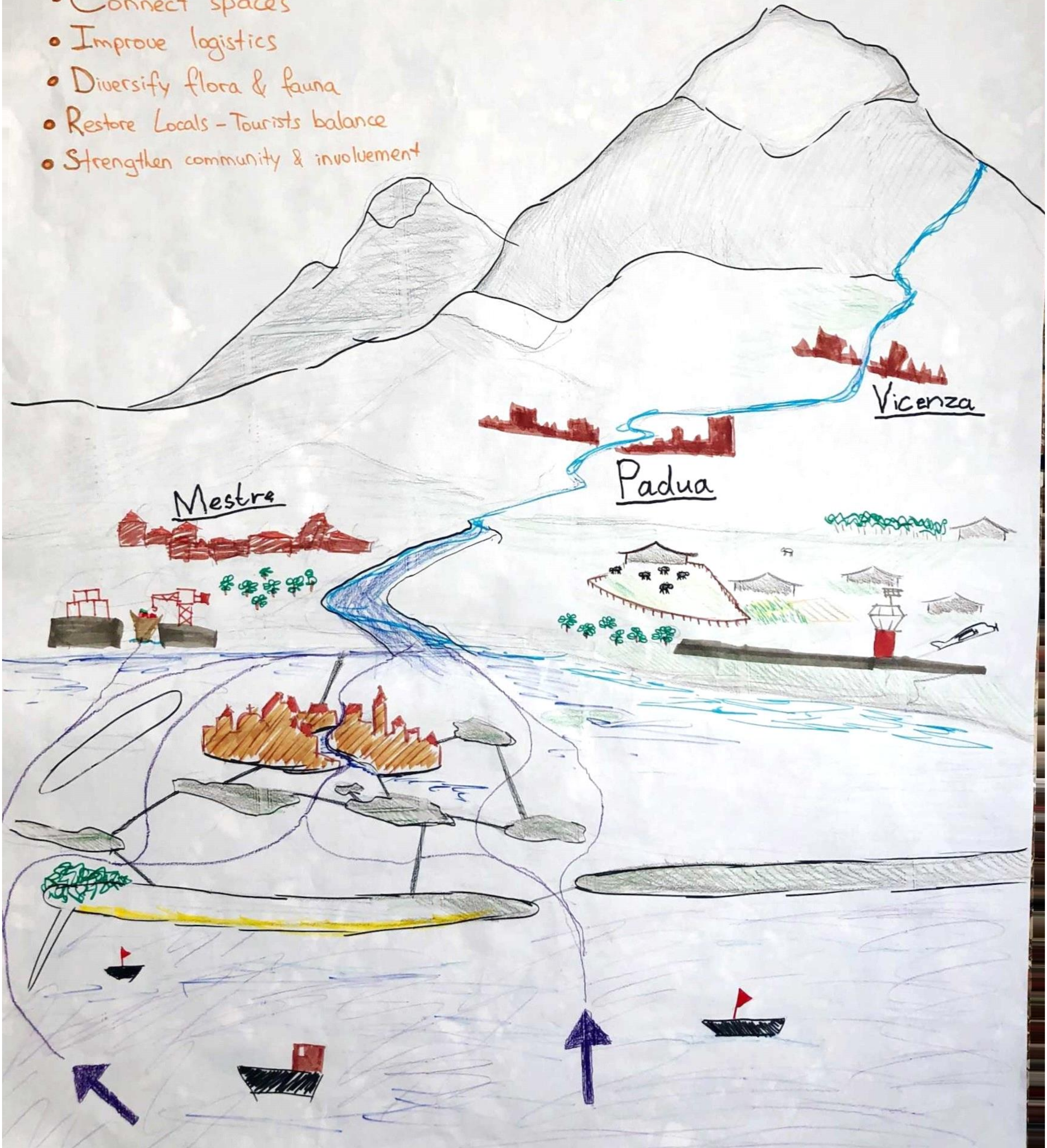
Figure K.9: Close-up top view showing the connection of the Brenta river as canal to the lagoon, providing additional freshwater input.

Figure K.10: Another close-up of the redirection of the Brenta river.

Symbiotic System

A network of spaces

- Connect spaces
- Improve logistics
- Diversify flora & fauna
- Restore Locals - Tourists balance
- Strengthen community & involvement



L

BOATS IN VENICE

(a) Gondola

(b) Garbage boat

(c) Police or ambulance

(d) Mototopo

(e) Vaporetto

(f) Ferry boat

(g) Taxi

Figure L.1: Boats Venice [26].

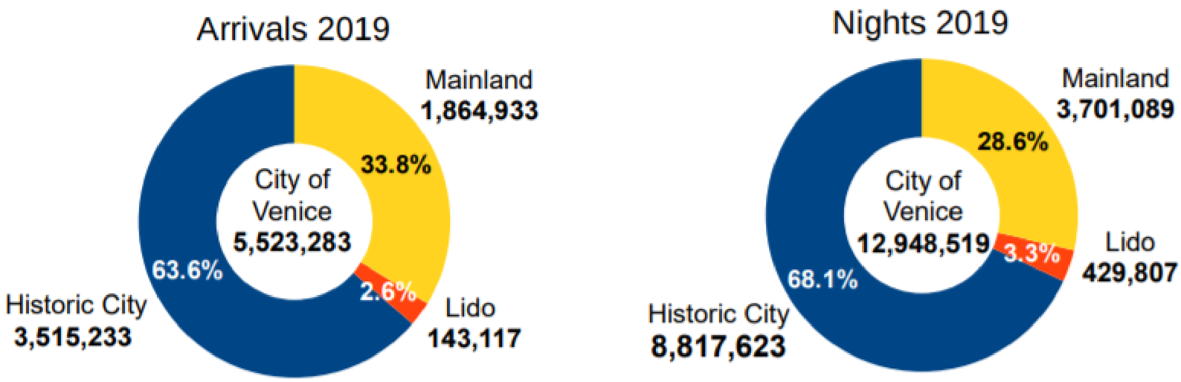
M

TOURIST DATA

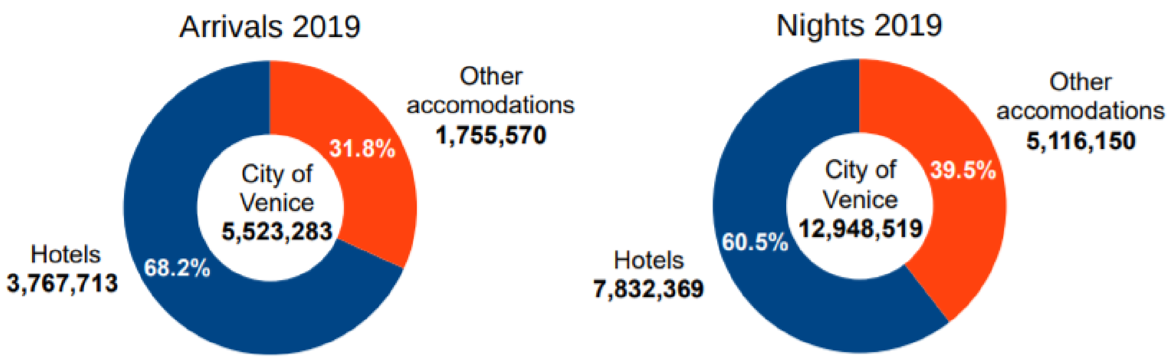
Year	Arrivals	% change	Nights	% change	Average Stay
2007	3,626,853	3.7%	8,842,874	7.2%	2.44
2008	3,433,775	-5.3%	8,487,539	-4.0%	2.47
2009	3,405,115	-0.8%	8,445,911	-0.5%	2.48
2010	3,708,407	8.9%	8,521,247	0.9%	2.30
2011	4,167,171	12.4%	9,417,872	10.5%	2.26
2012	4,106,161	-1.5%	9,310,132	-1.1%	2.27
2013	4,251,798	3.5%	9,778,225	5.0%	2.30
2014	4,280,632	0.7%	9,983,416	2.1%	2.33
2015	4,495,857	5.0%	10,182,829	2.0%	2.26
2016	4,645,567	3.3%	10,511,788	3.2%	2.26
2017	5,034,882	8.4%	11,685,819	11.2%	2.32
2018	5,255,499	4.4%	12,118,298	3.7%	2.31
2019	5,523,283	5.1%	12,948,519	6.9%	2.34

Source: City of Venice Tourism Department Processing – Tourism Observatory based on data from the Statistical Office of Veneto Region.

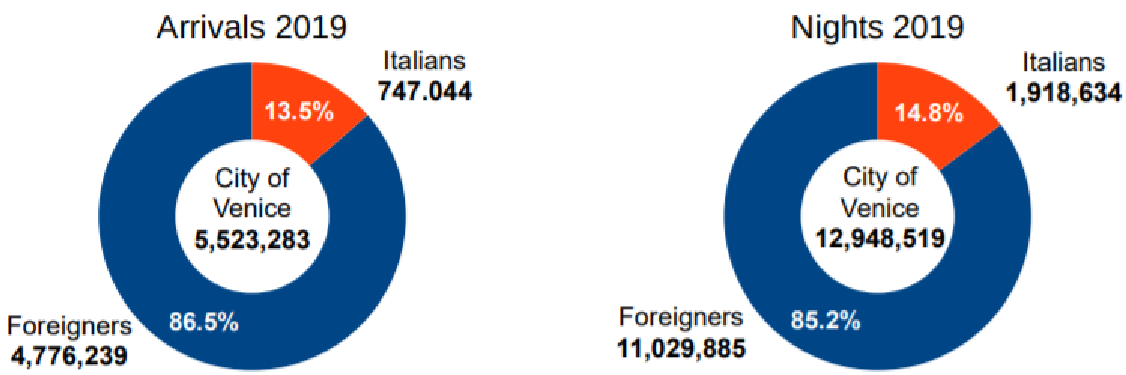
Figure M.1: Tourism in the City of Venice: historical series 2007- 2019) [5].



(a) Number of tourist arrivals and nights



(b) Accommodation tourists



(c) Accommodation tourists

Figure M.2: Tourist data city of Venice [5].

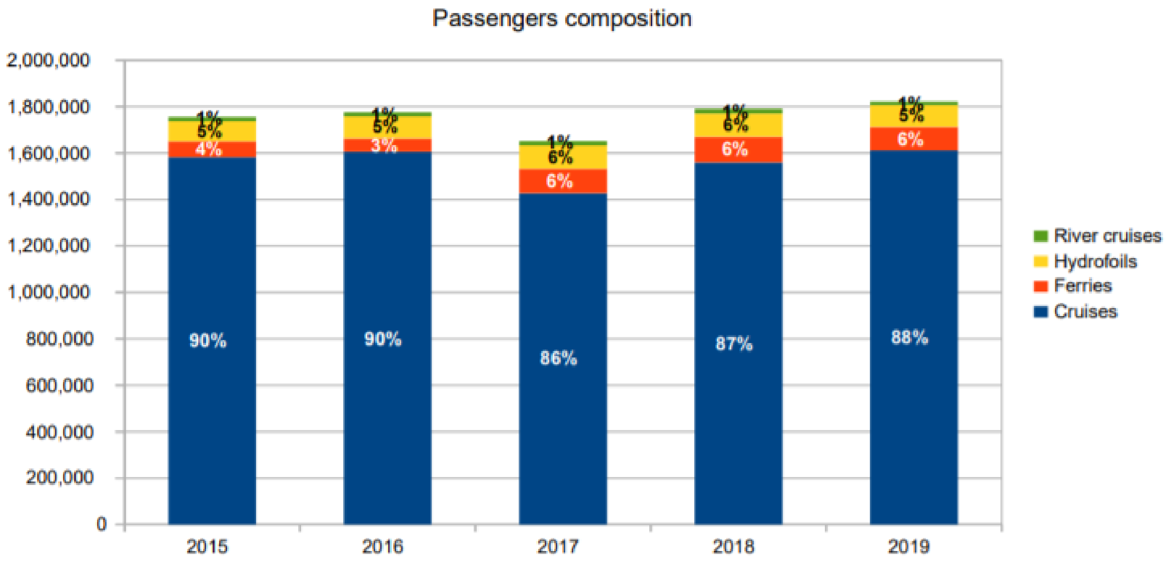


Figure M.3: Passenger traffic port [5].

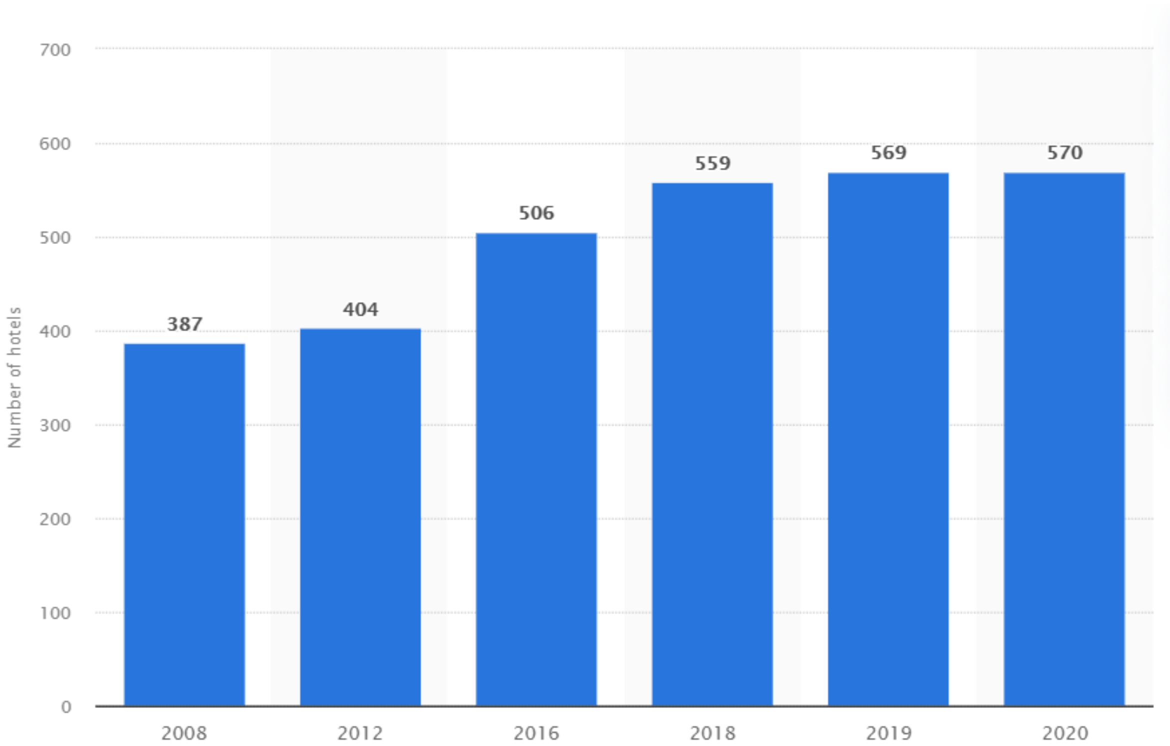


Figure M.4: Number of hotels in Venice [27].

N

COMPLETE STAKEHOLDER ANALYSIS

First stakeholder inventarisation

Categories

Governmental authorities	Businesses	Project-affected communities

Stakeholder	Description	Relevance to project
Residents of Venice	People living and working in the city of Venice	Residents both on the mainland and island will experience the direct and indirect consequences of the adjustments made to the lagoon. On the island, almost every resident works in the tourist-sector and is dependent on the tourists visiting Venice. Residents on the mainland work in (the neigbouring area of) the Venice Lagoon.
Tourists	Tourist visiting the historical city of Venice and its lagoon	The economy of Venice runs on the expenditure of tourists visiting the city and the lagoon.
Comune di Venezia	The municipality of Venice, responisible for managing the city of Venice, including Mestre	The adaptations made to the lagoon will fall under the jurisdiction of the Comune di Venezia
Comune di Chioggia	The municipality of Chioggia, responisible for managing the city of Chioggia	The adaptations made to the southern part of the lagoon will fall under the jurisdiction of the Comune di Chioggia
Comune di Padova	The municipality of Padua, responisible for managing the city of Padua	The adaptations that are going to be made to the lagoon will have possible consequences for the hinterland, including the city of Padua
Fishermen	People making their living by fishing in the lagoon	The fishermen have been using the lagoon for fishing since the first settlement of the city of Venice. Adaptations made to the lagoon will positively or negatively influence the fishing industry
Hunters	People making their living by hunting in the lagoon	Hunters have been using the lagoon for hunting since the first settlement of the city of Venice. Adaptations made to the lagoon will positively or negatively influence the hunting industry
Farmers	People making their living by working at farms in the lagoon	Farmers have been using the lagoon and its surrounding for farming since the first settlement of the city of Venice. Adaptations made to the lagoon will positively or negatively influence the farming industry
Marco Polo Airport	Largest airport in the vicinity of Venice that is largely used by commercial airlines to transport tourists in order to visit Venice	Adaptations made to the lagoon might influence the number of flights flying from and to Marco Polo Airport and it may limit its possibility to expand
Giovanni Nicelli Airport	Airport located in the lagoon on the island of Lido, mainly used for private flights	Adaptations made to the lagoon might influence the number of flights flying from and to Giovanni Nicelli Airport and it may limit its possibility to expand

Treviso Airport	Small airport nearby the city of Treviso, also used by commercial airlines to transport tourists in order to visit Venice	Adaptations made to the lagoon might influence the number of flights flying from and to Treviso Airport
Porto Marghera	Major port which is of large economical significance for the city of Venice and the hinterland	Porto Marghera is located in the middle of the lagoon and is directly affected by measures taken in the lagoon
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	The Superintendence of Archeology, Fine Arts and Landscape for the City of Venice and Lagoon. Organ of the Italian Ministry of Cultural Heritage and Activities and Tourism whose main action is the protection of goods of historic and architectural	This governmental organisation is protecting the city and the lagoon and will use its power to do so
Regione del Veneto	Regional government for managing the Veneto region	The adaptations made to the lagoon will fall under the jurisdiction of the Regione del Veneto
Città Metropolitana di Venezia (PATREVE)	Metropolian area of Padua, Treviso and Venice. The province of Venice has been replaced by this metropolitan.	The adaptations made to the lagoon will fall under the jurisdiction of the Città Metropolitana di Venezia
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Ministry for Environment, Land and Sea Protection of Italy, responsible for environmental and water related matters.	The ministry is responsible for all matters related to the environment, water and sea, including Venice and its lagoon.
Italian Government	Central Italian government, responsible for managing and leading Italy	The primary responsibility of the Venice Lagoon lies with the Italian Government
AVM/Actv	Main public transport operator in the urban area of Venice and the suburban areas up to Padua, Treviso and Rovigo	The public transport in the shape of busses and boats make use of the road and waterway infrastructure and are thus immediately affected by changes in the Venice Lagoon
Association of Sustainable Tourism Operators of the Venice Lagoon (OTS Laguna di Venezia)	Association of Sustainable Tourism Operators of the Venice Lagoon, organisation for developing and promoting sustainable tourism in the Venice lagoon	This organisation is promoting sustainable tourism in order to maintain the Venice Lagoon, therefore it will strive towards sustainable measures
Ministero della transizione ecologica	Ministry of environment, responsible for the development and maintance of projects/cases connected to water, air, energy,	This governmental organisation is protecting the lagoon and will use its power to do so
Cruiseships	Patrons/operators of cruiseships	Cruise ships will navigate through the Venice Lagoon to reach the Porto Marghera in order guide tourists to the historic centre of Venice
Cargo ships	Cargo shipping companies making use of the Lagoon and the Porto Marghera	Cargo ships will navigate through the Venice Lagoon to reach the Porto Marghera and the hinterland in order to deliver cargo

Ministero delle infrastrutture e della mobilità sostenibili	Ministry of sustainable infrastructures and transport, responsible for planning, financing, implementing and managing the infrastructural networks of Italy	This governmental organisation is responsible for all infrastructure and transport related projects
Ministero della cultura	Ministry of culture, responsible for protection and exploitation of Italy's cultural heritage, activities and tourism	This governmental organisation is responsible for the protection of cultural heritage, which is in large numbers present in the historical centre of Venice.

Stakeholder elaboration

	Stakeholders	Interests	Goals	Issues	Issues (main categories)	Type of power	Power (1-10)	Resources	Interest (1-10)
	Governmental organisations								
1	Comune di Chioggia	Managing the area within the municipality of Chioggia	Improved prosperity of the municipality of Chioggia	Adaptions made to the lagoon may upset its citizens	Adaptions made to the lagoon may upset its citizens	Production power	8	Legislative or statutory power	9
2	Comune di Padova	Managing the area within the municipality of Padua	Improved prosperity of the municipality of Padova	Adaptions made to the lagoon may upset its citizens	Adaptions made to the lagoon may upset its citizens	Production power	8	Legislative or statutory power	7
3	Comune di Venezia	Managing the area within the municipality of Venice	Improved prosperity of the municipality of Venice	Visible protection of the city of Venice from floods may upset its citizens	Protection of the city causes view obstruction	Production power	8	Legislative or statutory power	8
4	Città Metropolitana di Venezia	Improving the prosperity of the metropolitan area of Venice	Improved prosperity of the metropolitan area of Venice	Generating finances	Generating finances	Production power	8	Legislative or statutory power	9
5	Regione del Veneto	Improving the prosperity of the Veneto region and maintaining cultural and natural heritage sites	Improved prosperity of the Veneto region whilst cultural and natural heritage sites remain healthy	Generating finances	Generating finances	Production power	9	Legislative or statutory power	9
6	Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	Promote and preserve the artistic and landscape heritage of particular interest	Protection of goods of historic and architectural interest	Achieve financing for the protection of the lagoon might be difficult	Generating finances	Production power	8	Legislative or statutory power	9
7	Ministero della transizione ecologica	Stimulating ecology	Improved ecology in the Venice Lagoon	Achieve financing for the protection of the lagoon might be difficult	Generating finances	Production power	8	Legislative or statutory power	8
8	Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Managing the water, sea and the environment in Italy.	Protecting the Italian residents from the water and other environmental impacts	Achieve financing for the water related protection methods might be difficult	Generating finances	Production power	8	Legislative or statutory power	8
9	Ministero delle infrastrutture e della mobilità sostenibili	Managing infrastructure and transport related projects in Italy	Constructing sustainable infrastructural connections which contribute to the mobility in Italy	Achieve financing for the infrastructural inferences made in the lagoon	Generating finances	Production power	8	Legislative or statutory power	8
10	Ministero della cultura	Managing and protecting cultural heritage, activities and stimulating tourism	Improved protection and sustainable exploitation of cultural heritage	Achieve financing for protecting the cultural heritage	Generating finances	Production power	8	Legislative or statutory power	8
11	Italian Government	Improving the prosperity of Italy in general and achieving the UN Sustainable Development Goals	Improved prosperity and the achievement of the UN SDG's	Generating finances	Generating finances	Production power	9	Legislative or statutory power	7
	Businesses								
12	AVM/Actv	Generating profits by providing public transport in the Venice region	Increased revenues generated from public transport	Protection of the city and its lagoon may cause limitations for public transport	Protection of the city and its lagoon may cause limitations for public transport	Blocking power	6	Public transport	7
13	Cargo ships	Using the Porto Marghera to deliver cargo	Generating profits from transporting cargo	Protection of Venice and its lagoon may cause cargo ships to find new routes to the mainland or ports.	New routes to the port and mainland	Blocking power	6	Money	8

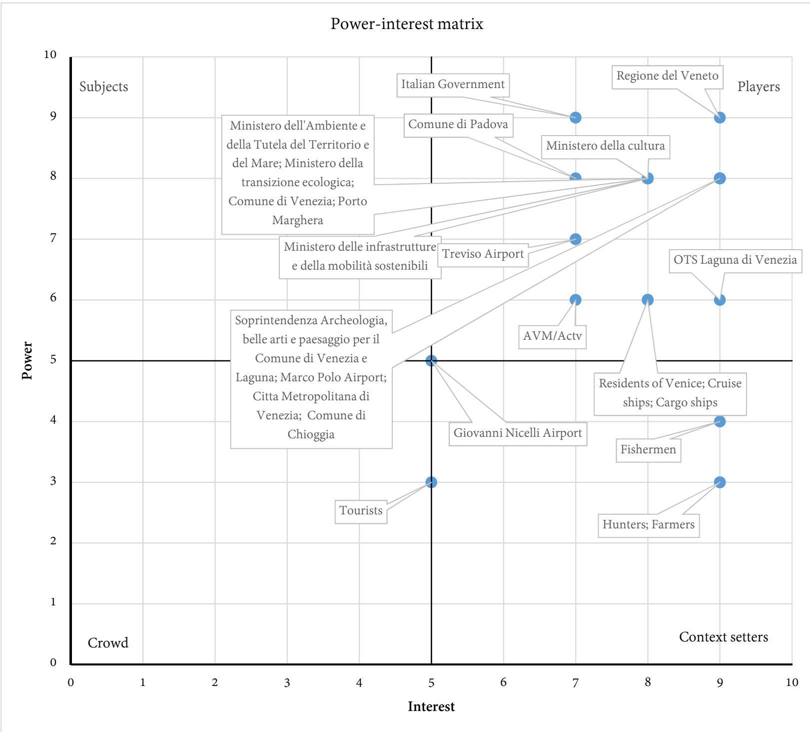
14	Cruise ships	Using the Porto Marghera to guide tourists to Venice	Generating profits from providing holiday tours to tourists	Protection of Venice and its lagoon may cause cruise ship operators to find new routes to the mainland or ports.	New routes to the port and mainland	Blocking power	6	Money	8
15	Porto Marghera	Generating profits	Increased capacity of the port and improved connection with the hinterland	Restriction of the possibility to expand, reduced activity, possible relocation of the port.	Reduced harbour activities and restricted expansion possibilities	Blocking power	8	Money	8
16	Giovanni Nicelli Airport	Generating profits	Increased revenues from flights	Reduced amount of flights	Reduced number of flights and restricted expansion possibilities	Blocking power	5	Transport and money	6
17	Marco Polo Airport	Generating profits	Increased revenues from flights	Restriction of the possibility to expand. A reduced amount of flights could also be a consequence.	Reduced number of flights and restricted expansion possibilities	Blocking power	8	Transport and money	9
18	Treviso Airport	Generating profits	Increased revenues from flights	Restriction of the possibility to expand. A reduced amount of flights could also be a consequence.	Reduced number of flights and restricted expansion possibilities	Blocking power	7	Transport and money	7
	Project-affected communities								
19	Farmers	Grounds available for farming	Continuing farming activities in the Venice lagoon and neighbouring areas	Future plans may involve a reduced amount of farming acitivities in the lagoon	Reduced or limited exploitation of the lagoon	Blocking power	3	Political support	9
20	Fishermen	Waters available for fishing	Continuing fishing activities in the Venice lagoon	Future plans may involve a reduced amount of fishing acitivities in the lagoon	Reduced or limited exploitation of the lagoon	Blocking power	4	Political support	9
21	Hunters	Grounds available for hunting	Continuing hunting activities in the Venice lagoon	Future plans may involve a reduced amount of hunting acitivities in the lagoon	Reduced or limited exploitation of the lagoon	Blocking power	3	Political support	9
22	OTS Laguna di Venezia	Stimulating sustainable tourism in the Venice Lagoon	Developing a strategic plan for the development of sustainable tourism in the Venice Lagoon	The current high number of tourists should be decreased in order to succesfully develop sustainable tourism	The current high number of tourists should be decreased in order to succesfully develop sustainable tourism	Blocking power	6	Political support	9
23	Residents of Venice	Living in Venice	Living in Venice without ruining the view and increased costs of living	Protection of the city of Venice from floods may obstruct the view	Protection of the city causes view obstruction	Blocking power	6	Political support	8
24	Tourists	Visiting the historical centre of Venice (and the lagoon to a lesser extent)	Enjoying their stay in Venice	Protection of the city of Venice may make the possibility to visit the historical centre more difficult. Furthermore, the number of tourists contribute to the decay of Venice and its lagoon.	Protection of the city may challenge tourists in visiting the city	Blocking power	3	Money	6

Stakeholder issues

Issue	Issue description	Stakeholders connected to issue
A	Protection of the city causes view obstruction	3 22 23
B	Protection of the city may challenge tourists in visiting the city	10 22 23
C	Adaptions made to the lagoon may upset its citizens	1 2 4 5 22
D	Reduced or limited exploitation of the lagoon	18 19 20 22
E	Reduced number of flights and restricted expansion possibilities	15 16 17 23
F	Reduced harbour activities and restricted expansion possibilities	14 23
G	Generating finances (for making adaptations to the lagoon)	1 2 3 4 5 6 7 8 9 10 11
H	Protection of the city and its lagoon may cause limitations for public transport	9 11 22 23
I	The current high number of tourists should be decreased in order to succesfully develop sustainable tourism	3 4 6 21 23
J	New routes to the port and mainland	9 11 12 13

Stakeholders' power and interest

Stakeholder	Power	Interest
Comune di Chioggia	8	9
Comune di Padova	8	7
Comune di Venezia	8	8
Città Metropolitana di Venezia	8	9
Regione del Veneto	9	9
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	8	9
Ministero della transizione ecologica	8	8
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	8	8
Ministero delle infrastrutture e della mobilità sostenibili	8	8
Ministero della cultura	8	8
Italian Government	9	7
AVM/Actv	6	7
Cargo ships	6	8
Cruise ships	6	8
Porto Marghera	8	8
Giovanni Nicelli Airport	5	5
Marco Polo Airport	8	9
Treviso Airport	7	7
Farmers	3	9
Fishermen	4	9
Hunters	3	9
OTS Laguna di Venezia	6	9
Residents of Venice	6	8
Tourists	3	5



Power-resource dependency

Stakeholder	Type of power	Resources	Dependency of other stakeholders on owners of the resource
Comune di Chioggia	Production	Legislative or statutory power	High
Comune di Padova	Production	Legislative or statutory power	High
Comune di Venezia	Production	Legislative or statutory power	High
Città Metropolitana di Venezia	Production	Legislative or statutory power	High
Regione del Veneto	Production	Legislative or statutory power	High
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	Production	Legislative or statutory power	High
Ministero della transizione ecologica	Production	Legislative or statutory power	High
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Production	Legislative or statutory power	High
Ministero delle infrastrutture e della mobilità sostenibili	Production	Legislative or statutory power	High
Ministero della cultura	Production	Legislative or statutory power	High
Italian Government	Production	Legislative or statutory power	High
AVM/Actv	Blocking	Public transport	Moderate
Cargo ships	Blocking	Money/Distribution of goods	Moderate
Cruise ships	Blocking	Money	Low
Porto Marghera	Blocking	Money/Distribution of goods	High
Giovanni Nicelli Airport	Blocking	Transport and money	Low
Marco Polo Airport	Blocking	Transport and money	High
Treviso Airport	Blocking	Transport and money	Moderate
Farmers	Blocking	Political support	Moderate
Fishermen	Blocking	Political support	Moderate
Hunters	Blocking	Political support	Moderate
OTS Laguna di Venezia	Blocking	Political support/Media	Moderate
Residents of Venice	Blocking	Political support	High
Tourists	Blocking	Money	High

Critical stakeholders

Stakeholder	Resources	Replaceability (High, low)	Dependency (low, moderate, high)	Critical?
Comune di Chioggia	Legislative or statutory power	Low	High	Yes
Comune di Padova	Legislative or statutory power	Low	High	Yes
Comune di Venezia	Legislative or statutory power	Low	High	Yes
Città Metropolitana di Venezia	Legislative or statutory power	Low	High	Yes
Regione del Veneto	Legislative or statutory power	Low	High	Yes
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	Legislative or statutory power	Low	High	Yes
Ministero della transizione ecologica	Legislative or statutory power	Low	High	Yes
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	Legislative or statutory power	Low	High	Yes
Ministero delle infrastrutture e della mobilità sostenibili	Legislative or statutory power	Low	High	Yes
Ministero della cultura	Legislative or statutory power	Low	High	Yes
Italian Government	Legislative or statutory power	Low	High	Yes
AVM/Actv	Public transport	High	Moderate	No
Cargo ships	Money/Distribution of goods	High	Moderate	No
Cruise ships	Money	High	Low	No
Porto Marghera	Money/Distribution of goods	Low	High	Yes
Giovanni Nicelli Airport	Transport and money	High	Low	No
Marco Polo Airport	Transport and money	Low	High	Yes
Treviso Airport	Transport and money	High	Moderate	No
Farmers	Political support	Low	Moderate	No
Fishermen	Political support	Low	Moderate	No
Hunters	Political support	Low	Moderate	No
OTS Laguna di Venezia	Political support/Media	Low	Moderate	Yes
Residents of Venice	Political support	Low	High	Yes
Tourists	Money	Low	High	Yes

Stakeholder roles - The Perfect Lagoon

Stakeholders	Power	Interest	Attitude	Why this attitude?	Critical?	3dSA-role
Comune di Chioggia	8	9	+	Preservation of the lagoon	Yes	Saviour
Comune di Padova	8	7	+	With the new canal, Padova becomes connected to the lagoon and the Adriatic Sea, increasing its economic position	Yes	Saviour
Comune di Venezia	8	8	+	Preservation of the lagoon and the historical centre of Venice	Yes	Saviour
Città Metropolitana di Venezia	8	9	+	Preservation of the lagoon and the historical centre of Venice	Yes	Saviour
Regione del Veneto	9	9	-	Removing the Porto Marghera will have economic consequences for the region, and harbour workers will become unemployed	Yes	Saboteur
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	8	9	+	Preservation and protection of the lagoon and the historical centre of Venice	Yes	Saviour
Ministero della transizione ecologica	8	8	+	Preservation and protection of the lagoon combined with the increased ecological importance	Yes	Saviour
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	8	8	+	Preservation and protection of the lagoon	Yes	Saviour
Ministero delle infrastrutture e della mobilità sostenibili	8	8	-	Even though the Perfect lagoon a sustainable solution is for the preservation of the historical centre of Venice and the lagoon, the removal of Porto Marghera is not favourable. After removing this infrastructural intersection, a new one needs to be made.	Yes	Saboteur
Ministero della cultura	8	8	+	Preservation and protection of the historical centre of Venice, safeguarding its cultural heritage	Yes	Saviour
Italian Government	9	7	+	The historical city of Venice will be protected	Yes	Saviour
AVM/Actv	6	7	-	Decreased amount of routes for public transport, resulting in decreased revenues	No	Saboteur
Cargo ships	6	8	-	Removing the Porto Marghera discards opportunity to dock	No	Saboteur
Cruise ships	6	8	-	Removing the Porto Marghera discards opportunity to dock	No	Saboteur

Porto Marghera	8	8	-	Porto Marghera will be removed from its current location and will be relocated somewhere else. This also weakens the connection to the hinterland	Yes	Saboteur
Giovanni Nicelli Airport	5	5	-	Possible limitations of airtraffic can be imposed by the creation of new dunes	No	Trip wire
Marco Polo Airport	8	9	-	Limited possibility to extend, further limitations of airtraffic can be imposed in order to protect the lagoon	Yes	Saboteur
Treviso Airport	7	7	+	Competition from Marco Polo is hampered by the perfect lagoon, improving the position of Treviso Airport	No	Saviour
Farmers	3	9	+	Extra farmlands are created on the dikes, creating more land for farmers	No	Friend
Fishermen	4	9	-	Decreased opportunity for fishing, since the lagoon will be mostly closed off from human intervention	No	Irritant
Hunters	3	9	-	Decreased opportunity for hunting, since the lagoon will be mostly closed off from human intervention	No	Irritant
OTS Laguna di Venezia	6	9	+	The current lagoon will be protected and preserved, thus creating more room for nature and sustainable tourism	Yes	Saviour
Residents of Venice	6	8	+	Preservation of the historical centre of Venice, without a highly visible protection measure.	Yes	Saviour
Tourists	3	5	+	Preservation of the historical centre of Venice	Yes	Acquintance

Stakeholder roles - Symbiotic System

Stakeholders	Power	Interest	Attitude	Why this attitude?	Critical?	3dSA-role
Comune di Chioggia	8	9	+	No radical change of the environment in the Chioggia municipality	Yes	Saviour
Comune di Padova	8	7	+	With the new canal, Padova becomes connected to the lagoon and the Adriatic Sea, increasing its economic position	Yes	Saviour
Comune di Venezia	8	8	+	The historical centre of Venice is preserved and protected in this design	Yes	Saviour
Città Metropolitana di Venezia	8	9	+	The historical centre of Venice is preserved and protected in this design.	Yes	Saviour
Regione del Veneto	9	9	+	The historical centre of Venice is preserved and protected in this design. The regional network will also be strengthened by the new connections	Yes	Saviour
Soprintendenza Archeologia, belle arti e paesaggio per il Comune di Venezia e Laguna	8	9	-	The historical centre of Venice is preserved and protected in this design, but the lagoon is not	Yes	Saboteur
Ministero della transizione ecologica	8	8	-	No ecological protective interventions will take place in the lagoon	Yes	Saboteur
Ministero dell'Ambiente e della Tutela del Territorio e del Mare	8	8	-	The historical centre of Venice is preserved and protected in this design	Yes	Saboteur
Ministero delle infrastrutture e della mobilità sostenibili	8	8	+	By reconnecting the hinterland with a canal, a new infrastructural connection has been made. Furthermore, the creation of the metro and trams	Yes	Saviour
Ministero della cultura	8	8	+	Preservation and protection of the historical centre of Venice, safeguarding its cultural heritage	Yes	Saviour
Italian Government	9	7	-	The symbiotic system is the most expensive design of Venice and its	Yes	Saboteur
AVM/Actv	6	7	+	More means of public transport will be constructed, creating more oppertunities to operate and produce revenues from these public transport	No	Saviour
Cargo ships	6	8	+	Improved logistic connection to the	No	Saviour
Cruise ships	6	8	+	No radical change of current operations	No	Saviour
Porto Marghera	8	8	+	No radical change of current operations	Yes	Saviour
Giovanni Nicelli Airport	5	6	-	Operations will be hampered by the usage of Lido as a barrier from the	No	Irritant
Marco Polo Airport	8	9	+	No radical change of current operations	Yes	Saviour
Treviso Airport	7	7	+	No radical change of current operations	No	Saviour
Farmers	3	9	+	No radical change of current operations	No	Friend

Fishermen	4	9	-	Fishing industry will be limited due to the bridges and sluices around Venice	No	Irritant
Hunters	3	9	+	No radical change of current operations	No	Friend
OTS Laguna di Venezia	6	9	-	More tourists are able to visit Venice, making it harder to enable sustainable tourism. Furthermore, no protective measures are taken for the lagoon	Yes	Saboteur
Residents of Venice	6	8	+	Functions are moved from the historical centre to the artificial islands, creating more room for the residents.	Yes	Saviour
Tourists	3	6	+	Islands are easier to visit for tourists and more room is created with the artificial	Yes	Friend

Faculty of Civil Engineering and Geoscience
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