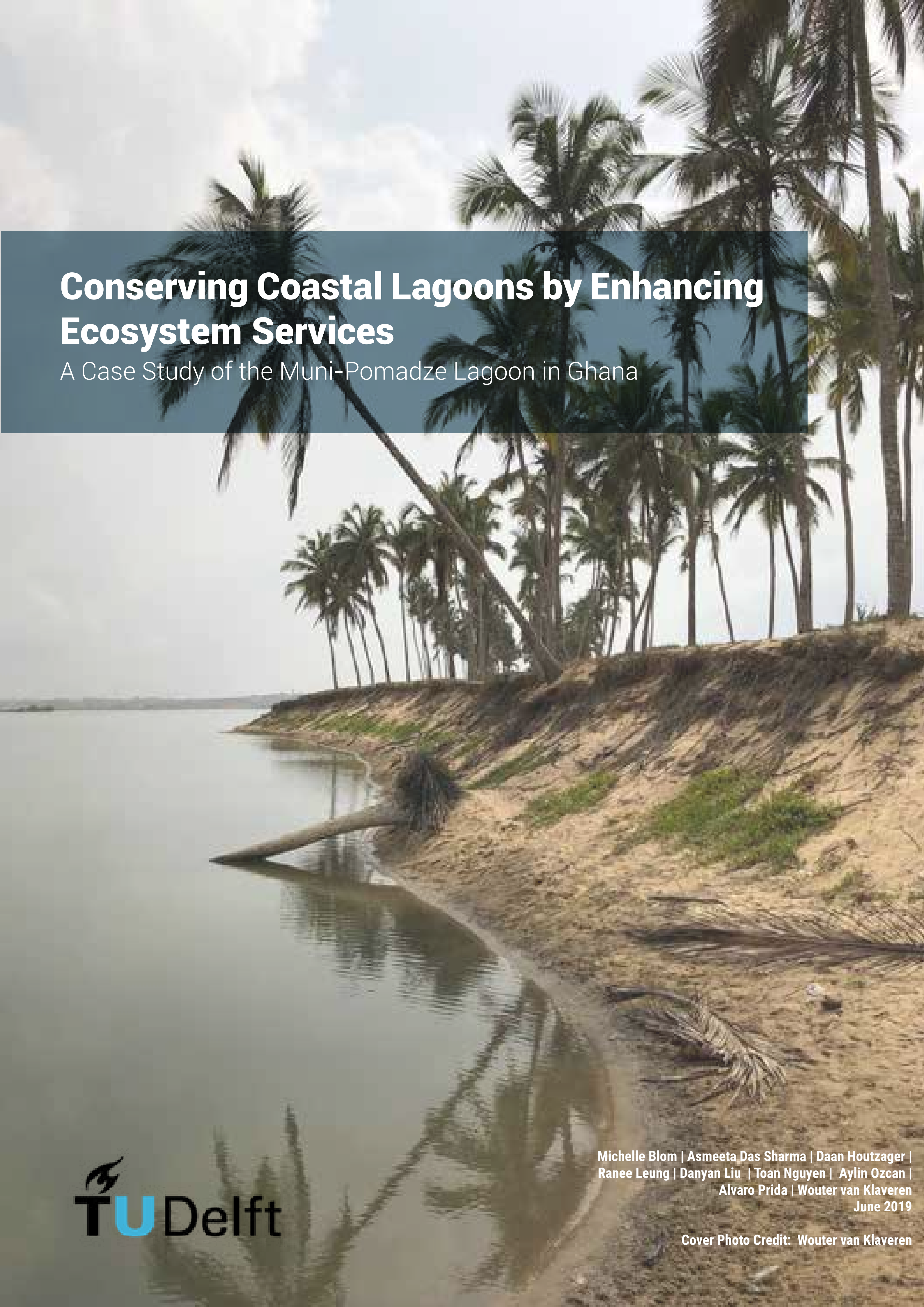

Conserving Coastal Lagoons by Enhancing Ecosystem Services

A Case Study of the Muni-Pomadze Lagoon in Ghana

Michelle Blom | Asmeeta Das Sharma | Daan Houtzager | Ranee Leung | Danyan Liu | Toan Nguyen | Aylin Ozcan | Alvaro Prida | Wouter van Klaveren

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Cover Photo Credit: Wouter van Klaveren

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Preface

Rapid urbanisation and globalisation are bringing increasingly complex issues to the forefront. Improper planning of human activities and over exploitation of the surrounding natural resources has successfully damaged the biodiversity and the natural processes. Today humanity is at a stage where these ecosystem services are essential for our existence but the resources have been exploited beyond their capacity. In addition, climate change adds additional long-term threats due to erratic weather patterns and extreme natural events.

Coastal Lagoons are one such geographical feature where such complexities are very visible. Given the high fertility of the surrounding land and the biodiversity hosted by the lagoons, they are rich resource banks for settlements to thrive on. This has led to issues like water pollution, loss of biodiversity and urban encroachment. Despite protection from the international communities like the Ramsar Convention, most wetlands are degrading everyday.

The need of the hour is to find innovative middle ground solutions, where the services can be availed without degrading the environment. Further, to plan these services in a way that they are instrumental in reviving and enriching the lost ecosystem. This project attempts to present one such design and strategy for the Muni-Pomadze Lagoon (MPL) in Ghana. Considering the complexity of the issues, the project chose a interdisciplinary and collaborative approach to produce a holistic solution for the site. Further, it uses the principles of Nature-Based Design and 4-P framework (People, Planet, Prosperity and Project) to guide and reflect on the design. (van Dorst & Duijvestein 2004)

This report attempts to contribute to the research on interdisciplinary design processes. Further, it aims to be a starting point and guideline for the Forestry Commission and Municipal body of Winneba, for better conservation of the Muni Lagoon.

Contents

List of Figures

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The Team

This project is organized with the aim of interdisciplinary and international cooperation. At Delft University of Technology, the interdisciplinary goal is not only about the connection between the faculty of CiTG and A+BE (hydraulic engineering and urbanism) but also establish cooperation in CiTG among hydraulic engineering and urban water management and in A+BE between urbanism, management in the built environment and landscape architecture to create integrated learning from the Lagoon reconstruction. The international cooperation is about maintaining knowledge exchange and develop ties between researchers and the universities at TU Delft (the Netherlands) and the University of Education, Winneba and University of Ghana in the fields of flood risk management, delta planning and design. Together with its existing partners A Rocha Ghana and Muni-Pomadze Ramsar Site of Wildlife Division (Forestry Commission), the students at the university have taken up the challenge of ecological degradation through urban encroachment in the region.

Taking the route of interdisciplinary approaches to complex issues, a group of 9 students from the fields of Hydraulic Engineering, Water Management, Urban Planning, Landscape Architecture and Project Management are currently investigating the issue. The aim is to develop a joint research project focused on Nature-Based design. To understand the context and on-site issues better, the students organised a visit to the Lagoon in the month of February, 2019.

Figure 1 Salt pans located on the Muni-Pomadze site, photo by Ranee Leung

01 Introduction

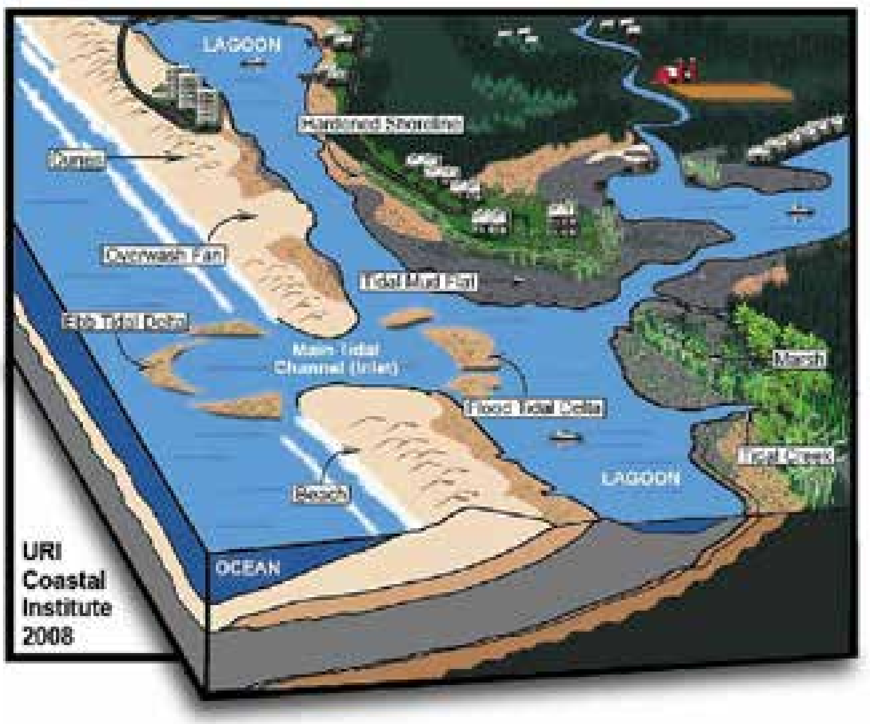


Figure 2 Ideal coastal lagoon, Source : (Illustration by Nate Dibble. Used with permission from the URI Coastal Institute, 2008)

Figure 3 Laguna de Términos, Mexico, Source : Earth.com

“Take from the land but also give back to the land”

Wetlands are one of the most productive natural systems in the world. They support a wide range of species of flora and fauna and have countless benefits or ‘ecosystem services’ for humanity. These services range from fresh water supply, sustenance, flood risk reduction, climate change mitigation and maintaining the water cycle. (Gardner et al, 2015)

Despite their irreplaceable value for the human existence, the quality of these wetlands continues to decline in most regions of the world. The loss and degradation has been estimated to be between 64-71% in the 20th century. This decline is estimated to have caused a loss of more than 20 million US dollars of ecosystem services annually. Further, wetland species are increasingly moving towards extinction. (Gardner et al, 2015)

Multiple studies and initiatives have been launched globally for the protection and conservation of these ecosystems. The oldest one being the Ramsar Convention. It is an intergovernmental environmental agreement, negotiated in the 1960’s. The convention internationally recognises and guides the member countries on the management of the Ramsar Sites.

1.1 Coastal Lagoons

Coastal Lagoons are a type of wetland which are transitional zones between land and the sea. They are shallow inland water bodies which are separated from the sea or ocean by a natural barrier. However, it is connected, at times intermittently, by one or more restricted inlets. These lagoons can be further classified by their water salinity, tidal regime and geo-morphic type. (Flanders Marine Institute, 2012)

These lagoons are attractions for human settlements due to their unique ecology. They are hubs for fishermen communities due to the rich marine life as well as traders due to the direct access to the sea. Further they enjoy a diverse bird population and sea life who use the area as a breeding ground and habitat. However, due its transitional state, coastal lagoons are naturally stressed systems. They are exposed to the uncertainties of the sea and the water quality depends on the interaction with the salt water. Climate Change is also predicted to have a considerable impact on the water temperature, fresh water and sea water input and their temporal patterns. This has a considerable consequence on the biodiversity and the ecosystem services provided by the lagoon.

The combined forces of human processes like urbanisation and climate impact, have already led to the loss of one third of the coastal mangrove forests and one fifth of the coral reefs of the world (Gardner et al, 2015). This report presents nature-based solutions to address these multi-lateral issues. It aims to restore and further conserve the ecological balance of a coastal lagoon by planning and enhancing the ecosystem services. It uses the ecosystem services as a tool to achieve this.

The Muni-Podmaze Lagoon, Ghana, is used as a test case for an inter-disciplinary strategy which responds to the threats of urbanisation, water pollution and optimizes its interaction with the sea. The proposal is a holistic design which incorporates a regional spatial design, strategies and careful engineering solutions. An inter-disciplinary approach is necessary to fully address the scope, complexity and issues of the site. The overall approach also includes a revised governance and stakeholder management structure.

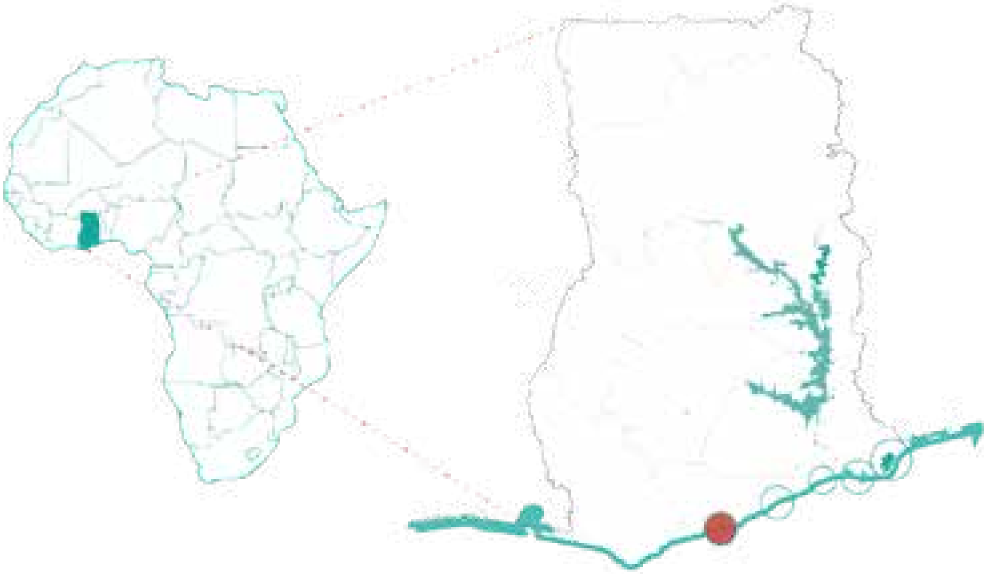


Figure 4 Geographical location of the Muni-Pomadze Lagoon

Figure 5 Map of Ramsar sites along the coast of Ghana

1.2 Context - Ghana & Muni-Pomadze

The Muni-Pomadze site is located in Central Ghana and is adjacent to the growing city of Winneba. The site itself also acts as the key source of livelihood (grazing, farming, fishing and hunting) and sustenance for its people. A Coastal Zone Indicative Management Plan (CZIMP) was prepared to protect coastal sites under the management and submission of World Bank. This project eventually became the Ghana Coastal Wetlands Management Project (CWMP) and in 1992, the Muni-Pomadze site became designated as one of the five designated Ramsar sites (Figure 5). It is noted that the CWMP aims "to preserve the ecological integrity of the important coastal wetlands of Ghana, while at the same time enhancing the socio-economic benefits of the wetlands to local communities. To achieve this goal, the activities, advocated under the CWMP, included the development of a technical information base on the interactions between the biotic and abiotic elements of the wetlands." (Gordon, Ntiamoa-baidu, & Ryan, p. 448, 2000). Apart from its international significance, the area also has high income generating potentials. Collaborations between the local communities, governmental and non-governmental conservation agencies continue to strive to promote the conservation and protection of the Ramsar site.

The Muni-lagoon is a shallow, semi-closed, saline coastal lagoon. The size of the wet area of the lagoon varies depending on the season from 100ha in the dry season to over 1000 ha in the wet season. An integral part of its ecosystem is the large variety of flora and fauna. The Lagoon, along with its floodplains, consists of two forest reserves and an adjacent sandy beach on the seafront. The two protected areas adjacent of the lagoon, namely the Yenku A and B Forest Reserves make up 10% of the site, while traditional hunting areas of the Effutu people make up 15% of the site (Gordon, Ntiamoa-baidu, & Ryan, p.2, 2000). The total area accounts for 9500 ha and three main tributaries, the Pratu, Boaku and Muni drain into the Muni Lagoon. The catchment is also bordered by the Yenku Hills and in the south-west by the Egyasimanku Hills. Majority of the site (53%) is classified as natural vegetation, 32.5% as agricultural lands and the 11 communities that reside on the site account for the 12.6% that is residential development.

Figure 7 Project site in focus, Muni-Pomadze and neighboring areas of importance

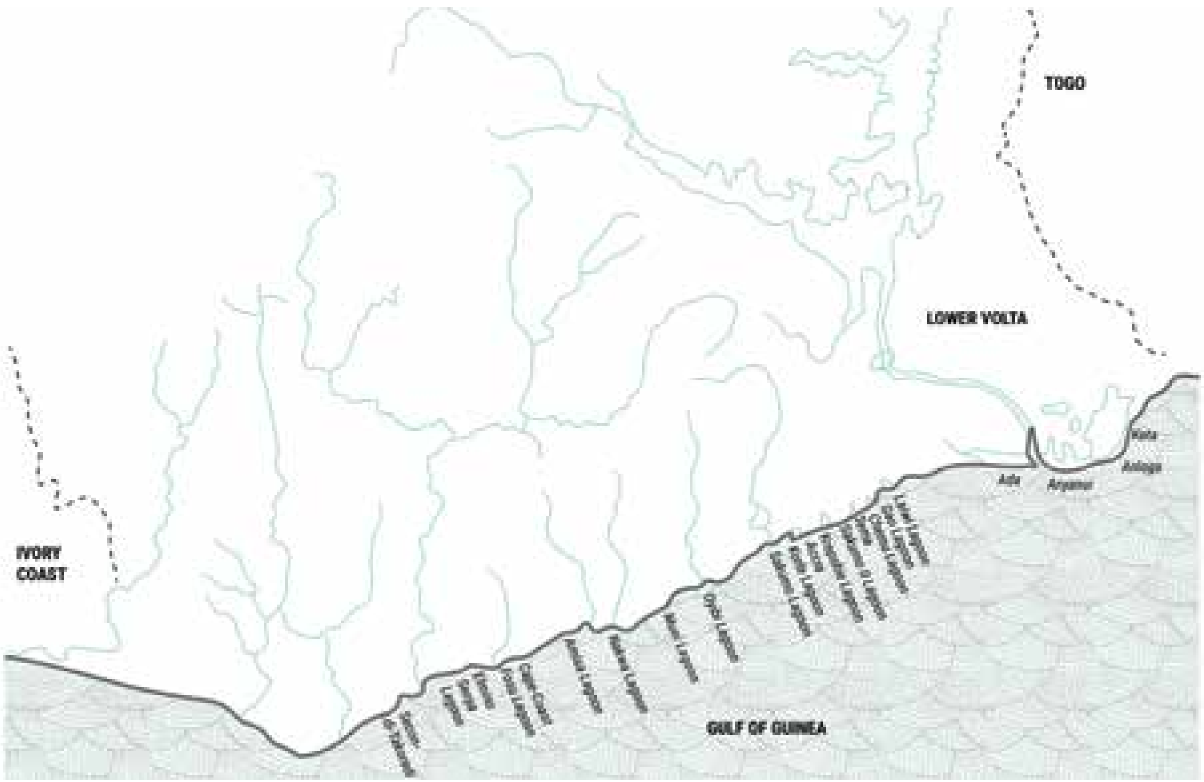


Figure 6 Water network and notable lagoons along the coast of Ghana

Vegetation & Biodiversity

The MPL is separated from the sea by a sand bar that may be breached on occasion. Second, the general coastal lagoon is characterized by flood plains (including mangrove and wetland vegetation), sand dunes, degraded forest, farmland and marsh areas that are subjected to seasonal inundation. The lagoon shoreline is covered by a series of species ranging from the sesuvium portulacastrum, paspalum virginicum and sporolobus virginicus (Gordon et al., 2000). In the northern areas of the wetland, the predominant vegetation consists of mangroves and other typical freshwater hydrophytes. In the upland areas, the vegetation is comprised mainly of grassland, thickets and pockets of eucalyptus and cassia plantations.

The small strip of beach separating the lagoon to the sea is covered mainly by coconut plantations that provides habitat for sea-birds but also attracts birdwatchers and tourists. In addition, one of the primary tourist attractions in the area are the marine turtles that nest on the sandy shores. The area is also a habitat of over 48 species of water birds (estimated population of 23,000) and a diverse set of 75 butterfly fauna (Gordon et al., 2000). However, there is a constant threat to this and the four other Ramsar sites in coastal Ghana due to the pollution from domestic waste, habitat destruction from industrial and urban developments as well as over-exploitation of wetland resources.

Figure 8 Sesuvium Portulacastrum

Figure 9 Paspalum Virginicum

Figure 10 Sporolobus Virginicus

Socio-Economic Conditions

As previously mentioned, within the Muni catchment areas, there are 11 communities and settlements (Gordon et al., 2000) with a total of 39,000 inhabitants. There is also a constant growth rate of more than 2% per annum and the pressure on these systems is bound to grow in the future (World Population Review, 2019). The ethnic groups in the area have distinctive areas of divided lands where the Effutu and Gomoa groups own the northern drainage areas while the Effutu primarily owns the lagoon area. The existing fishing community residing on the beach is called the Akosua Village. Although the area is experiencing coastal erosion, majority of the fishing community is comprised of Ewe fisherman that originated from the coast of the Volta Region of the eastern part of Ghana (Gordon et al., 2000). Besides farming and fishing, the main form of employment includes hunting, production of charcoal, salt mining, the distillation of alcohol and rock quarrying. Literature rates in the communities are roughly 80% and inhabitants have access to clinics, hospitals and schools. However, sanitation and waste disposal facilities are extremely poor or unmanaged. The traditions and community values in the area are important to conserve. Without the consideration of working with the local populations and their livelihoods, the cultural values within the area will be easily lost.

Figure 11 Erosion occurring along the sand bar, (Asmeeta Das Sharma, 2019)

Figure 14 Fisherman reeling in net at the Muni-lagoon, (Aylin Ozcan, 2019)

Figure 12 Pollution found along the coast, (Daan Houtzager, 2019)

Figure 13 Settlements along the periphery of the lagoon, (Danyan Liu, 2019)

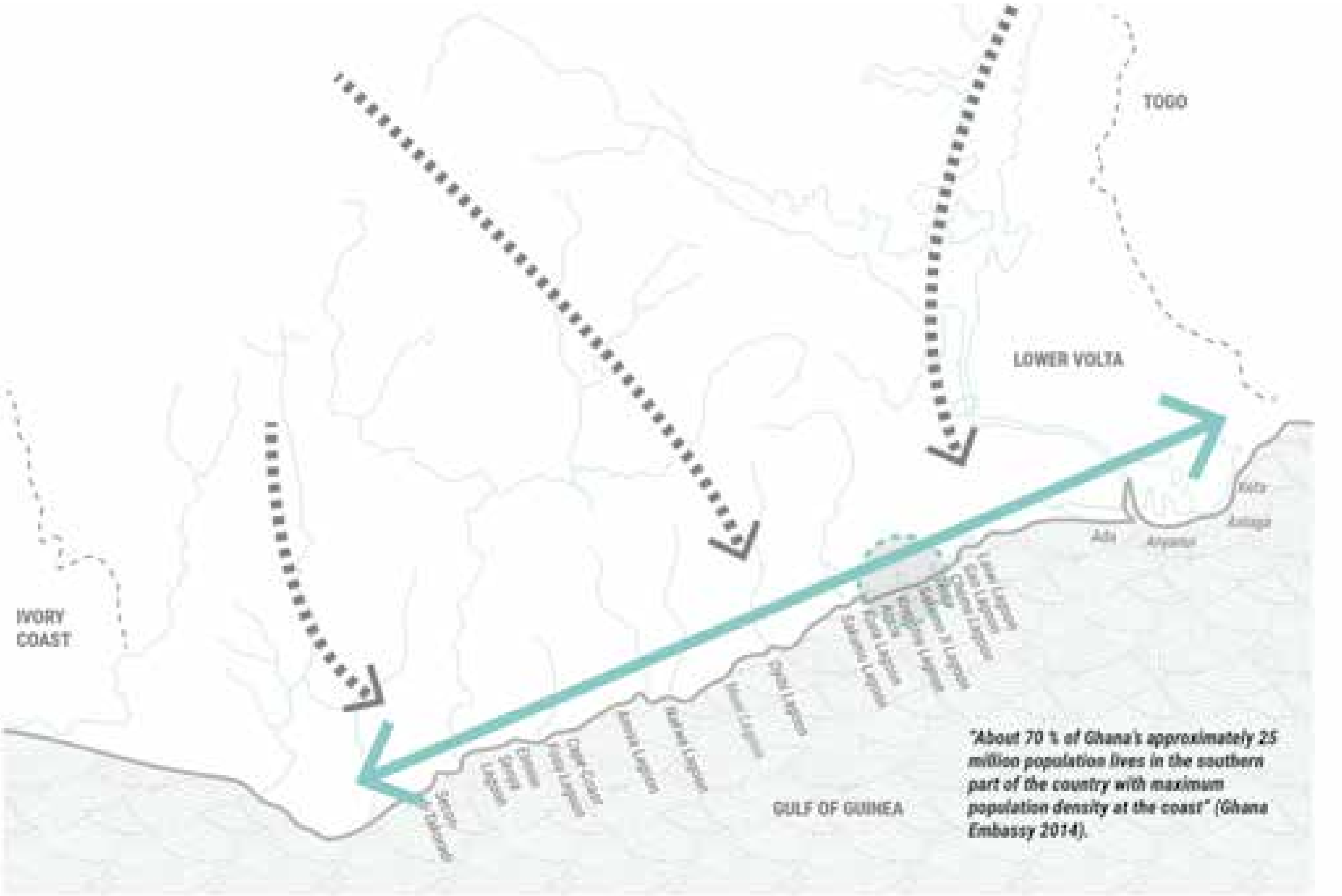


Figure 15 Growing pressures from coastal urbanization

Current Threats and Future Trends

Growing human developments on the fringes of the area, like the city of Winneba, are proving to be an increasing threat to the natural environment. Illegal hunting, over-fishing and habitat destruction for firewood and other resources and encroachment by the growing cities as well as the use of the forest area for garbage disposal are visible threats which have caused critical degradation of the ecological areas. In addition, with the current governance structure, mindset of the existing population and poor vehicle access throughout the site, there has been a struggle to enforce laws. In an attempt to protect their coastal environment and biodiversity, the Ghanaian Forest Commission, aims to restore the balance on the Muni-Pomadze Ramsar Site within three years. Their vision is to leave the future generation with richer, better and more valuable wetlands by developing sustainable livelihood opportunities and restore the original habitat for the biodiversity. However, there is also a growing concern on the rate and magnitude of the coastal urbanization occurring in Ghana.

There is a specific trend where the spatial urban pattern is dominated by urban sprawl (Akubia, 2016). This is due to the growing tourism urbanization that is emerging that is driven by the expansion of infrastructure for tourists and government policies developing coastal tourism. Another explanation of the large urban transformation in coastal areas is due to the rise of industrial development. Roughly 75 percent of Ghana's industrial facilities are found along the coast supported by exports and imports. As a result of the increased concentration of socio-economic and industrial activities, a higher concentration of residents have claimed their place adjacent to the coastline (Akubia, 2016).

Current Threats

Loss of ecological systems
- Water Pollution
- Flooding Risk
- Loss of biodiversity

Encroachment
Water and Waste Pollution
Population Growth

Future Trends

Endangered ecological systems
Mass Urbanization
Extreme weather events
Loss of livelihoods
Loss of critical resources
Climate Change

Figure 16 Levee on the Muni-Pomadze site, photo by Ranee Leung

02 Methodology

2.1 Problem Field
2.2 Research Aim
2.3 Research Questions
2.4 Vision
2.5 Research Framework
2.6 Methods (Scoping)
2.7 Time line

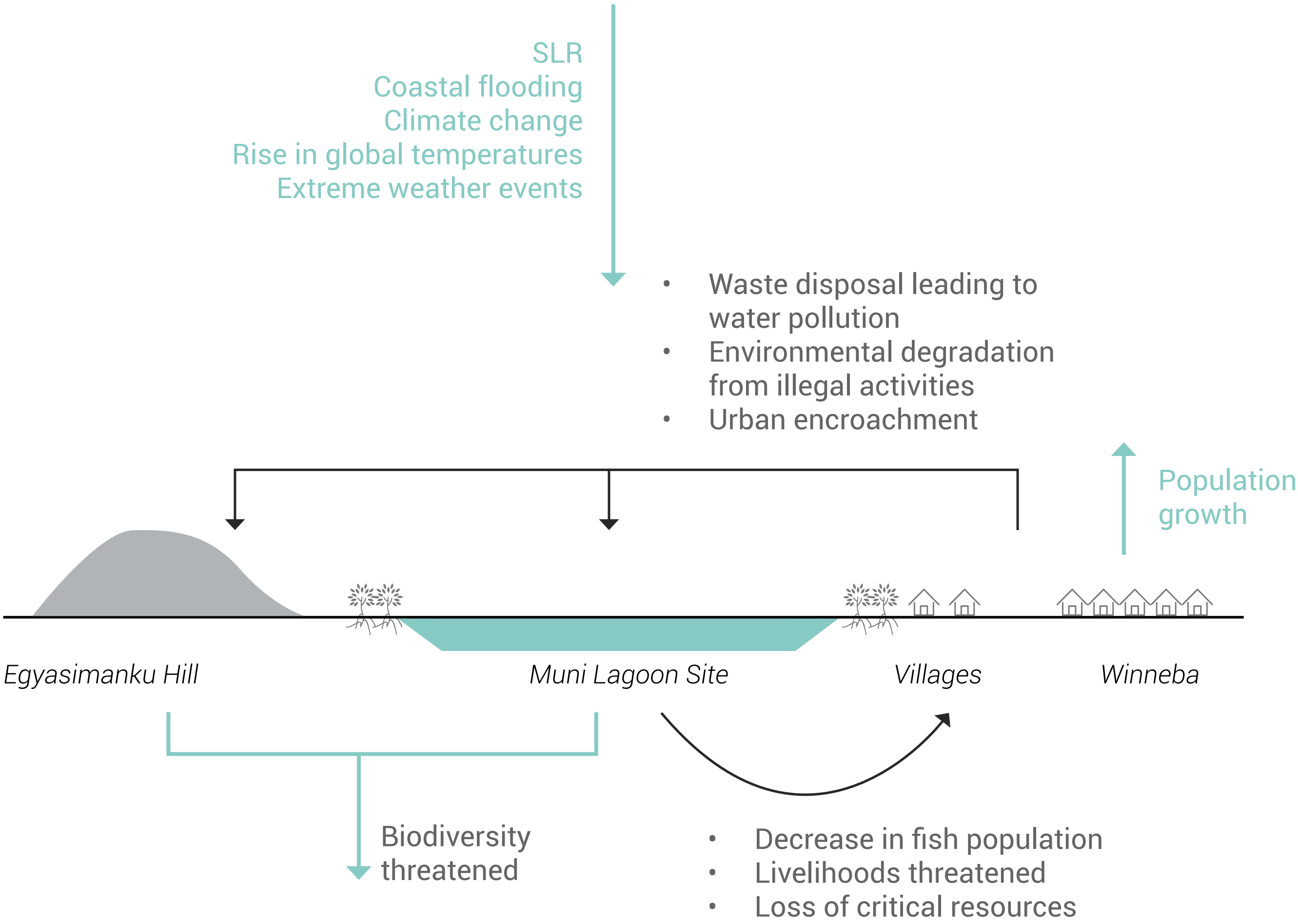


Figure 17 Problem Field Concept Diagram

2.1 Problem Field

The diverse ecosystem of the Muni-Pomadze Lagoon in Winneba, Central Ghana, is threatened to extinct in the near future due to critical degradation of the ecological areas. The causes of these adverse effects are the population growth and the climate change.

According to the Ghana Embassy (2014), more than 70% of Ghana's population live in coastal areas. In these regions, the subsistence is more feasible than in the hinterland due to the available coastal resources. These circumstances have led to an increase in the urban encroachment, with negative effects in the natural ecosystems.

Winneba is a coastal city that is physically limited to the West by the Muni-Pomadze Lagoon. Progressively, the population is settling in the proximities of the MPL due to the natural resources the lagoon offer. During dry season, informal buildings are constructed in the temporary dry areas, causing a negative impact in the ecology of the lagoon. The uncontrolled waste disposal in these locations also contributes to the degradation of the ecosystem. Furthermore, these areas are exposed to serious risk of flooding during wet season.

The effects of climate change in the MPL are already noticeable (USAID, 2017). A first consequence of the climate change is the rise of the sea level. The average rate of sea level rise during the twentieth century, according to the measurements taken by the Takoradi tidal station, is 3.34 mm per year (Sagoe-Addy and Appeaning Addo, 2014). The country's Environmental Protection Agency predicts that sea-levels will rise by 1 m during 21st century (Mensah and Fitzgibbon, 2013). As a result of the sea level rise, the soil salinity can rise, affecting the vegetal species of the lagoon ecosystem and the agricultural production. Furthermore, the salinity of the sea water can contaminate the water sources and can affect the coast morphology.

Moreover, it is expected a rise in temperatures of 1.4 to 5.8 degrees by 2080 (USAID, 2017). This fact can drive the extinction of ecological communities and crops. The fish population of the lagoon could also be affected, particularly the popular tilapia, due to the increase of water temperatures. The average river flows could also be reduced as a consequence of climate change, due to the reduction of average precipitation.

2.2 Research Aim

The research aims to improve the ecosystem services and the natural livelihood of the MPL by restoring the ecological balance of the ecological community. The involvement of the inhabitants in the design process is crucial to fulfil the mentioned ambitions.

2.3 Research Question

The gradual degradation of the ecology in the MPL requires a deep analysis of the causes of this negative phenomenon. With this purpose, the following research question is formulated:

How can a Coastal Lagoon be ecologically conserved and enriched by integrating natural processes and anthropic processes for the future?

2.4 Vision

The design proposal pursues the development of an ecologically enriched lagoon, which strengthens the ecosystem services for the local communities in the Muni-Pomadze Ramsar Site.

2.5 Research Framework

PROBLEM DEFINITION

PROBLEM STATEMENT

Destruction of the natural ecosystem of Coastal Lagoons due to exploitative ecosystem services and human processes.

RESEARCH QUESTION

How can a coastal lagoon be ecologically restored and enriched by integrating natural processes and anthropic processes for the future?

SUB QUESTIONS

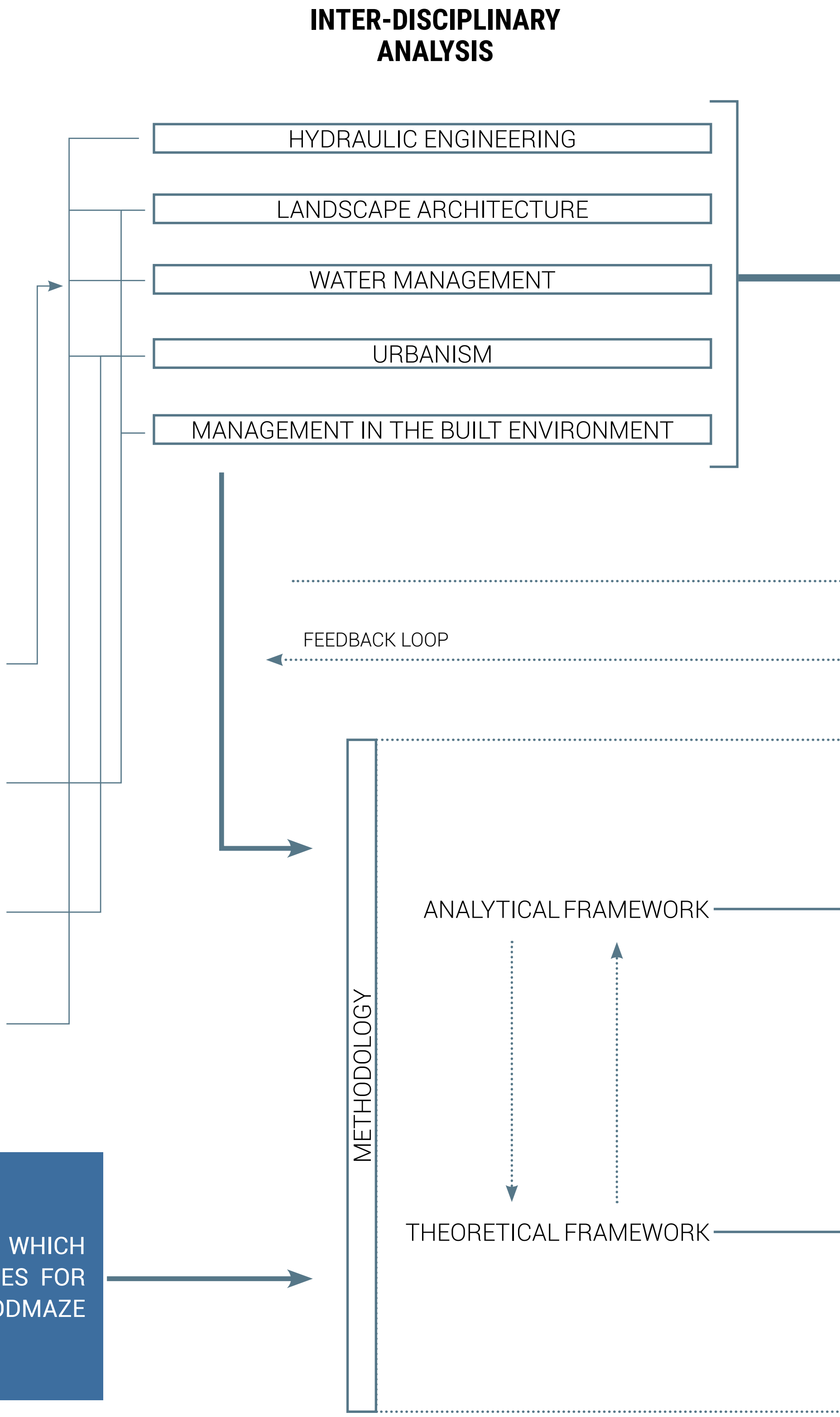
What are the dominant threats to the Lagoon and who are the major stakeholders?

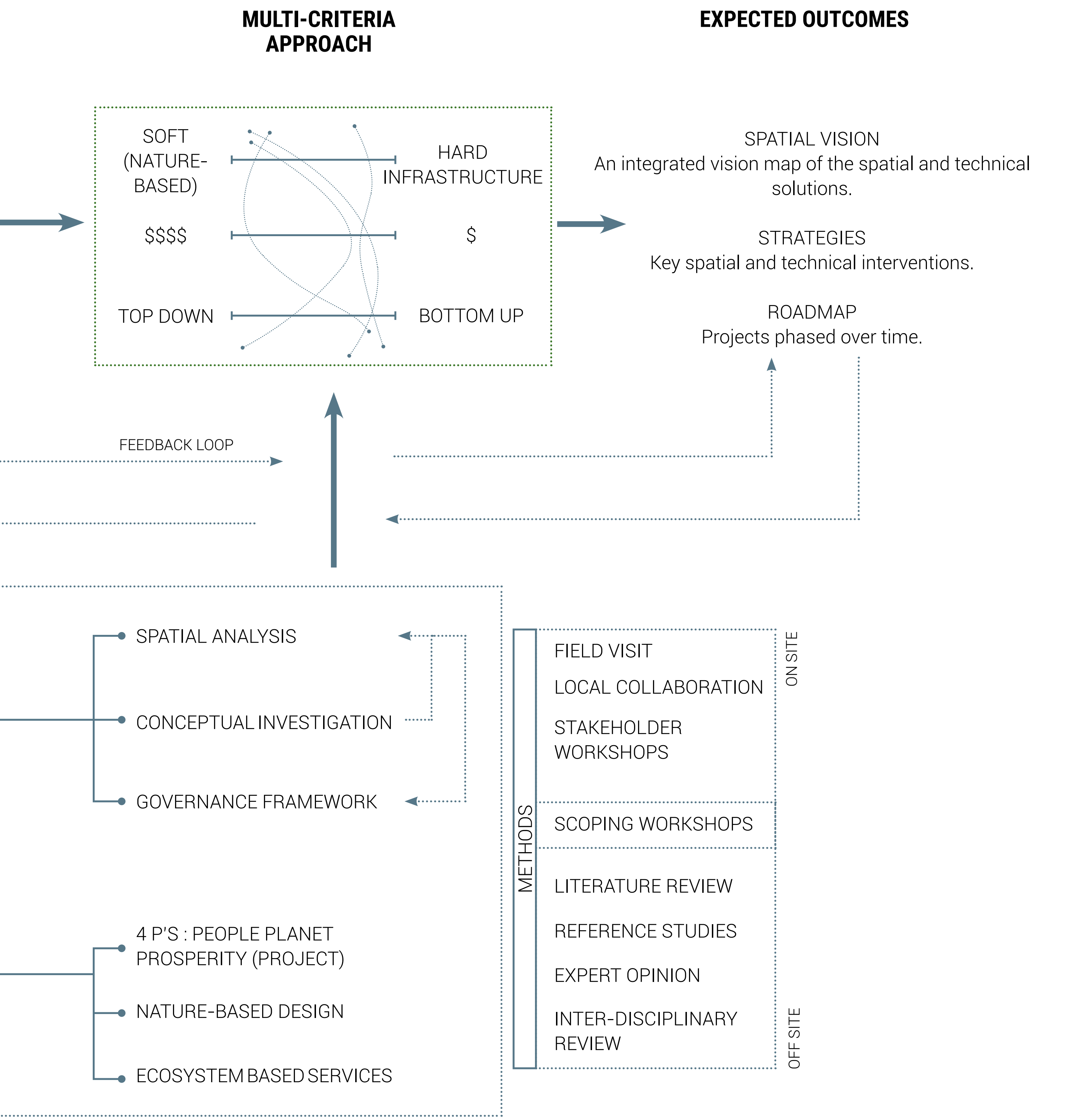
What are the ecosystem services involved and how can they be used for restoring the ecological balance?

What steps can be taken to protect the lagoon from the increasing urbanisation?

How can we use nature-based technical solutions to improve the water quality of the lagoon?

AN ECOLOGICALLY ENRICHED LAGOON WHICH STRENGTHENS THE ECOSYSTEM SERVICES FOR THE LOCAL COMMUNITIES IN THE MUNI PODMAZE RAMSAR SITE.




MULTI-CRITERIA APPROACH
EXPECTED OUTCOMES
SOFT (NATURE-BASED)
HARD INFRASTRUCTURE
$$$$
$
TOP DOWN
BOTTOM UP
SPATIAL VISION
An integrated vision map of the spatial and technical solutions.
STRATEGIES
Key spatial and technical interventions.
ROADMAP
Projects phased over time.
FEEDBACK LOOP
SPATIAL ANALYSIS
CONCEPTUAL INVESTIGATION
GOVERNANCE FRAMEWORK
4 P'S : PEOPLE PLANET PROSPERITY (PROJECT)
NATURE-BASED DESIGN
ECOSYSTEM BASED SERVICES
METHODS
FIELD VISIT
LOCAL COLLABORATION
STAKEHOLDER WORKSHOPS
ON SITE
SCOPING WORKSHOPS
LITERATURE REVIEW
REFERENCE STUDIES
EXPERT OPINION
INTER-DISCIPLINARY REVIEW
OFF SITE

2.6 Methods (Scoping)

An exploratory and interdisciplinary approach is used in this project. An exploratory strategy means that a combination of qualitative and quantitative analysis techniques are applied (Krishnan et al., 2018). While an interdisciplinary approach guarantees resilience and addresses the complexity of the issue in the design proposal.

The approach was applied to the project through a scoping exercise, determining specific requirements and a multi-criteria analysis to weigh the various solutions for the problem field identified. Figure 18 shows that the process was an iterative one wherein each discipline begins with multiple possibilities. Through continuous discussion and knowledge sharing, the discipline then narrows down its scope to fit within the guiding themes of the project. The strong guiding theme for this case was nature based design. All the disciplines were required to optimize their solutions economically and be sensitive to the context. Thus, a holistic and interdisciplinary design was achieved.

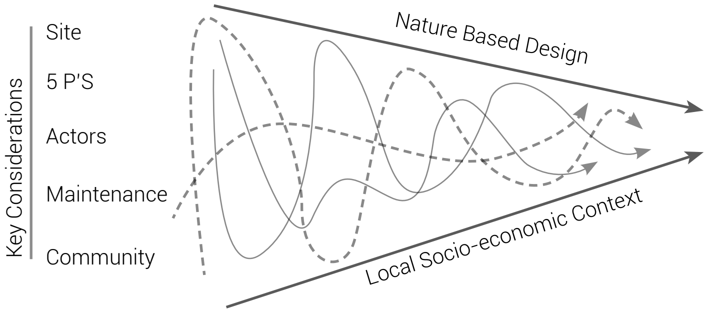


Figure 18 Frame of reference adapted from Van Dooren, 2014

During the preparation phase (figure 22), workshops were held to analyse the interdisciplinary relationships between the 9 students and their 5 disciplines of expertise. These workshop sessions were carried out according to the charrette method of Lennertz and Lutzenhiser (2006). This method is a type of participatory planning process that helps the interdisciplinary team to come up with a solution to a given problem. To enhance dialogue and contribution of ideas, the process consisted of various sessions.

The first step of the process consisted of pairing up disciplines to discuss their fields and understand the key issues for each domain. This specific workshop of getting to know each other was crucial before starting to work in an interdisciplinary way. It equipped the group members with the understanding and knowledge of each others abilities and expertise. (Hooimeijer & Tummers, 2017)

Further, a mono-disciplinary analysis was conducted related to the site. This means that each discipline came up with possible problems and solutions related to the Muni-Pomadze Site.

The next step during the site visit marked the beginning of the charrette process and consisted of dividing the team into two subgroups based on their disciplines, together with the Ghanaian students and two hydraulic engineers from Witteveen+Bos. The diversity within the subgroups was intended to stimulate participation and promote the end goal of a shared solution. A range of intermediate solutions were identified along the axis based on the 3 P's (People, Planet and Prosperity). (van Dorst & Duijvestein 2004) (Hooimeijer & Tummers, 2017)

During the scoping exercise, communication was a key factor to ensure that each discipline understood what was being expressed. This information exchange needed to take place in a transparent and open way to be able to come up with a shared vision and a agreeable solution. Therefore, all disciplines came up with possible solutions from their perspective and further extensively discussed them to generate a combined single design incorporating the most appropriate components of each discipline. Subsequently, each member sought to forge connections between disciplines to determine how defined choices could affect another design choice and thus accommodate these choices to produce an interdisciplinary design for the Muni-Pomadze Ramsar Site (see Figure 20).

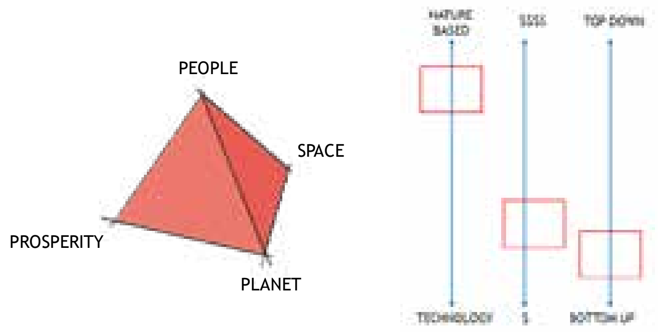
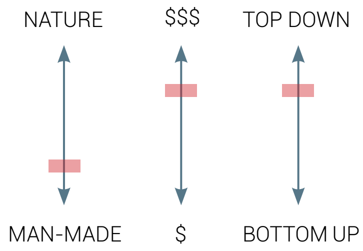
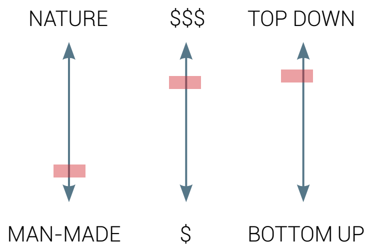


Figure 19 Scoping exercise

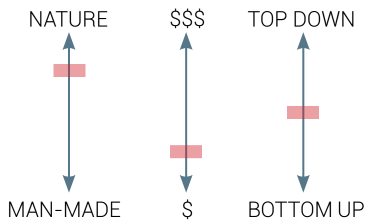
Fully open lagoon	
(+) Better water quality, [WM , LA]	(-) Increased salinity, [WM , LA]
(+) Flushing the nutrients pollutants, [WM , LA]	(-) Expensive structure & maintenance needed, [HE]
(+) Biodiversity/Ecosystem, [LA , URB]	(-) Decrease of fresh-water [WM , URB]
(+) Improve mangrove growth [LA]	(-) Impact on Fish Population and livelihood [URB]



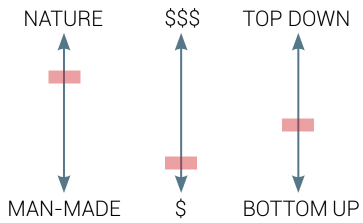
Semi-open lagoon: structural solution (S)	
(+) Permanent solution and is controllable [HE]	(-) Lack of coordination amongst decision-makers [URB]
(+) Controllable water level due to a gate [HE]	(-) High investments [HE , URB]
(+) Flood control [HE, URB]	(-) Maintenance is needed [HE]
(+) Biodiversity, [LA , WM]	(-) Unsustainable in current situation [HE]
(+) Navigation/Accessibility [HE , URB]	(-) Needs a hard structure intervention [HE]



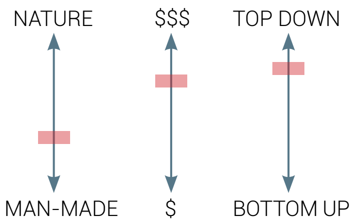
Semi-open lagoon: natural solution (N)	
(+) Simple [HE]	(-) Lack of coordination amongst decision-makers [URB]
(+) Maintains a natural system [WM , HE]	(-) Requires community mobilisation [URB]



Closed lagoon	
(+) Free,	(-) No water flushing,
(+) No plastic in the beach	(-) Bad for ecosystem: less fish, no nutrients for mangroves, etc. [URB , WM , LA]
	(-) Flood risk [URB , WM]
	(-) Pollution [URB , WM , LA , HE]



Prohibit Use of Site (Law and Enforcement)	**Planned Use (Community participation)**
(+) Top Down Implementation - Easy to Control Activities	(+) Value for the community retained
(+) Possible faster ecological restoration	(+) Use of Traditional Sustainable Practices
(-) Resource Intensive	(-) Long Term Planning
(-) Alienating Communities and destroying livelihoods	(+) Different Revenue Models for Implementing engineering and other solutions



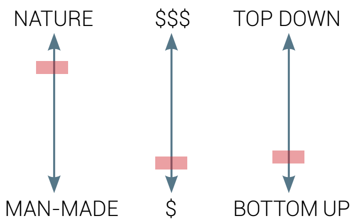


Figure 20 Table showing design choices and its effects

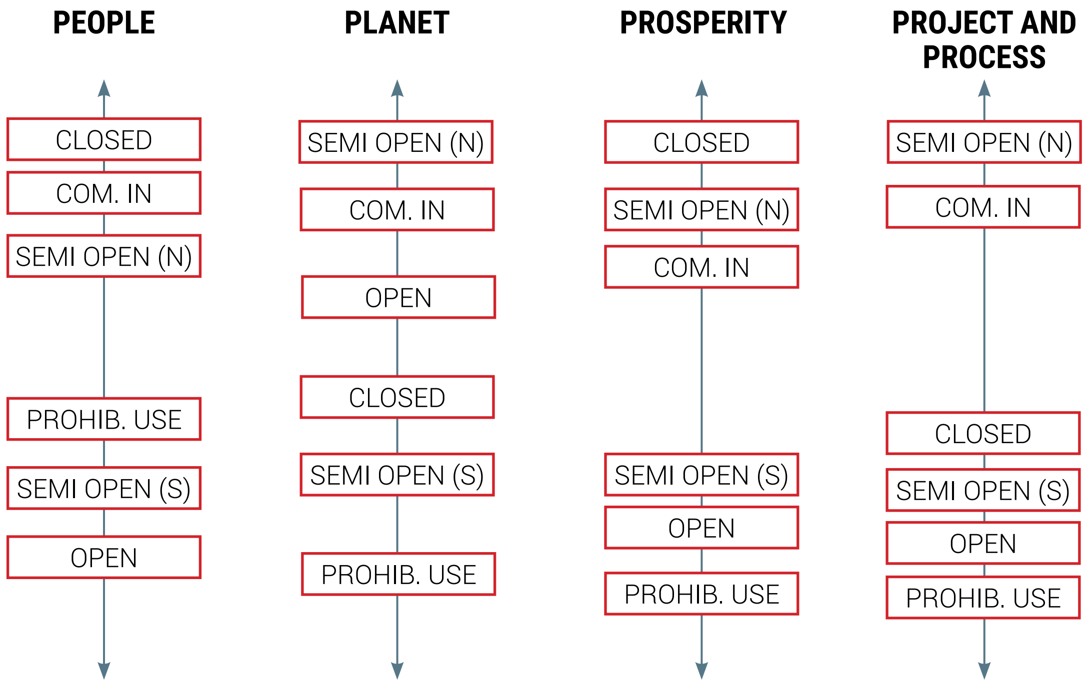


Figure 21 Scoping exercise for lagoon decision-making

The key consideration as understood from the local experts and the site visit was the quality of water and the interaction of the lagoon water with the sea. The complete ecosystem of the Lagoon is dependant on the water. Hence, the solutions primarily responded to this and each solution had certain consequences for the different disciplines. The second issue considered was the conservation of the site where 2 scenarios were considered.

From these examples, it is clear that every design has a considerable impact on the lagoon. However, to decide which solution would be taken into account, a number of design requirements were set for each P (see chapter 6) including boundary conditions were taken into account while coming up with a final integrated design for the Muni-Pomadze lagoon.

Later once the conceptual design was settled as shown in figure 21 (end conclusion during the charrette workshop in Ghana), each discipline clarified their part of the solution to incorporate calculations or more detailed drawings. This integrated design was checked to see if all the combined elements still fitted together and if not the designs were adjusted. This iterative process was repeated until a holistic design was achieved with the aim of strengthening the ecosystem services for the local communities in the Muni Pomadze Ramsar Site. More is explained in the following chapters of this report.

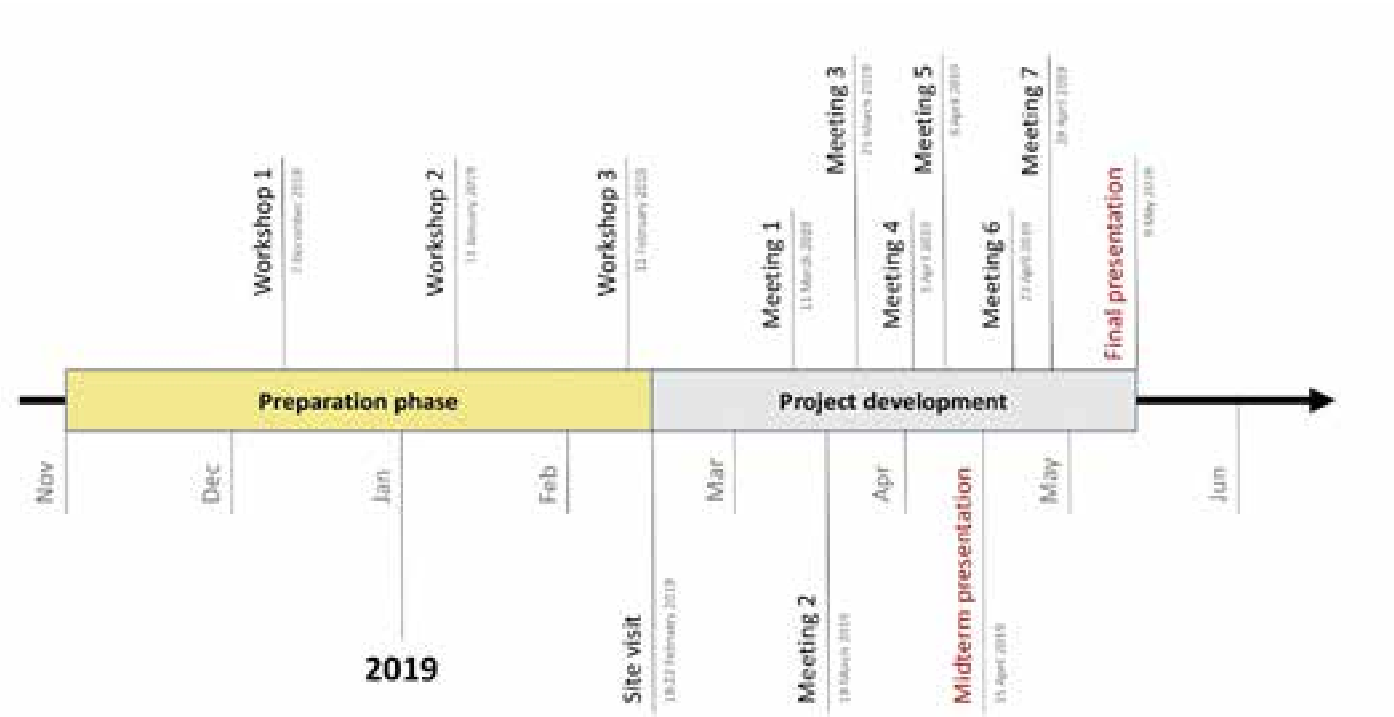


Figure 22 Time line of the project

2.7 Timeline

The organization of the tasks to carry out in the project is fundamental to guarantee efficient work sessions. With this purpose, a timeline of the project activities has been elaborated. There are schedules four types of activities:

Workshops: the goal of these activities is the preparation of the site visit. Before the workshops, every discipline develops a literature research and previous projects in the site of study and their field of knowledge. Workshop 1 and Workshop 3 took place at TU Delft, while Workshop 2 was developed at the headquarters of Shell in The Hague.

Site visit: during the field trip to Winneba (Ghana), the site of study was visited and meetings with experts and stakeholders were set up. Furthermore, work sessions at the Winneba University of Education were carried out, in which it was possible to share perspectives and build up conceptual solutions together with Ghanaian students.

Meetings: after the site visit, the project is developed in The Netherlands. Weekly work sessions of are scheduled. Before the start of the project development phase, a list of goals are set for every meeting, in order to enhance the performance of the sessions.

Midterm and final presentation: one work progress check is schedule one month before the final presentation, in which the design strategy of the team is assessed by the project supervisors. After receiving some feedback, the team focuses on the final design, which is outlined in a final presentation. In figure 20, a scheme of the timeline of the project is shown.

Figure 23 Levee on the Muni-Pomadze site, photo by Ranee Leung

03 Theoretical Framework

3.1 The 5P's

Nowadays, sustainability is being specified as the 'triple bottom line' consisting of the three P's: People (social sustainability), Planet (ecological sustainability) and Prosperity (economical sustainability) (UN, 2002). To achieve a balanced sustainable design, the cohesion of different disciplines through collaborative and interdisciplinary strategies is crucial. In addition to the 3 P triangle, a fourth and fifth P - Project and Process -has been integrated into the framework by van Dorst and Duijvestein (2004). This enhances the current approach by introducing a better understanding of the spatial quality, diversity and the interactions between the involved stakeholders for the design.

The Project approach addresses the multi-scalar nature of the issue, valuing the regional networks and further consequences of local actions. For example, the water system of the lagoon cannot be managed without looking at the regional network to tackle the pollution at source. Further, for any engineering or spatial design, it is essential to follow a robust analysis and design process by considering all the factors of influence and to visualize the spatial quality which is aimed to be achieved.

Lastly, the Process is very crucial for this research. Considering the difficult institutional context and the complex relations of the stakeholders involved, designing a planning system defining their roles and involvement in the project is essential for its success.

This tetrahedron of sustainable construction theory (figure 24) is one of the core theories that is being used to establish a coherent and holistic outcome for the conservation design of the Muni-Pomadze lagoon. The research aims to provide a solution to optimize the impact on the people with minimal economic input for the larger benefit of the planet. It then proposes a robust process to achieve the projects outlined in the solution.

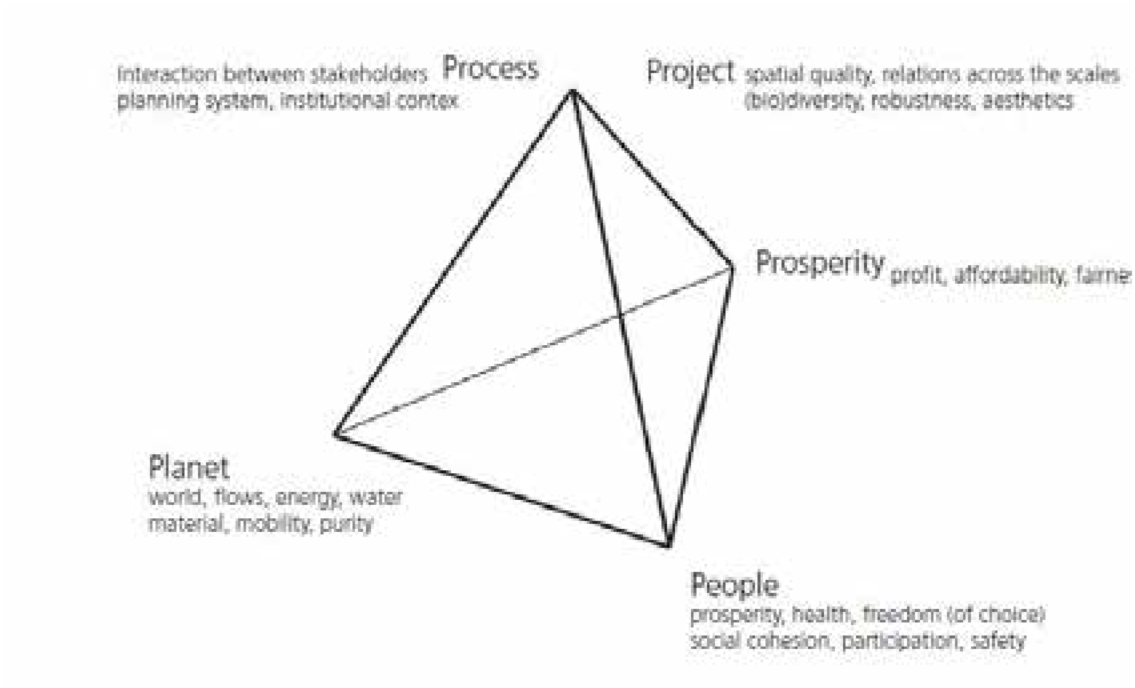


Figure 24 The tetrahedron of sustainable construction (van Dorst and Duijvestein, 2004

3.2 Nature-based Design

In the execution of Building with Nature (BwN) projects, significant benefits can be seen in added coastal protection and ecosystem services. Designing with natural material and natural processes can create cost-effective and resilient solutions that are adaptable to growing pressures such as changing climates, population growth and lack of available living space. The BwN approach is comprised of different ecosystem services and "stimulates a mutual interest and shared commitment of multiple stakeholders, thus creating a multi-functional, sustainable design which adds value for people, profit and planet" ("Building with Nature - Ecoshape - Ecoshape," 2019). In contrast to traditional grey infrastructure, most ecosystems are able to adapt to sea-level rise. ("Building with Nature - Ecoshape - Ecoshape," 2019)

Research has also been gaining traction that the ecosystem engineering concept can contribute to ecological applications in assisting restoration and ecosystem management" ("Building with Nature - Ecoshape - Ecoshape," 2019). A notable amount of coastal defence projects with BwN properties have risen in the recent years, especially in properties related to reducing wave energy, trapping sediments to make species such as mangroves and salt marsh plants.

As Ecoshape (2019) defines, ecosystem engineers (plants or animals) are species that influence their own habitat and form complex modifications to sub-tidal and intertidal zones. In order to successfully integrate these species into coastal protection, specific requirements need to be met for sustainable growth such as hydrodynamic conditions, water quality, light availability and etc. Additional added value from BwN type projects is that it forms a beneficial relationship between natural coastal barriers with forest-forming ecosystems. The implementation of these projects combine intended primary functions with associated "economic and social returns, with biodiversity habitat restoration/conservation" ("Building with Nature - Ecoshape - Ecoshape," 2019)

3.3 Ecosystem Services: Consumption to Participation

The concept of Ecosystem Services (ES) is intended to establish the interdependent relationship between humans and the ecosystems in which they reside (Nicholls, Hutton, Adger, Hanson, Rahman & Salehin, 2018). Humans are often thought of as separate from nature, whereas ES intend to place people as part of the natural environment and therefore should be managed as such. This concept focuses on the range of services that ecosystems may provide to humans, as well as what the system uses to support itself as a whole (Nicholls et. al, 2018). ES can be separated into four general categories (Ronchi, 2018):

- Provisional (ex. food, water, fuel)
- Regulatory (ex. flood and atmospheric regulation)
- Cultural and Recreational (ex. recreational parks and tourism)
- Supporting (ex. nutrient cycling, biodiversity, habitat)

The Muni-Pomadze site provides a number of these services to the local community. The following is a summary of these services:

Regulatory	Supporting	Provisional	Cultural
• Pollution Filteration • Plastics 'collection' • Nutrient Cycling • Water Quality Improvements • Flood Protection and Regulation	• Biodiversity and Habitat Provision (fish, bird, and mammal habitat) • Nutrient Cycling • Atmospheric Regulation	• Fishing Industry • Bush Hunting • Wood Extraction for Fuel • Salt Pans (past use) • Crop Farming • Pasture Grazing • Use of Fresh Water for farms • Shells for building construction	• Effutu Traditional Hunting Grounds • Religious/ Spiritual Meaning to the community • Recreation • Ecotourism

As previously stated, the provisional and cultural benefits which are obtained from the site are beginning to outweigh the site's ability to regulate itself. These issues are magnified by the declining state of the closed lagoon over the past few years. Though we are using the ES concept to understand the practices on the site, it also reinforces the practice of human consumption. ES creates an understanding that humans within an ecosystem have the role of consumption. If humans are part of the natural system, they must also create services to regulate and support the ecosystem. This provides an opportunity for the project to use the ES concept in a different framework. The intent is to define the connections between Regulatory/Supporting Services and Provisional/Cultural Services and to identify solutions where human use of services in this ecosystem can also enhance the quality and performance of the lagoon. This would be a movement towards human participation within the ecosystem, rather that consumption.

Figure 25 Levee on the Muni-Pomadze site, photo by Ranee Leung

04 Investigating the Context

4.1 Spatial Analysis: Connections

Figure 26 Main connections from Winneba and surrounding neighbourhoods to the Muni-Pomadze site

General findings:

- Poorly connected site
- Access primarily for communities
- Pollution through indirect activities like sewage lines and garbage
- Regulation difficult due to multiple access points
- Potential to increase connectivity for regulated use
- Difficult to access the site through four wheeled vehicles

4.2 Spatial Analysis: Land-use

Figure 27 Main connections from Winneba and surrounding neighbourhoods to the Muni-Pomadze site

Land Use/Land Cover	Area (ha)	Percentage
Built up/residential	1197	12.6
Agricultural lands	3084	32.5
Natural vegetation	5038	53.1
Water bodies and floodplain	144	1.5
Salt pans and salt flats	25	0.3
Referenced from Amatekpor,1994		

Built-up Residential
Open/Agricultural Lands
Natural Vegetation
Water Bodies
Floodplain
Salt Pans and Salt Flats

4.3 Spatial Analysis: Wet & Dry Seasonal Boundaries

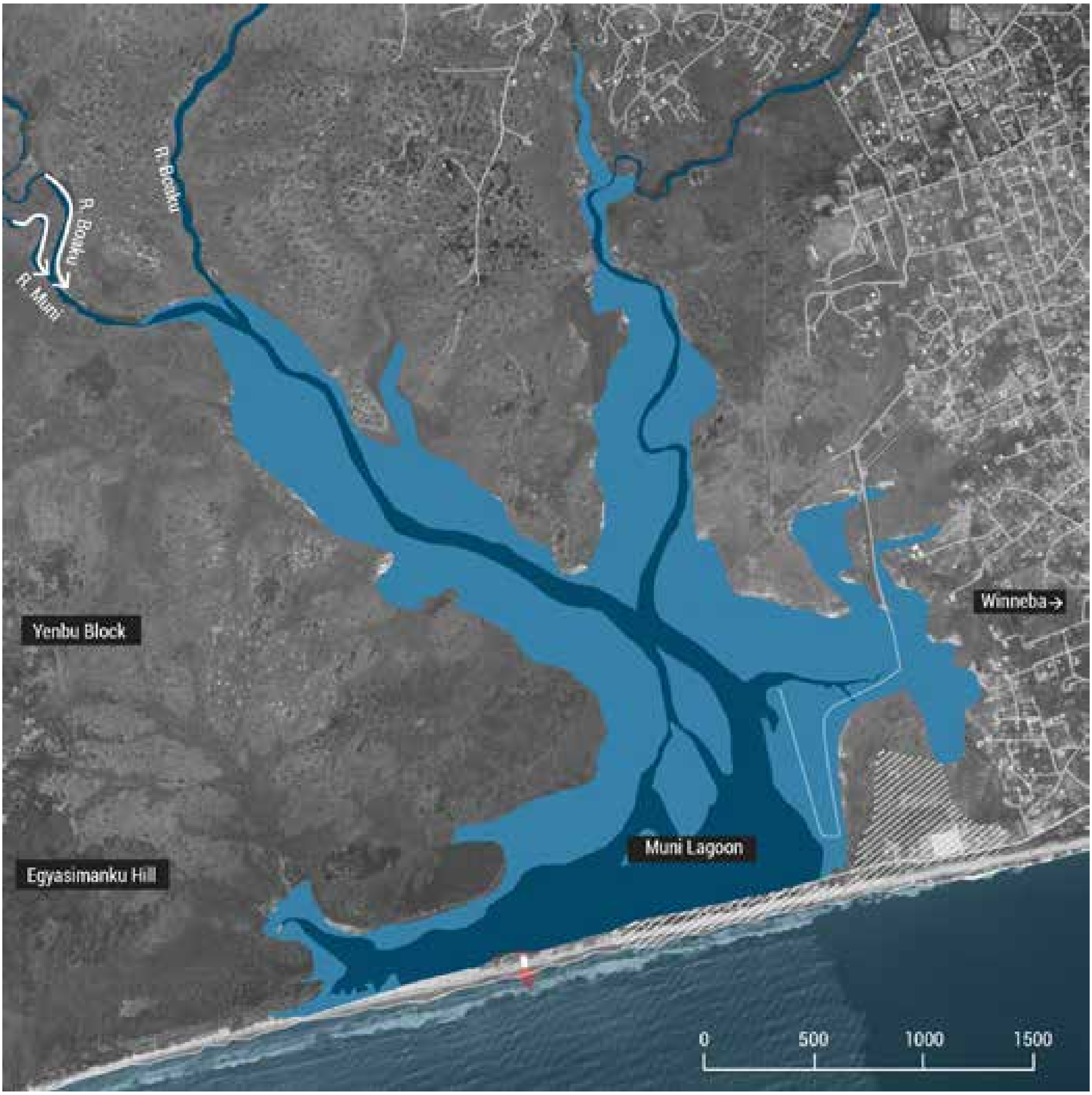
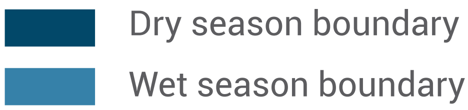


Figure 28 Wet and dry season boundaries

General findings:
The size of the lagoon area varies depending on the season from 100ha in the dry season to over 1000 ha in the wet season.



4.4 Water Network

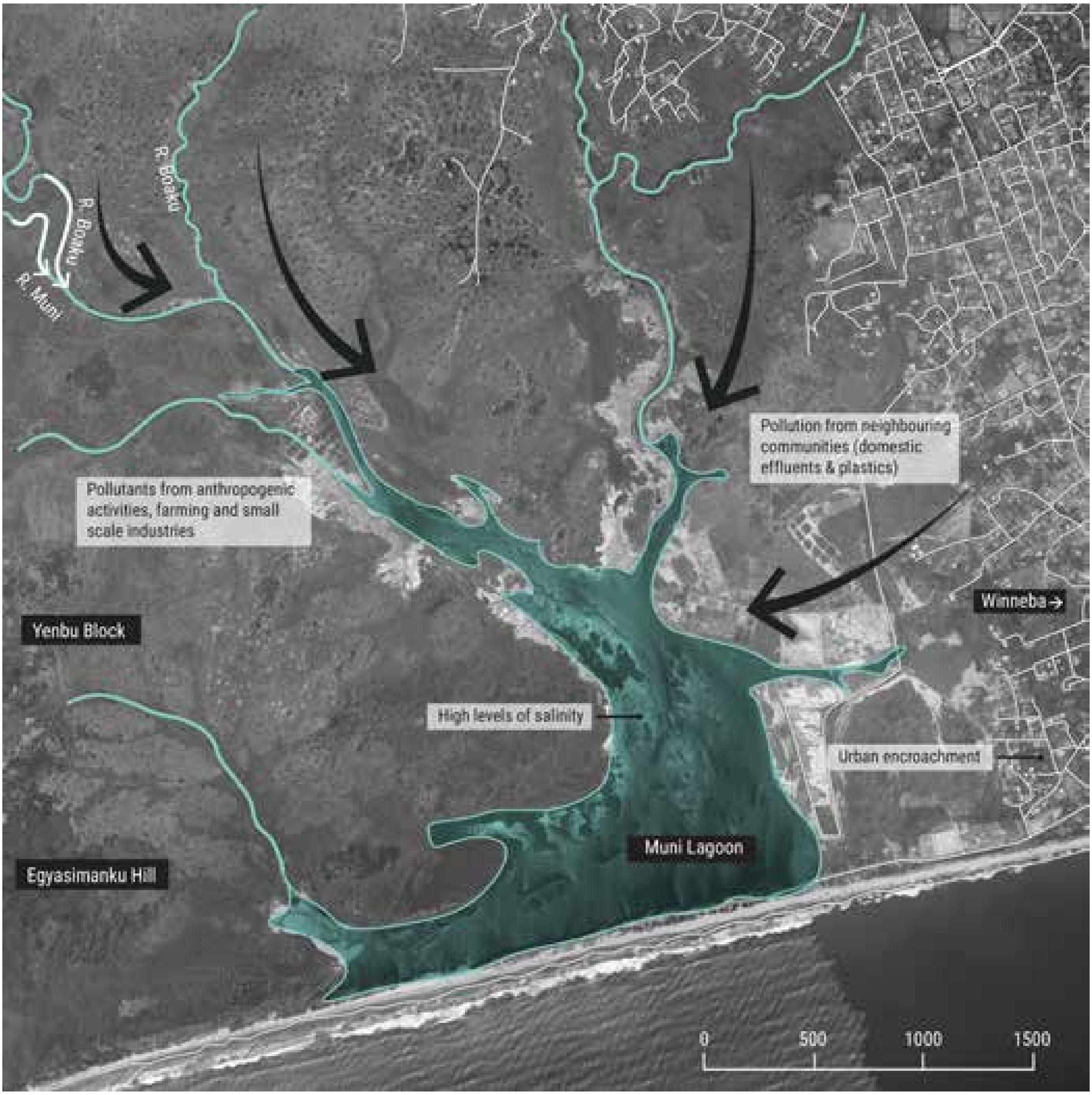


Figure 29 Existing water network

General findings:
The total catchment area accounts for 9500 ha and three main tributaries, the Pratu, Boaku and Muni drain into the Muni Lagoon. The catchment is also bordered by the Yenku Hills and in the south-west by the Egyasimanku Hills.

4.5 Spatial Analysis: Urban Encroachment

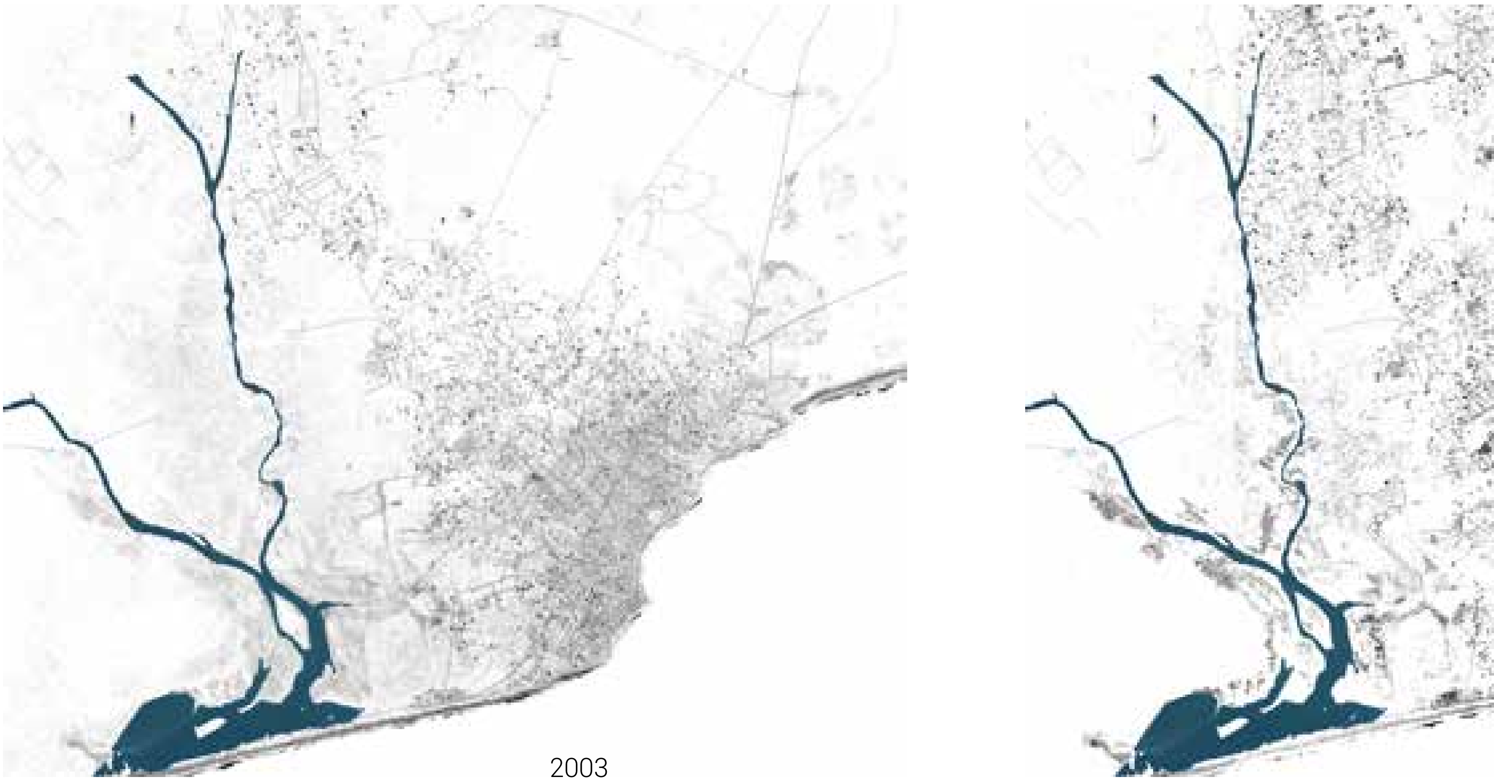


Figure 30 Urban Growth 2003 - 2018 ; Source : Google Earth

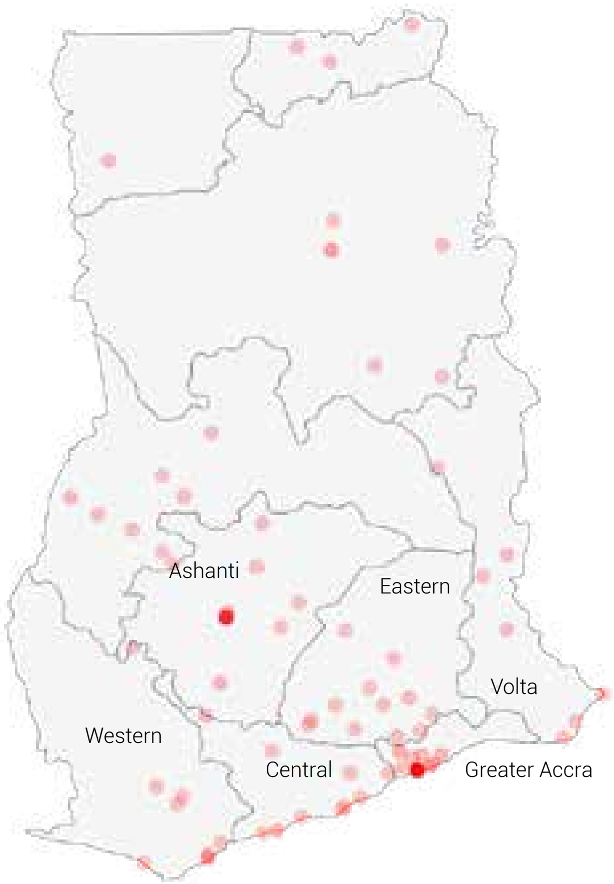
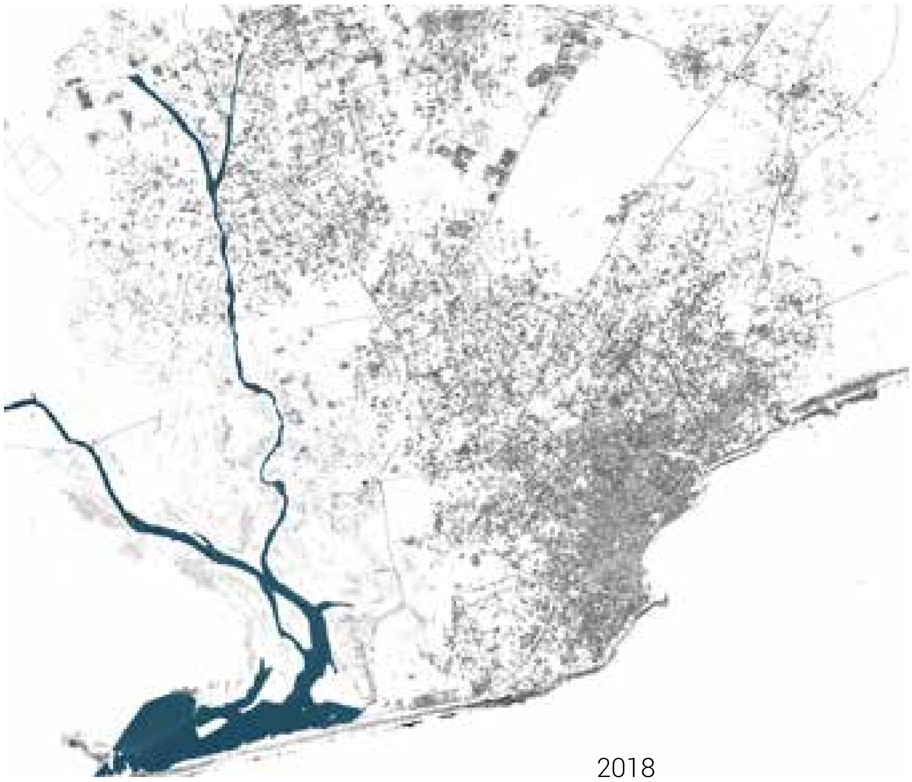


Figure 31 Population Density of cities in Ghana (World Population Review, 2019)

Initial research of the population trends of Ghana revealed an increased concentration in the coastal region of the country. With a higher number of cities and population densities, including the mega city of Accra, the coastal natural ecosystems are faced with an unsustainable amount of pressure. This pressure is visible on the land-use, natural resource management and the socio-economic conditions of the region.

Further, with a constant growth rate of more than 2% per annum, the pressure on these systems is bound to grow in the future. (World Population Review, 2019) The Ghana Statistical Services (2014) identifies the Western and Greater Accra Region to be high in-migration areas. Figure 29 shows the increase in sprawl of the city of Winneba from 2003 to 2019. It is an indication of the increased pressure on the lagoon ecosystem for provisional services.

2013



2018

Figure 32 Illegal construction on the Site (Forestry Commission, 2018)

Figure 33 Law enforcement by the Wildlife Division (Forestry Commission, 2018)

During the site visit it was gathered that a majority of the land in Ghana is owned privately by the Traditional Chiefs or communities. This land ownership model makes it difficult to control the purchase of the protected land of the Ramsar Site and the consequent construction on it. While by law it is prohibited to construct on the floodplains of the Lagoon, the boundaries of the site are not commonly known or acknowledged. Further, the encroachment on the site is not being monitored by the planning and environmental authorities. This has left the Wildlife Division of the Forestry Commission with the primary responsibility of managing the site. The division acts as the enforcement body for the regulations surrounding the site and demolish any up coming structures. Figures 32 and 33 show some site pictures from the Wildlife Commission.

However, due to limited financial and human resources, the enforcement is not as effective.

*These findings are a result of the conversations with the local authorities and other stakeholders.

4.6 Water Quality Analysis

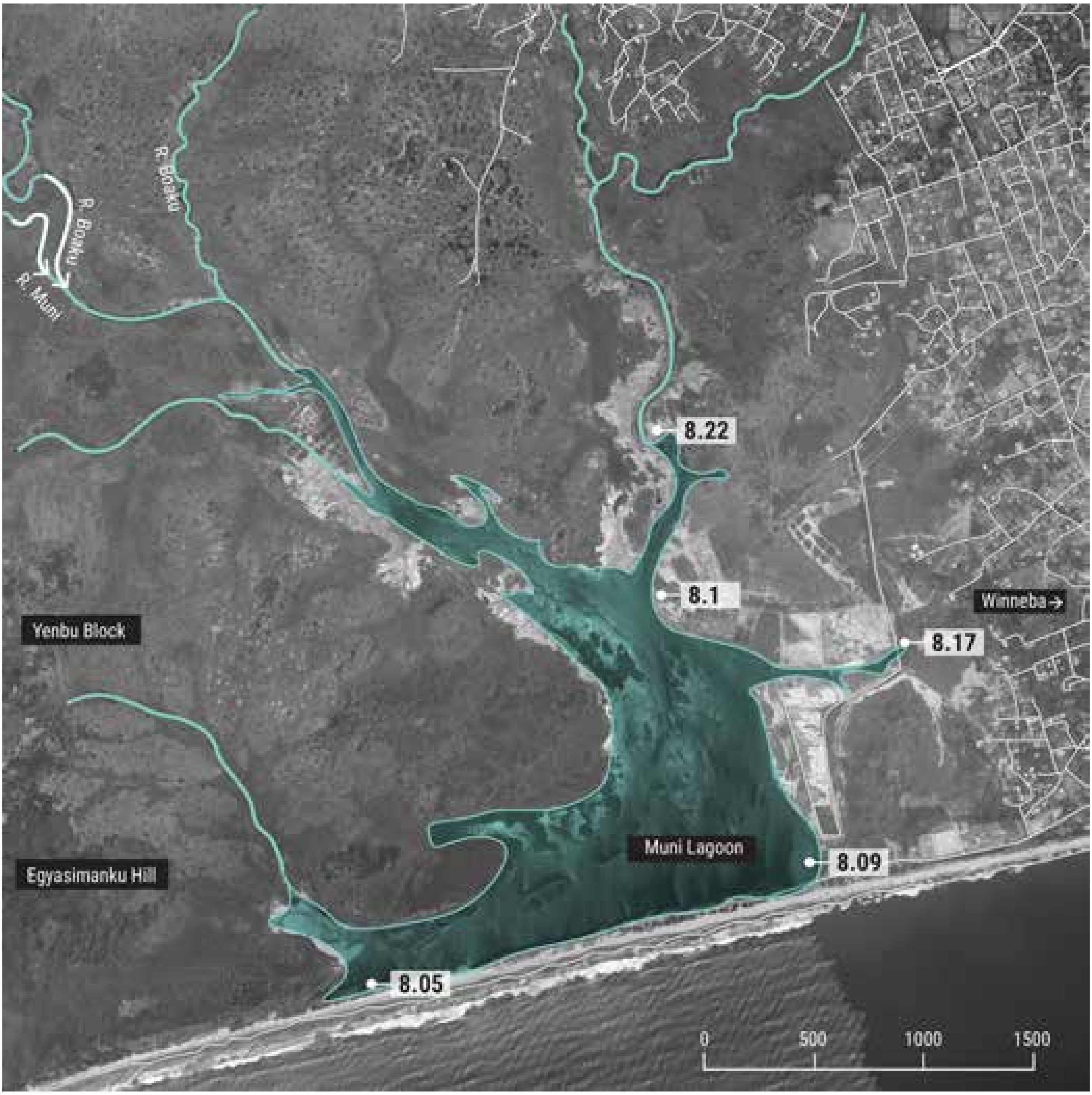


Figure 34 Water quality measurements (pH levels) taken on site during field visit in February 2019.

The water quality was measured at different location in the Muni-Pomadze Lagoon in the dry season. It is based on five water chemical indicators: the salinity, the nitrate concentration, nitrite concentration, pH and the temperature. The water chemical indicators are compared with the water quality standards of EU of surface water to classify whether or not the lagoon water is polluted.

The pH is the indicator for acid or alkaline water. Salinity is the indicator how saline the water is and the nitrate/nitrite concentration is an indicator for the amount of wastewater or pesticides in the surface water. The measurement methods are described in the appendix.

pH
The acidity (pH) of water is within a safe range. The pH of lagoon varies between 8.22 and 8.05 which mean that the water is more alkaline. The north side and the area with the illegal sewage pipes are dealing with a higher rate of pH than in the other measured locations. This could mean that

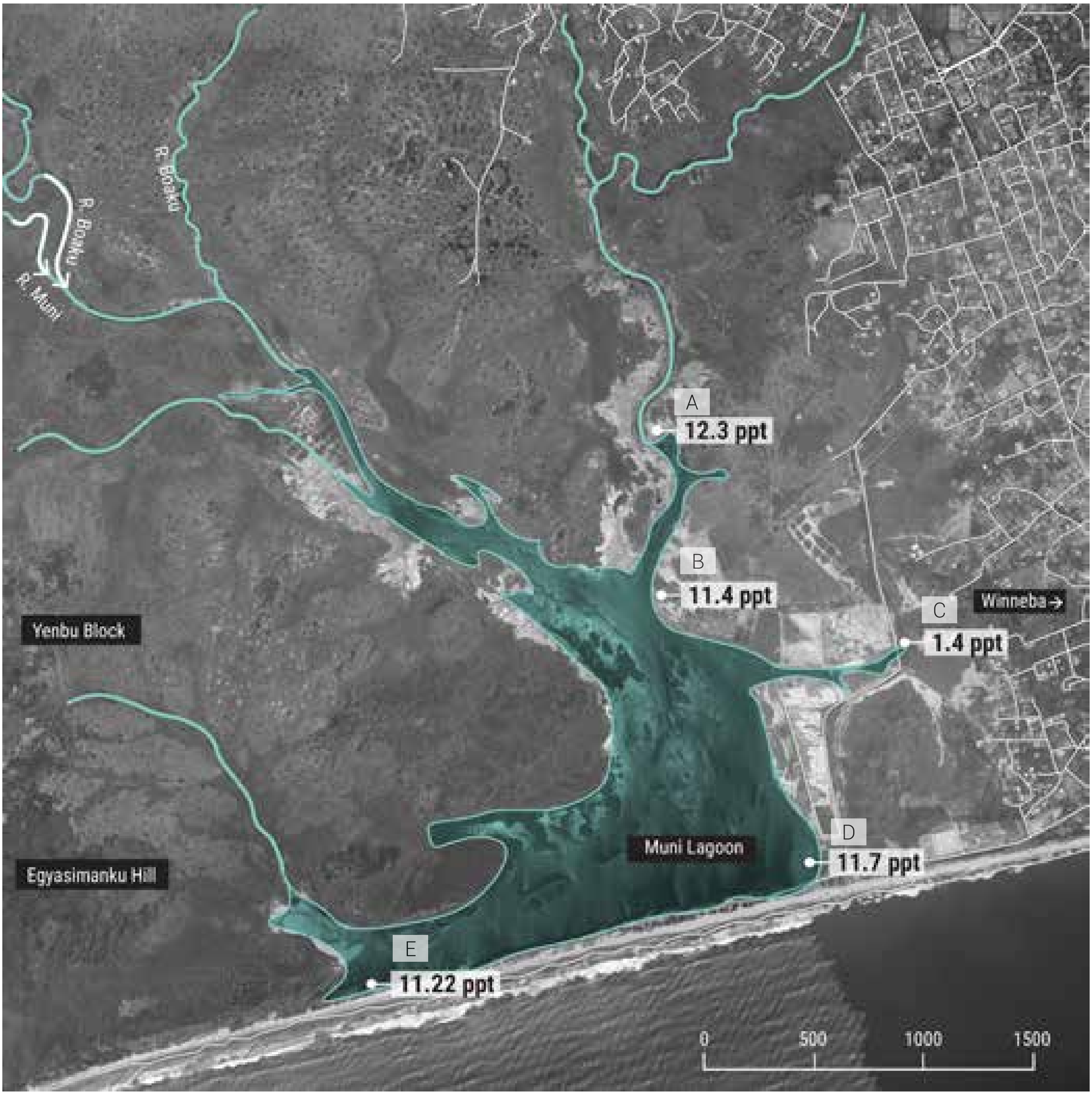


Figure 35 Water quality measurements (pH levels) taken on site during field visit in February 2019.

the water is contaminated by the agriculture and the urban areas surrounding the lagoon. This is subject to change in the rainy season and further research needs to be done. However, the preliminary pH values do not exceed the European water quality standards of 7-9 (Ministerie van Volkshuisvesting, 2009).

Salinity

The Salinity which is based on the measurements in the dry season varies from 12,3 ppt (salt concentration per thousand particles) in the northern area until 11,2 ppt at the south-west point of the lagoon. In the current situation, the northern area has a higher salinity rate. This might be explained by a high evaporation rate in the dry season with less water in this lagoon. This phenomenon is called hyper salinity which is also found in literature (Ntiamoa-baidu, et al., 2000). However, in comparison with the data of 30 years ago (Ntiamoa-baidu, et al., 2000), the salinity is less than in the current situation which could be the result of a closed lagoon. It is caused by a higher rate of freshwater due to precipitation in the wet season. The salinity rate of sea water is above 30 ppt.

Nitrate/Nitrite

In MPL the nitrite and nitrate concentration are the highest in the northern side of the lagoon while the lowest concentration was found in the breach of the lagoon. In normal fresh water, the nitrate concentration should be lower than 50 mg/l. However, the concentration was 50 mg/l at the measurement location (A). This exceeds the water quality standards in comparison with EU Regulations for surface water and could be indicated as contaminated. High concentration of nitrate or nitrite can lead to a decay of biodiversity by inhibiting growth of certain vegetation. This is therefore a threat to biodiversity in the MPL.

Temperature

The temperature in the lagoon water does not vary a lot. It lies between 28°C in the southern area (D) and the northern area 30.3°C. The temperature is higher in the northern side of the lagoon, because the lagoon water is shallow in this part. The temperature exceeds the water quality standards which could threaten the eco-biodiversity in this area.

Location	**Data**	
Measurements of North side of Lagoon (A)		
Salinity (EC)	12.3	Sal
Temperature	30.3	degrees
pH	8.22	
Nitrate	50	ppm
Nitrite	0.15 -0.3	ppm
Measurement at the conjunction of the rivers (B)		
Salinity (EC)	11.4	Sal
pH	8.1	
Temperature	30	degrees
Nitrate	10	ppm
Nitrite	0.3-1	ppm
Measurement before Reed (C)		
Salinity (EC)	1.4	Sal
pH	8.17	
Temperature	30	degrees
Nitrate	30	ppm
Nitrite	0.3	ppm
Measurements at the end of the lagoon (D)		
Salinity (EC)	11.7	Sal
pH	8.09	
Temperature	28.8	degrees
Nitrate	10-20	ppm
Nitrite	10	ppm
Measurements (E)		
Salinity (EC)	11.2	Sal
pH	8.05	
Temperature	30.6	degrees
Nitrate	1	ppm
Nitrite	0-15	ppm

Figure 36 Water quality data from Muni-Pomadze lagoon

4.7 Overview of Tidal Lagoon

The MPL is a coastal water system nourished by salty waters coming from the ocean and fresh waters coming from three rivers. From the coastal engineering perspective, the MPL can be categorized as a wave-dominant system with medium to high wave energy and low mesotidal (Davies & Hayes, 1984), provided that the wave height and the tidal range at the coast of Winneba are both approximately 1.25 meters (Tides Chart, 2019). During the wet season (from March to July and September to November) the lagoon area ascends to 1,000 square kilometres, while during the dry season the area reduces to 100 square kilometres.

According to satellite photographies of the area, the lagoon is subjected to a cyclic process of connection and disconnection from the ocean. During long periods (e.g. decades (Davies, Zhang, & Agyekumhene, 2018)), the lagoon is closed by a sand dune (Figure 37).

However, extreme rainfall during the wet season can lead to an increase of the water levels in the lagoon, causing occasional breaching of the sand dune and creating a tidal inlet (Davies, Zhang, & Agyekumhene, 2018). Consequently, the water from the sea can enter the lagoon by means of a tidal inlet. The natural opening will be progressively sealed in time, due to the accretion in the tidal inlet.

Figure 37 Overview of the MPL with a closed entrance (Google Earth, 2019).

Geomorphological Changes of the Tidal Inlet (2013-2018)

In the figures below (Figure 38 (2)), the development of the tidal inlet at the lagoon is shown, for the period 2013-2018.

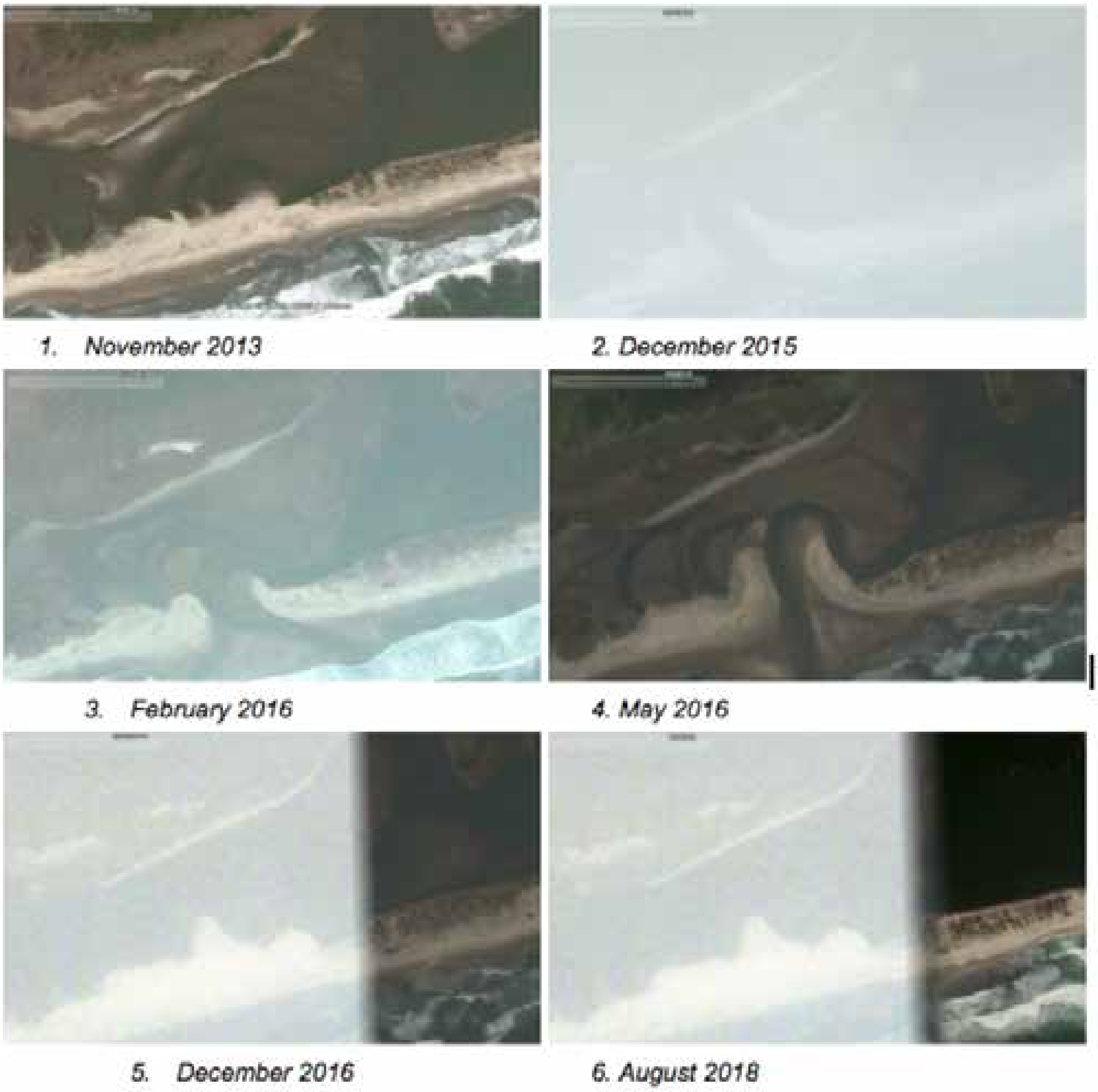


Figure 38 Development of the lagoon opening along the period 2013-2018 (Google Earth, 2019).

From the picture in November 2013 (the lagoon was closed), it is observed that behind the sand dune there is accumulation of sediment oriented to the East Figure 39 (3). The explanation of this might be that during an opening period in the past, accretion was produced inside the lagoon following the mentioned direction due to the direction of the waves.

The sand dune breached as a consequence of extreme rainfall in 2014 and the lagoon remained open for a period of two years (2014-2016). After the opening of the lagoon, accretion of sediment occurred in the tidal inlet, as observed in Figure 39 (3) (second and third picture). Moreover, part of the sediment transported along the coast enters the lagoon. This reduces the amount of sediment nourishing the coast to the East of the tidal inlet, causing erosion in this location (Davies, Zhang, & Agyekumhene, 2018).

The accretion phenomenon inside the lagoon can be observed in the pictures from December 2015 and February 2016 Figure 3. Sand shoals developed at the West and the East side of the tidal inlet.

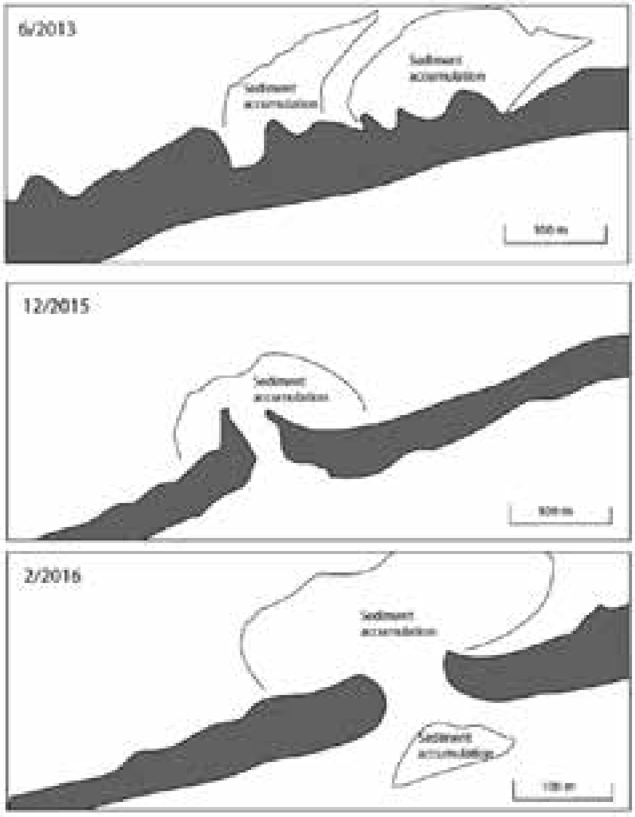


Figure 39 Development of sediment in the opening from 2013-2016 (Davies, Zhang, & Agyekumhene, 2018).

The opening also provokes erosion at the inner side of the sand dune, to the East of the tidal inlet. This sand barrier is stable due to the presence of palm trees with deep roots. The cause of the erosion might be the impact on the barrier of wind waves coming from the West and eddies (a circulation in the water flow) that are generated due to the water inflows (Davies, Zhang, & Agyekumhene, 2018).

Another reason for erosion might be the large flow velocities that occur in the tidal channels formed close to the sand dune, particularly during wet season (Figure 41(2), May 2016). The critical situation in this case happens when the water from the tides and from the heavy rainfalls is evacuated into the sea. Large volumes flow along the channel provoking large flow velocities that might induce erosion, which can be particularly critical for the stability of the sand dune.

In (Figure 41 (4)), the effects of erosion in the sand dune are shown. In the perpendicular direction to the coast, the lagoon side of the stable banks have been eroded, leading to a narrowing of almost 2 meters in 2 years (Davies, Zhang, & Agyekumhene, 2018). As a result of the width reduction of the sand dune, some of the palm trees are toppled. Also, the barrier has developed steep profiles and a berm.

Besides the erosion of the inner part of the sand dune, it is noticed that the location of the natural opening is progressively shifting to the East. While the Western limit of the tidal inlet accretes, the Eastern part erodes. This leads to a progressive migration of the opening in time. As shown in Figure 41 (5), between July 2014 and July 2016 the tidal inlet has migrated almost 185 meters.

Figure 40 Erosion at the inner side of the lagoon

Figure 41 Shifting of the tidal inlet to the East (Davies, Zhang, & Agyekumhene, 2018).

4.8 Mangrove Analysis

Current Mangroves Growth Conditions on Site

Two types of mangroves can be found in Muni-Pomadze Lagoon: black mangrove (Avicennia Germinans) and red mangroves (Rhizophora racemosa). The black mangrove are mainly located at coastal region while red mangroves are more located at the inland of the MPL. These were naturally found in the area but have now degraded to becoming an endangered species.

Possible Reasons of Mangroves Degradation

Healthy mangroves are an important precondition of all aspects of lagoon protection. Sufficient sediment and the right mix of brackish water supply and connections with other ecosystem are important factors for the mangrove ecosystem (Spalding et.al., 2014). Conversely, the degradation of water quality and overexploitation threaten the mangrove habitat. In Muni-Pomadze Lagoon, red mangroves are decaying, which is a result of poor water quality, destruction of resources and livestock farming. Cattle grazing is a threat for the growth of mangrove species which occur in this MPL. The decline of mangroves further changes the sediment pattern in MPL. Because mangroves play a crucial role in catching the sediment and stabilizing the soil. That could be a factor resulting in the erosion happening at the south side of lagoon.

Conditions of Mangrove Growth

- Black Mangrove (Avencinna Germinans)
- Size: It can reach 3-15 m high.
- Habitat: It grows well on a sand and mud beaches and shores that exposed to air at low tide and under water at high tide.
- Soil: It tolerates heat (but require moisture), poorly drained water, neutral to alkaline soils.
- Temperature: 10°C - 35 °C
- Salinity: It could grow in the exposure to both aerial and soil salinity, and fresh water. They can also can survive under high saline conditions.
- pH: 6 - 7.5

(Nguyen et.al,2015 & Arnold, 2013)

Red Mangrove (Rhizophora racemosa)

- Size: It can reach 30–50m in height, although commonly will grow 5–8 m.
- Habitat: The intertidal wetland zone, with variable rainfall and elevation of 0–6 m elevation between mean sea level and highest tides. They have an optimal temperature condition from 20-30 Celsius degrees and a pH limit between 6-8.5.

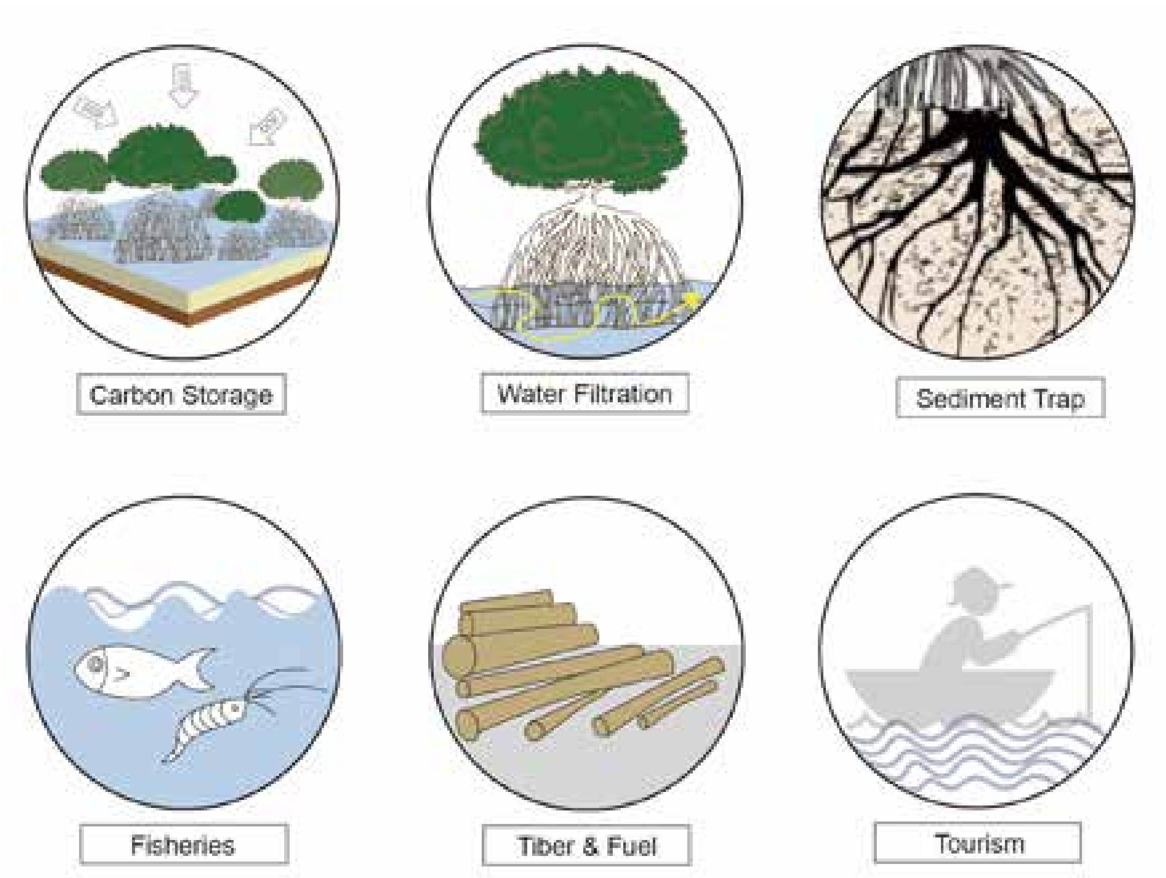


Figure 42 Benefits of Mangroves Restoration (Adapted from Spalding et al., 2014)

Figure 43 Existing condition of the mangroves (Toan, 2019)

Figure 44 Ailing Mangroves (Danyan Lui, 2019)

- Soil: Fine clay, black mud sediments with relatively high loads of organic carbon. Sites with aerobic sediments consisting of fine sands to coarse stones and rocks, and coral ramparts. Salinity: The plants survive well in fresh water and grow best in saline soils. The optimal salinity range is 8–26 ppt (parts per thousand), compared with approximately 34–36 ppt for seawater (Allen & Duke 2006).

The growth conditions for the two mangroves are analysed in order to gain insight about restoring those two species in the lagoon. The Rhizophora species have an optimal temperature condition from 20-30 °C degrees and a pH limit between 6-8.5. Besides that, the optimal soil salinity rate for growth is 8-26 ppt (Duke N.C and Allen J.A., 2016). In comparison with the water quality data, the salinity and the pH are within the limits for growth when it is assumed that the soil salinity is the same as the salinity of the water. However, the temperature in Northern side of the lagoon and nearby the breach exceed the temperature limits.

The Avicennia species can survive under high saline conditions. The growth of the seedlings are suitable for water which has the same salinity range of 25 until 75 procent seawater (Nguyen et.al, 2015) roughly 7.5 - 22.5 ppt. Seawater has a salinity of 30 - 50 ppt. Furthermore, the salinity in the MPL is in the range of 11-12. Hence, the salinity does not exhibit the growth of Avicennia Germinans. Furthermore, the Muni-Pomadze lagoon water temperature is also in the range of 10°C - 35 °C. The pH of the Muni Pomadze lagoon of 8.05 - 8.22 exceed the limit for Avicennia Germinans to grow, because the pH tolerance for this species is limited between 6 - 7.5. (FAO,1992). Therefore, this could be the problem.

Restoration of Mangroves

To restore the ecosystem of Muni-Pomadze Lagoon, the priority is to restore the mangroves. Moreover, the restoration of mangroves will flourish the tourism, fisheries, timber & fuel, water filtration, sediment trap and carbon storage(Spalding et.al., 2014).

The mangroves have an important role in the ecological environment of the MPL. Those mangroves provide a habitat for many wildlife species such as birds and fishes. However, it was observed that the mangroves are decaying. On the one hand, it is caused by social factors such as agricultural practices which lead to overgrazing. On the other hand, it is caused by the poor water quality of the MPL which inhibit the growth of the mangroves. Yet, the salinity does not have an impact on the growth of Avencinna Germinans and Rhizophora Racemosa. The temperature and the pH of the Muni Pomadze lagoon might be the reason why those mangroves are decaying by comparing those parameters with the suitable growth range of the mangroves. Therefore, the MPL water should have an optimal water quality to preserve and protect those vegetation in this ecological environment. This could be done by implementing nature based solutions which tackle the sources of pollution such as the urban waste dumping and opening the lagoon. Opening the lagoon will have an effect of the amount of nutrients and the water temperature in the lagoon. The maximum seawater temperature is 28.4 °C (Global Sea Temperatures, 2019) which is lower than the temperature in the lagoon. However, the effects on opening the lagoon should be further analysed.

4.9 COMMUNITY AND GOVERNANCE

Stakeholder Analysis

A stakeholder is an individual or a group that has an interest, is affected by or has the power to influence the development of a project. A thorough stakeholder analysis is important to achieve an implementable strategy of the lagoon's conservation by taking into account the interest of all the involved stakeholders and their expected added value for the Muni-Pomadze site. The outcome of the stakeholder analysis is the elaboration of a list of requirements, also called boundary conditions of the design. Any design should accomplish all the mentioned requirements to be considered as a final proposal. For this research, stakeholders were identified during the field visit and then classified on the basis of their position with respect to the conservation of the lagoon.

Depending on their position with respect to the project, the stakeholders can be classified as internal or external stakeholders. While internal stakeholders take active part in the elaboration of a list of requirements for the design, the external stakeholders can influence the internal stakeholders in their demands (Winch, 2010). Further, their overall goals as well as their aspirations with respect to the site were documented. They were then aligned according to their power to influence the projects on the site to inform the implementation strategy for the project.

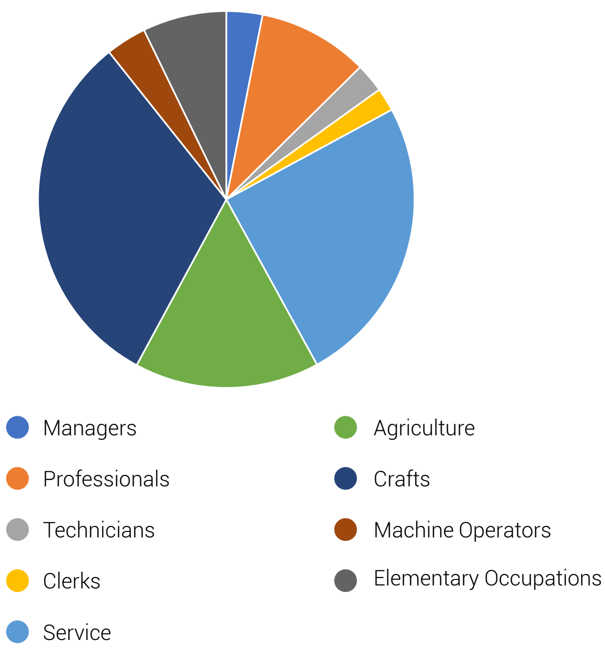
Workshops were dedicated to understanding the dynamics between the stakeholders from the local people. The analysis involved identifying the conflicts and similarities in the interests. Understanding the power dynamics helped in identifying the actions which had negative or positive effects on the ecosystem Further, an attempt was made to address these through design to create synergies, accommodating the interests of all the parties.

The stakeholder dynamics for the MPL was found to be drastically different from the western norms. A power dynamic between the government agencies and traditional governance systems was found to be unique. While the lagoon was protected and laws were enforced by the government agencies like the Wildlife Division (Ministry of Environment), the land ownership lies with the traditional chiefs. This gives them the power to control the land and its activities and often leads to unwarranted construction on the floodplains of the lagoon.

The chiefs present in the Effutu Municipality concentrate a large power, due to their cultural and historical importance. Unfortunately, the position towards the lagoon management strategies may differ amongst the different tribes. The mediation between tribes should be facilitated by the local governmental authorities, which should inform about the about the importance of the lagoon and promote a mutual agreement between the parties involved for the project.

The authorities should keep a permanent contact with the knowledge groups from the University, in order to receive an adequate assessment of the possibilities and consequences of every project alternative. On the other hand, the governmental authorities should promote the law enforcement, to guarantee the positive results of the new lagoon management strategy.

In figure 45, a description of the stakeholders of the MPL is given, together with their objectives related to the lagoon and their power of influence in the lagoon management.



Stakeholder	Function	Objectives related to the lagoon/ Impact	Power/Influence
Traditional Council/Chief	Managing the livelihood of its community and providing quality of life + conserve culture, financial benefits, development for people	1. Maintain power over the lagoon/ Decide opening or closing	Make local laws, land title
Elders: fishermen chief, fishnet owner, youth organization board	Managing the fishing community and finding jobs for the youth	Providing a source of food/income; encourage youth to go fishing/job application around lagoon	
Fishermen	Earn money from fish to receive income	open estuary to get more biodiversity and range of fish species/ waste, fish population	Producer of food, labor power, democratic power
Farmers (crop & cattle)	Produce good crop for consumption and sale	Irrigation/spring water. Using fertilizer, pesticide, crops to grow in catchment area; grass for cow/ influence the upper water flow, pollution	Producer of food, land title and democratic power
Inhabitants for Akosua village & Bewadze (feet of the lagoon/rivers)	Being safe from flooding; living happily with their neighbours; having all the resources they need	Hunting culture;	
Schools	Giving education	Flooding area of lagoon - want safety and accessibility	
Private Landowners	Build infrastructure on the land for use / commerce	To have hard infrastructure like loads and services to expand on the lagoon land	
Government Enforcement Agency (Andy's team)	Protect the area so that nobody can establish any built infrastructure	to maintain the vegetation/habitat for animals	
Citizens of the city	Higher quality of life, safety and security, decreased flood risk, Water security	pollution, garbage, expansion into the lagoon land	Consumer power, democratic power

Figure 45 Internal stakeholders

- Government or Governing bodies
- Private Investors
- Citizens
- Civil Society and NGO's

Stakeholder	Function	Objectives related to the lagoon/ Impact	Power/Influence
Ministry of Environment : Forestry Commission	Preservation of the ecosystem, Natural resource management and planning		To make laws and guidelines and law enforcement + funding
Wildlife Division	protect vulnerable species (mangrove, fish, birds, & turtles) form being endangered	1. to continue to monitor illegal firewood collection 2. To continue to monitor/check/ specify fishing net standards and prevent chemical usage for fishing 3. has conflict with local people	Law enforcement/ regulations
University of Winneba	To generate knowledge and educate	1. to conserve biodiversity 2. Increase planting mangrove in lagoon 3. continue collaborations with organizations & NGOs 4. continue assisting in educating residents 5. patronization 6. not openly sharing data from research conducted	Knowledge generating and recommendation +influence + data collection
NGO : Aroacha	To clean the coast and support the conservation of natural resources	Temporary solution: 1. Provide alternative livelihoods 2. Assist in micro-financing	Local collaboration, stakeholder working and funding [ngo's)
NGO : Friends of the earth	Environmental conservation	Temporary solution: 1. continue assisting in planting mangroves 2. Continue coastal cleaning practices	Local collaboration, stakeholder working and funding [ngo's)
Municipality of Winneba	To protect and conserve wetland, increase tourism (birdwatching) and continue coordination amongst communities and organizations	1. eco-tourism 2. maintain and enforcing by-laws 3. Create land-use specific to wetlands and preventing encroachment 4. manage/guide urbanisation	Bylaws, Development Decision and enforcement
Ramsar Convention for International Wetlands	To protect and conserve biodiversity	(same as goals) - can also google this	Internationally protect the lagoon by classification
Environmental Protection Agency	To protect the environment - ensure a regulated environment to understand the environmental impacts	1. Continue regulating the impacts on the environment with proposed infrastructure 2. Assess impacts through the Environmental Impact Assessment (EIA) - any new construction	
Inhabitants of Winneba	Increase amount of residents and job opportunities; also make a profit from fishing and tourism; Being able to participate in the process	1. Continue to make a living, profit, benefit and grow with the lagoon	

Swedeu Township	Want to occasionally have options for leisure and relaxation (tourists)	1. Requirement of safe residents and services within vicinity; want to acquire a relaxing place for a holiday and sightseeing	
Ghana Water Company	Provide water services to communities and settlements	Make potable water accessible	
Electricity Ghana Company	Provide electricity services	Same as goal	
Ghana Tourism Authority	To enhance tourism potential and shaping the image of the area	1. Access and find opportunities in tourism potential 2. Collaborate with the municipality 3. Continue to survey the site to develop (waiting for the local government to send funds; but everything else has been completed)	
Ocean's Club	Want to develop an attractive and beautiful location for tourists	The group is ready to develop a part of the lagoon (Mankwaadze Hill) but are awaiting for people to sign documents	
Land Commission	Regulate land use	don't understand complexity	Regulation

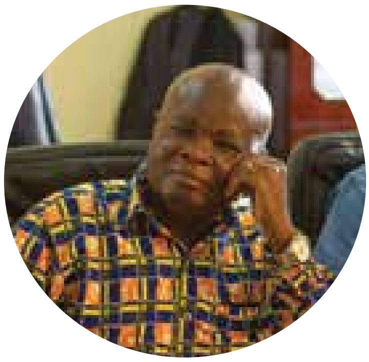
Figure 46 External stakeholders

Government or Governing bodies

Private Investors

Citizens

Civil Society and NGO's

INTERNAL		EXTERNAL	
TRADITIONAL SYSTEMS	 	STATE	
		ENFORCEMENT	
LIVELIHOODS		KNOWLEDGE	
PEOPLE		PEOPLE	

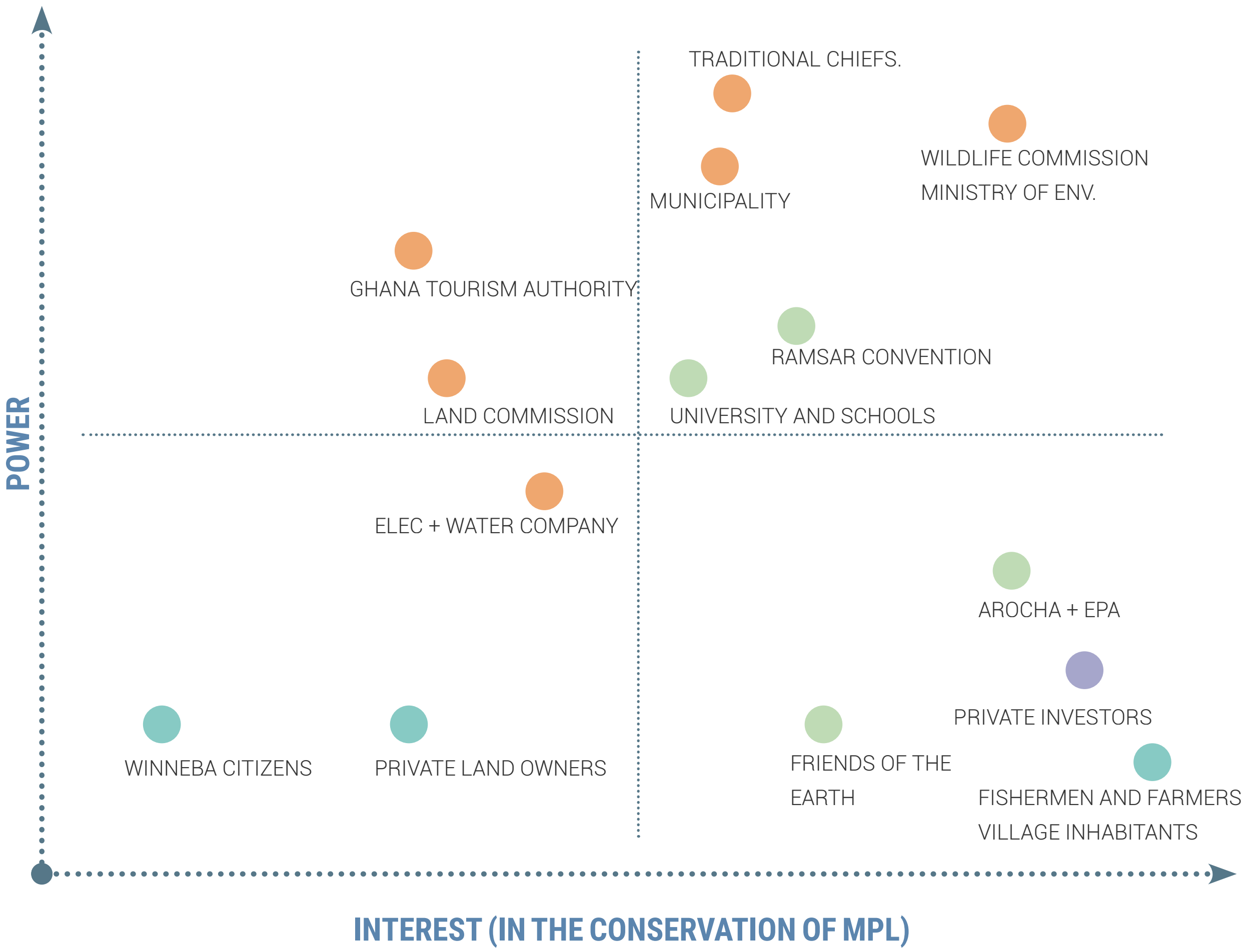


Figure 47 Power Interest Grid

The power-interest grid represents the current top-down approach to conservation for the Muni Lagoon. While due to their direct dependence the bordering communities like the fishermen have the highest interest in the conservation of the lagoon, their power to make the change is very little.. Similarly, the current enforcement based approach to limit the livelihood and illegal activities on site may not be the only method to manage the area. The communities need to be empowered to own the site and feel responsible for its conservation and health.

It would be ideal to utilize the power of the municipality and traditional chiefs to mobilize the local population for such initiatives. More power to the high interest civil society organisations is also instrumental for adequate on ground implementation. Additionally, in order to attract much needed revenue for the site, private investors should be given incentives to invest in eco-tourism and regulatory activities which enhance the supportive ecosystem services of the lagoon.

Community Value

Winneba, traditionally called Simpa, has many traditions embedded in the ecosystem of the Lagoon. The most important being the Aboakyer Festival which is a competition in the warrior clan to catch a live deer with bare hands for the King or the Traditional supreme. Due to poaching activities, the festival has been unsuccessful due to the low deer population. The community has since decided to protect the Sacre Forest area to restore the biodiversity.

Traditionally the communities are known to be living in harmony with nature. Such practices make the lagoon of high cultural value for the communities and give a sense of ownership to the people. It is essential to document all the practices and the traditional knowledge possessed by the people and incorporate them in the conservation plans for the site. This will not only give a more sustainable conservation model but also preserve the intangible cultural values of the area.

4.10 SWOT Analysis

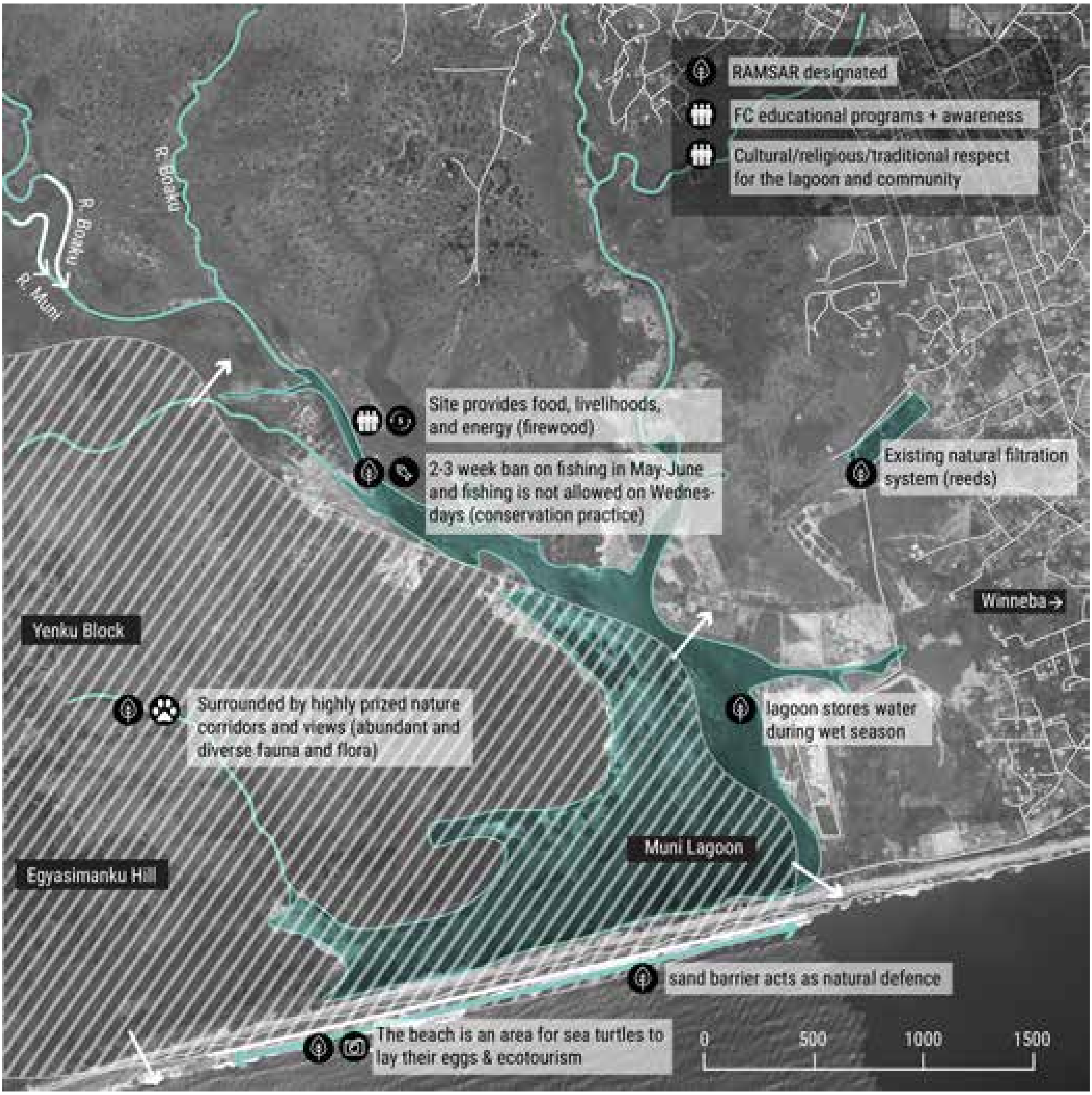


Figure 48 Strengths within the MPL

- Fishing Affected
- Biodiversity/Ecology Affected
- Tourism
- Prosperity
- Fauna Affected
- People/Communities Affected

Strengths
Planet • The beach is an area where turtles lay eggs • A lagoon creates an environment for special plants and species • Natural filtration system: the reeds provide a natural filtration system and the forestry commission pays special attention to preserving the current state because it lowers the chemical levels • Lagoon stores water during the wet season **People** • Aboakyir festival (hunting) • Cultural/religious/traditional respect for the lagoon and community **Prosperity** • Provides food • Provides energy (wood) • Birds and turtles - tourism • Farming **Process** • The Forestry Commission has several education programs in place ie. Replanting of trees, mangroves, construction "chorkor" fish smoking kilns, rehabilitating mangrove stands (they have nursed and planted over 10,000 mangroves) (Ghana, 2016) • The local population are aware of the situation and willing to protect the lagoon area • Legal practices • 2-3 week ban on fishing in May-June and fishing is not allowed on Wednesdays (conservation practice) **Project** • Nature (beautiful area, wildlife) • There are existing land uses in place for preservation • RAMSAR designated • Barrier acts as a natural flood control

Figure 49 SWOT analysis

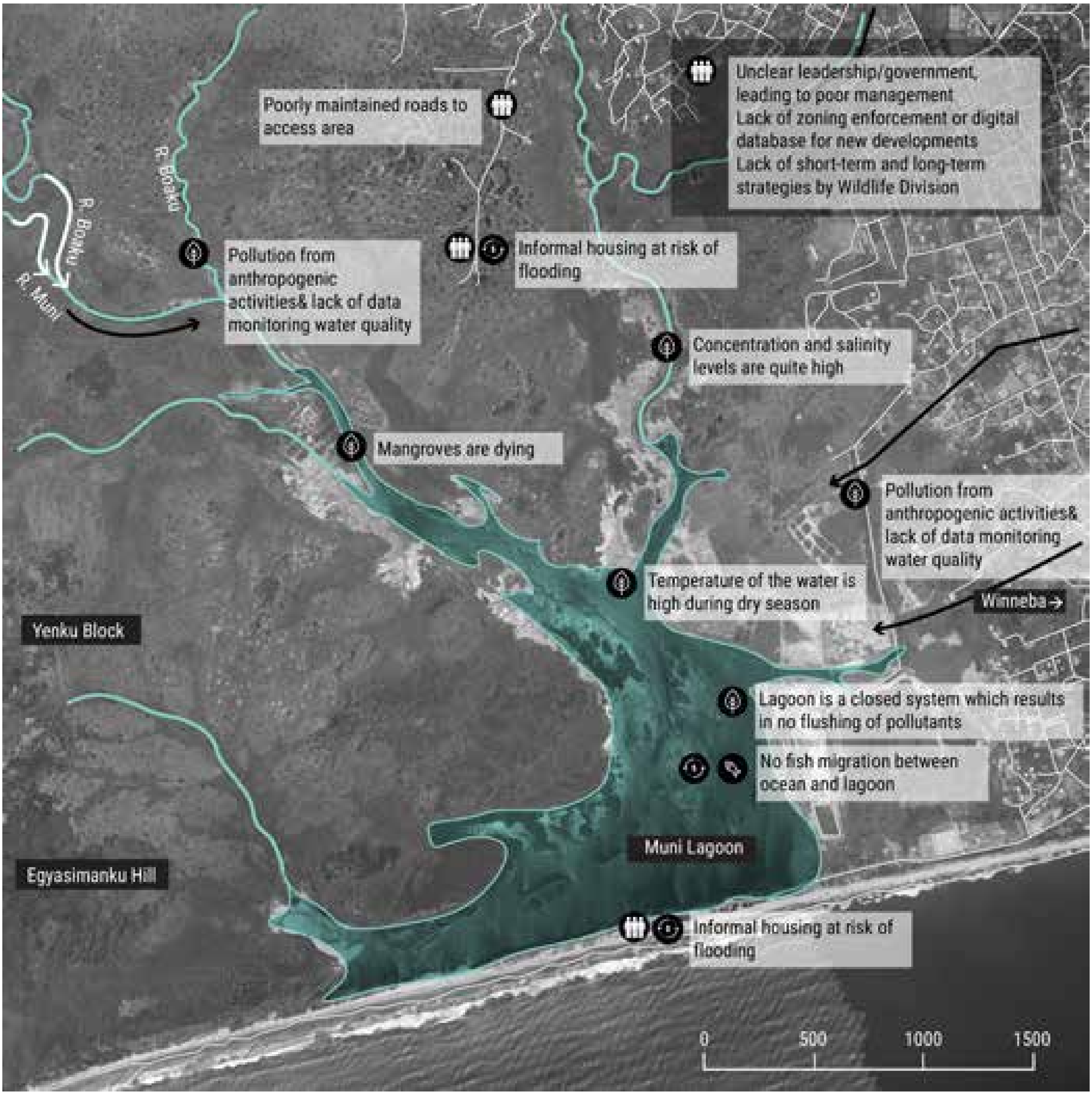


Figure 50 Weaknesses within the MPL

Fishing Affected

Biodiversity/Ecology Affected

Prosperity

People/Communities Affected

Weaknesses
Planet • In a closed system there are: stable nutrients, no flushing of pollutants, less shellfish • Temperature of the water is high during dry season • No fish migration between ocean and lagoon • Concentration and salinity levels are quite high • Mangroves are dying - also decreasing the biodiversity in the area, lack of seawater mixing and lack of data on what conditions are needed for the mangroves to thrive • Pollution • Adjacent communities are dumping their waste into the lagoon to claim back land • Farmers from the north are chemically polluting the water • The wastewater from Winneba flows partly into the lagoon **People** • The communities adjacent to the lagoon still directly dump their waste into the lagoon. They then cover it with sand to redeem back "lost territory". This is also where most of the plastic pollution comes from. Hard to change the mentality of the people. **Prosperity** • Decreasing fish population for fishermen • Informal housing (in catchment area) at risk for flooding **Process** • Decision-making (who has the control over the lagoon) • Lack of zoning enforcement or digital database for new developments • Lack of short-term and long-term strategies by Wildlife Division • Unclear leadership/government is leading to poor management (illegal fishing etc) **Project** • Lack of data/monitoring of water quality • Accessibility: lack of poorly maintained roads

Figure 51 SWOT analysis

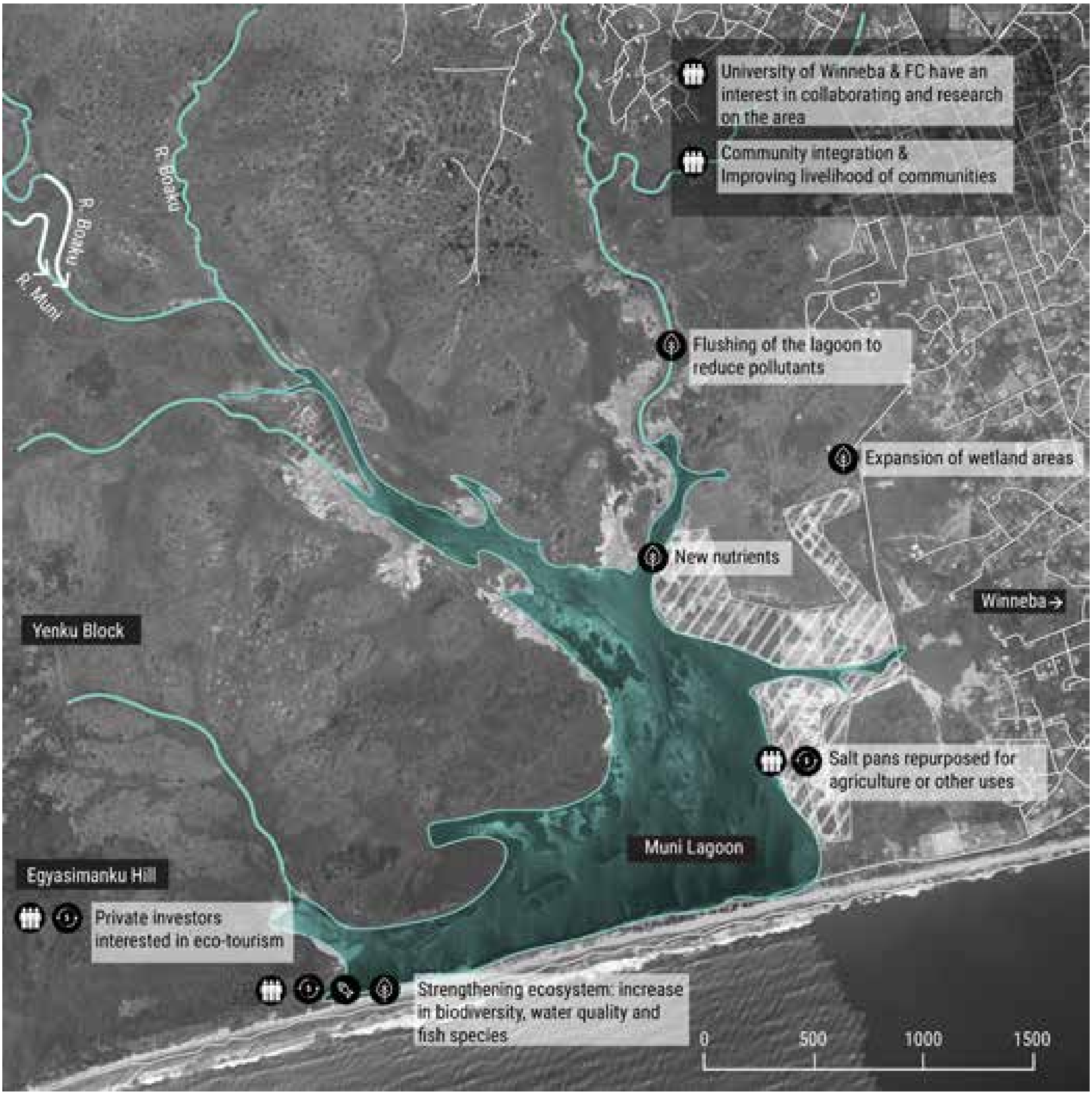


Figure 52 Opportunities within the MPL

- Fishing Affected
- Biodiversity/Ecology Affected
- Prosperity
- People/Communities Affected

Opportunities
Planet • Strengthening ecosystem: increase in biodiversity, water quality and fish species • Flushing the lagoon during wet season > reduce pollutants • New nutrients **People** • Improving livelihood of communities **Prosperity** • Salt pans can be re-used for agricultural purposes or other uses • Job opportunities • Open lagoon attracts large fish from deeper offshore waters • Can extract nutrients from chemical waste • Investors already have interest and money for the mountain (Eco-tourism) **Process** • University of Winneba & FC have an interest in collaborating and research on the area • Community integration **Project** • "The main advantage of a tidal lagoon is that it has less environmental impact than tidal barrages because they don't block the entire flow of water into and out of a given area. They can also more easily be combined with intermittent pumps that use renewable energy to raise the level of water within the lagoon higher." (Tidalpower.co.uk, 2013-2015) • Expanding the natural filters (reeds)

Figure 53 SWOT analysis

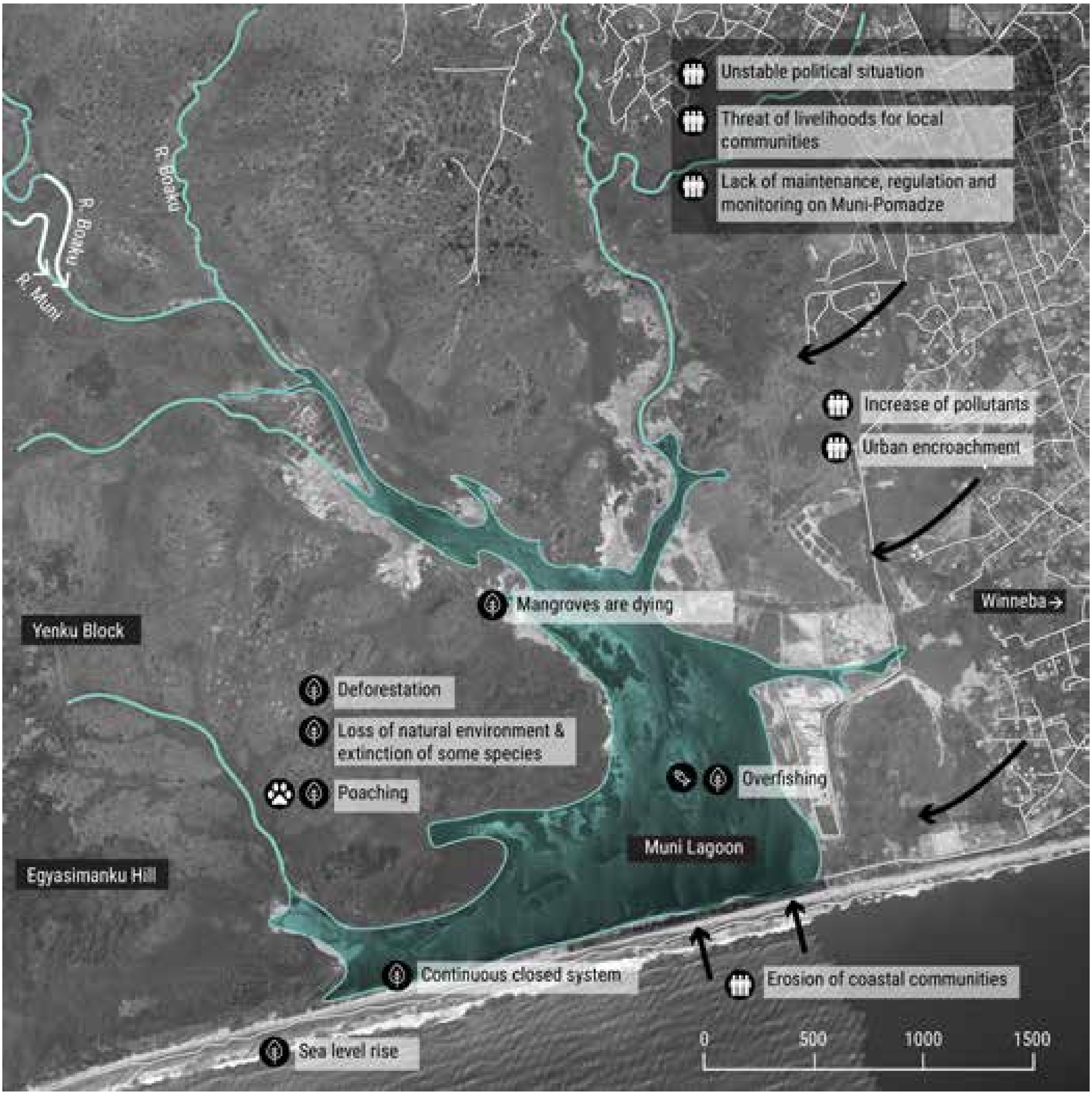


Figure 54 Threats within the MPL

Fishing Affected

Biodiversity/Ecology Affected

Profit

Fauna Affected

People/Communities Affected

Threats
Planet • Continuous closed system: • The mangroves are dying because of poor water quality • Loss of natural environment • Deforestation/illegal wood cutting • Poaching • Extinction of some species **People** • Population growth • Increase in pollutants and waste water • Dumping of wastewater and plastics • Lack of opportunities and/or alternatives for local communities • Erosion of coastal communities results in the displacement of people **Prosperity** • Flooding • Decline of biodiversity • Overfishing **Process** • Unstable political situation **Project** • Urban encroachment/urbanization • Lack of maintenance • Changing climate • Sea level rise

Figure 55 SWOT analysis

After having analysed the involved stakeholders, the next step is analysing the project itself by using the SWOT methodology. SWOT stands for strengths, weaknesses, opportunities and threats (table 48-50). On the one hand, this framework is a suitable approach to assess the current situation of the Muni-Pomadze lagoon, while on the other hand, it is important to be able to manage the threats and opportunities on the project. These threats are seen as risks, which may affect the accomplishment of the project goal. Furthermore, finding out the possible opportunities is helpful to proceed with the project mission while creating value and satisfying the interests of the stakeholders.

From the SWOT analysis it can be concluded that if no urgent action is being taken to preserve and conserve the Muni-Pomadze lagoon, the actual fauna and flora may not last longer. On the other hand, this circumstance may lead to other future problems within the living community. Hence, the existing dilemma about opening or closing the lagoon must be resolved between the stakeholders. Taking all these outcomes into consideration, a strategy is designed to mitigate the undesired findings resulting from the SWOT analysis.

Figure 56 Levee on the Muni-Pomadze site, photo by Ranee Leung

05 Case Studies

Figure 57 East Kolkata Wetlands bordering the city of Kolkata ; Own Image

Figure 58 View of the wetlands ; Source : https://www.telegraphindia.com/states/west-bengal/plea-to-regularise-east-calcutta-wetlands-road/cid/1672879

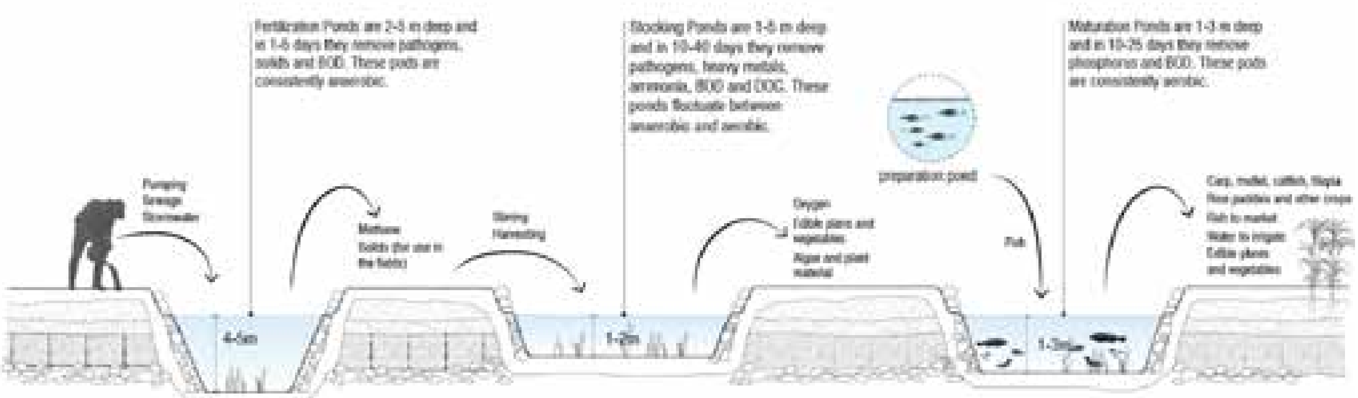


Figure 59 Working of the Wetlands ; Source : Illustration by Despo Thoma ; Source : https://www.studiorede.com/india-wasterwater-wetlands

5.1 East Kolkata Wetlands

The Eastern Kolkata Wetlands (EKW) are a unique and perfect example of a mutually beneficial human-nature relationship. Managed by local communities since the 1960's. the EKW are the largest organic wastewater treatment systems in the world. Classified as a Ramsar Site in 2002, the site is a community run and managed system which personifies all the principles of circularity and conservation through ecosystem services. The 12,500 hectare wetland comprises of 254 sewage fed fisheries, agricultural plots and solid waste farms. Initially a buffer zone, the area was used as a dump-site for the city's waste. The communities slowly developed the practice of sewage fed pisciculture and agriculture. With 45.93% of man-made water area, the waste water goes through many processes of purification before reaching the fields or the fish ponds. (Saha, Pal, Kundu , 2008)

250 million gallons of sewage flows into the fertilization pond through a sluiz gate made with bamboo sticks which segregates the plastics and floating solid waste. The water and sludge then sits in the fertilization pond for 1-5 days where all the pathogens, solids and BOD are removed through bioremediation and anaerobic processes. These ponds are harvested for Methane and solids for agricultural use. The water then moves to shallow stocking pond through gates where reeds and a mix of aerobic and anaerobic processes remove the heavy metals and ammonia from the water. Finally the water moves to a fish pond where the fish through consistent aerobic processes make the water fit for irrigation.

Ecosystem Services

The wetland is a source of livelihood to close to 50,000 people from the communities which reside within and on the fringes of the wetlands. Their work ranges from managing the different processes of water purification to garbage segregation and recycling. They use traditional methods for recovering the resource and produce 2-4 times the average fish produce from a regular pond. Further, the communities also manage the wholesale of their produce and provide for 1/3rd of the vegetable, rice and fish requirement of the city.

12,500 hectares of Wetlands purifies 1/3rd of the city's waste to produce 13,000 tons of fish and 1/3rd of the food requirement for a city of 14 million people.

Governance

After the EKW was declared a Ramsar Site, the State government formed an exclusive committee called the East Kolkata Wetlands Management Authority to manage the wetlands. The Authority consists of representatives from all sectors, from the Department of Urban Development, Department of Environment to NGO's and civil society representatives. The committee mapped all the land uses and plots of the site area and formed a sub-committee for outlining a conservation plan. The plan mandated that no construction or alteration in the landscape can take place without the permission of the Authority. (Saha, Pal, Kundu , 2008)

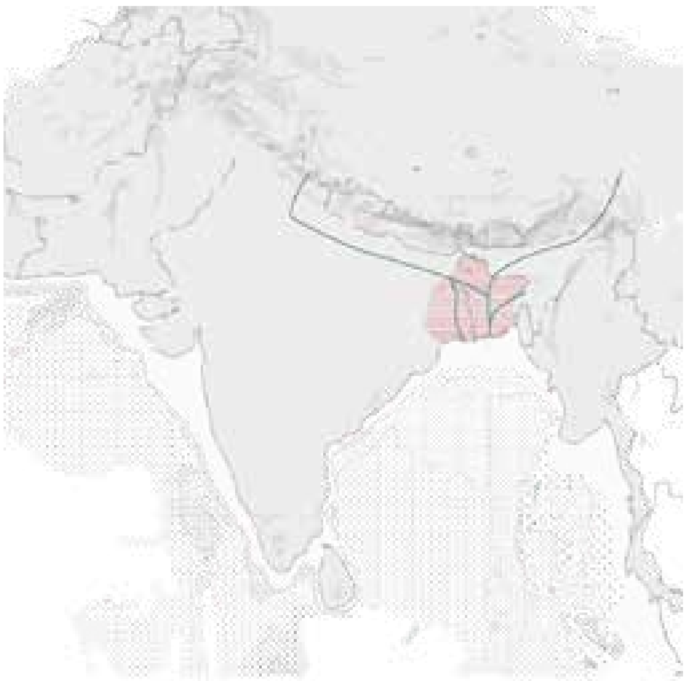


Figure 60 Enabling the indigenous to be involved in the restoration planning. Photo: Pūnui River Care.

Figure 61 Inexpensive technologies of water purification by planting local reeds and plants ; Source : waikato and waipā river restoration strategy

Figure 62 Community assessment of the project according to cultural indicators

5.2 New Zealand : Shared Governance Model

New Zealand was the last piece of land to be occupied by man. The first tribes arrived from Polynesia and derived their culture from the natural state of the land. However when the Europeans (mostly British) left, there was a rise in complaints regarding the environmental degradation and water quality. In 1975, in response to all the discussions, the government established the Waitangi Tribunal which since 1990, introduced the co-governance and co-management model to manage the natural resources with the local tribes. One of the applications of this model was for the Waikato River Authority. The Authority was created for the conservation of the River Waikato and to protect it for future generations. (Denyer, Akoijam, Ali et al, 2018)

The Waikato River Authority constitutes of 10 members - 5 from each river tribe and 5 of the government officials. There are 2 chairpersons, one appointed by the tribes and one by the Minister for the Environment. The purpose of the authority was to set the strategy to achieve the restoration of the river ecosystem, guide the implementation of this strategy and fund the programs aimed at rehabilitating the river.

"The Authority's vision is for "a future where a healthy Waikato River sustains abundant life and prosperous communities who, in turn, are all responsible for restoring and protecting the health and well-being of the Waikato River, and all it embraces, for generations to come.""

In addition, the Authority welcomes relevant projects proposed by external bodies like landowners, charitable trusts, other tribes, research agencies and schools and even private individuals or industries. Special attention has been given to utilising the local knowledge and re-establishing the cultural practices which played a major role in the protection of the environment in the past. These practices have been documented and promoted. In process, many social enterprises have also come up to meet the demand of replanting of the native plants and the labour required for it. (Denyer, Akoijam, Ali et al, 2018)

The Muni Lagoon can benefit from the co-governance model. This will help overlap the objectives of the traditional tribes and the conservation efforts of the Government and produce more effective results as seen in New Zealand.

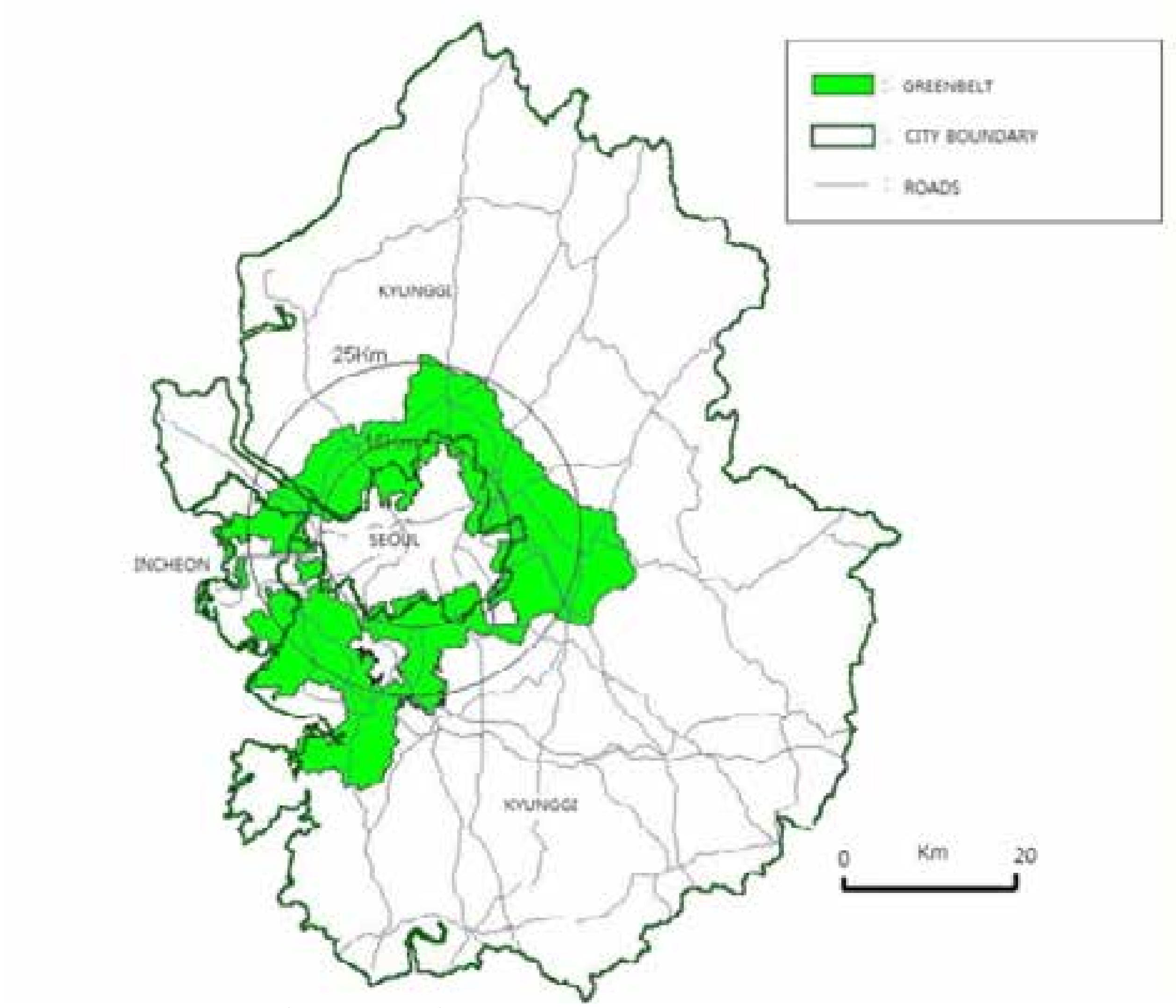


Figure 64 Map of the Green Belt in Seoul; Source : (Jin Jun, Jae jim, 2017)

Figure 63 Seoul from a mountain ; Source : https://www.onceinalifetimejourney.com/once-in-a-lifetime-journeys/asia/things-to-do-in-seoul-attractions-things-to-do-and-see/

5.3 Green Belt for Urban Containment

Unrestricted urban sprawl and land-consumptive development is increasingly proving to be a complex issue with a range of social and environmental consequences. Many cities are working on managing urban growth and protect open space through policy and spatial instruments. According to Pendall et al (2002) there are three types of urban containment policies : greenbelts, defined urban growth boundaries separating urban from rural through spatial instruments like zoning plans and urban service boundaries which define boundaries beyond which services such as sewage infrastructure etc will not be provided. While the latter two are flexible approaches which accommodate according to the predicted growth, the greenbelt is a physical area which forms the boundary of the growth (as cited in Bengston, Chang Youn, 2006).

Greenbelts are created by acquiring through public or non-profit ways and strictly regulating the development rights of the space. It is the most restrictive form of containment policy and was first implemented in London in the late 1930's. While many negative consequences have been highlighted like rising land prices and higher commuting costs, they have known to generate social and environment al benefits. They are known to protect open space, create recreational value and supporting ecosystem services. (Bengston, Chang Youn, 2006)

A frequently quoted successful case for this policy has been Seoul, Republic of Korea. Seoul was the fastest growing city in the world from 1950-1975. The greenbelt system was introduced in 1971 as a response to this growth. It was introduced in the City Planning Law within the National comprehensive Physical Plan. Amongst other security related reasons, the greenbelt was introduced to eradicate informal growth on the outskirts of the city and control urban sprawl. The primary reason for its success, however, remains its value for the people of the city. In a city with almost no open spaces, the belt acts as a breather with heavy use of its recreation activities. Apart from this, the greenbelt has also increased savings on public services due to the compactness of the city and offers a wide range of ecosystem services. Air purification, biodiversity protection, flood risk mitigation and water quality and supply are a few of the services provided to the city. While limited analysis has been done on the benefits of these services, there is literature on the high importance of these services. For example, Bangkok utilizes its green belt or zones to control flooding of the Chao Phraya River and its paddy fields on the fringes significantly control the summer heat in the residential areas. These areas are also an important habitat for diverse biodiversities, some of which are endangered. (Bengston, Chang Youn, 2006)

The city of Winneba is still in its initial stages of sprawl. However, the trends from the past decade indicate its rapid growth and hence increasing the threat on the border Muni-Pomadze Lagoon. Introduction of a similar green belt with a high value for the citizens as well as the authorities can limit the growth side of the city which borders the Lagoon.

5.4 Analysis based on the 5P framework

Kolkata Wetlands	New Zealand Shared Governance Model	Green Belt for Urban Constraints East
People		
Managed by local communities and the committee called the East Kolkata Wetlands Management Authority to manage the wetlands. Relies on the traditional knowledge of the communities for the daily processes. The provisional ecosystem services are instrumental for conserving the wetlands.	Utilising the local knowledge and re-establishing the cultural practices which played a major role in the protection of the environment in the past. A community assessment framework has been implemented , making the communities responsible for the site.	Green belt acts as a breather and recreation space for the people as well as gives them opportunities to reside closer to nature.
Profit		
With the use of traditional methods for recovering the resource, the community produce 2-4 times the average fish produce from a regular pond. Further, the communities also manage the wholesale of their produce and provide for 1/3rd of the vegetable, rice and fish requirement of the city.	Many issues are tackled through community initiatives and locally without state intervention.	Some negative consequences such as the rise in land prices and higher commuting costs.
Planet		
• Principles of circularity and conservation through ecosystem services. • The practice of sewage fed pisciculture and agriculture • Use of a sluiz gate to segregate the plastics and floating solid waste. • The wastewater goes through many processes of purification before reaching the fields or the fish ponds (Man-made water area). • Managing the different processes of water purification to garbage segregation and recycling.	Traditional methods and community involvement allow more sustainable conservation practices to be used. The local knowledge of the biodiversity and conditions is beneficial for restoring the regulatory services for the surrounding areas.	Green Belts are protecting open space, create recreational value and supports ecosystem services: Air purification, biodiversity protection, flood risk mitigation and water quality and supply are a few of the services provided to the city
Project		
• Mutually beneficial human-nature relationship • Largest organic wastewater treatment systems in the world • A 12,500-hectare wetland of 254 sewage fed fisheries, agricultural plots and solid waste farms.	Achieve the restoration of the river ecosystem, guide the implementation of this strategy and fund the programs aimed at rehabilitating the river. Creates community public spaces along the river.	Greenbelts are created to eradicate informal growth on the outskirts of the city and control urban sprawl. Creates opportunities for designing recreational public spaces.

Kolkata Wetlands	New Zealand Shared Governance Model	Green Belt for Urban Constraints East
Process		
• Classified as a Ramsar Site in 2002 • Permission of the Authority is needed for any construction or alteration in the landscape	In 1975, the government established the Waitangi Tribunal which since 1990, introduced the co-governance and co-management model to manage the natural resources with the local tribes.	• Implemented in London for the first time in the late 1930s. • Later on, the greenbelt system was introduced in 1971 as a response to the growing city of Seoul, Republic of Korea. • Regulatory approach

Since every project is unique and has different requirements, we can see that each of the analysed cases responded differently to the 5 P's. However, understanding these past experiences are detrimental for us to gain knowledge on how to proceed for the future of the Muni-Pomadze lagoon to implement these solutions, such as the green belt, a new governance model and the use of water purification systems. In the next chapters, more explanations on the integrated design can be found.

Figure 65 Levee on the Muni-Pomadze site, photo by Ranee Leung

06 Discussion of the Design Alternatives

6.0 Requirements and Constraints

Based on the analysis of the site of the study, several concepts are proposed in order to enhance the ecology and biodiversity of the ecosystem of the lagoon. These concepts are created based on the experience of the team members in every field of study. However, based on the theoretical framework of the 5P's (People, Profit, Planet, Project and Process), a concept can only become an actual alternative for the design if it satisfies a list of requirements. In this project, the requirements have been gathered in five main categories:

1. People-oriented: the strategies to follow must consider human development in the natural environment. The requirements are:

- The proposal should minimize the erosion of the barrier, in order to protect the settlements located on the sand dune.
- The urban encroachment in the MPL should be regulated, in order to reduce the flood risk.
- The water quality of the lagoon should be enhanced, so as the use of the water of the lagoon does not represent a risk for human health.

2. Profit-oriented: the strategies to follow must be cost-effective. The requirements are:

- The system should be financially sustainable. The strategies proposed should trigger new opportunities to activate the economy of the area.
- The benefit obtained from the activities mentioned in the previous requirement should be fairly distributed amongst the MPL stakeholders.
- In order to ensure the feasibility in the long term, the maintenance costs of the activities in the MPL should be kept low.

3. Planet-oriented: the strategies to follow must be environmental-friendly. The requirements are:

- Nature-based solutions are preferred.
- The use of local materials should be promoted.
- The strategies should aim to recover the original ecosystem of the area. For instance, it should be studied the possibility to grow back mangroves.

4. Project-oriented: the strategies should be adaptable according to the short term responses to the interventions. The requirements are:

- The stiffness of the interventions should be kept low so as modifications in the initial plan are not difficult to implement.
- The performance of the interventions should be easily assessed, in order to detect which part of the proposal should be adopted.

5. Process-oriented: the strategies should be implemented in such a sequence that the cost-efficiency of the project on the long term is ensured. The requirements are:

- Due to the high uncertainty about the success of the interventions proposed, the risk should be kept low, by giving preference to low investments in the implementation sequence of the interventions.
- The self-maintenance of the system should also be considered when elaborating the roadmap of interventions.
- In order to demonstrate the effectivity of the interventions to the population, the positive impact of the design should be visible in the short term.

Nevertheless, the accomplishment of these requirements is limited by several external constraints. In the case of the people-oriented requirements, it is likely that the interests of some stakeholders are confronted. This conflict should be solved by evaluating the influence of the different stakeholders in the project, by means of so-called stakeholder analysis (chapter 4.4). Regarding the profit-oriented requirements, the constraint lies in the budget limitation of the project. In this line, the designers are aware that the proposals should be financially feasible. Attainable objectives are set for the short term. The planet-oriented requirements are subjected to the possibilities that nature offers. Climate change is modifying the conditions of the MPL, which can hinder the effectivity of a proposal. For instance, further studies should be carried out to evaluate the effects on the growth of the mangroves of higher water levels or higher temperatures inside the lagoon. The constraint in the project-oriented requirements lies in the timescale to evaluate the performance of a solution. An intervention might be adaptable, but an adequate evaluation of its impact might take much longer. Finally, the degree of satisfaction of the population and the time that the population take to assimilate the benefits of an intervention is uncertain, what makes difficult to elaborate the optimal intervention roadmap.

6.1 Design Alternatives

From the analysis in section 5, it is concluded that the MPL has water quality issues which can be solved by creating an opening between the ocean and the lagoon: a tidal inlet. By creating a connection with the ocean, the tide will flow in and out of the lagoon which flushes pollutants, causes a water level change over the day, redistribute sediment within the lagoon and is expected to improve the conditions for mangroves to grow.

In order to open the lagoon, different tidal inlet designs are possible. The different options that came out of the scoping workshop (see, table/figure scoping chapter) have been further elaborated and resulted in two alternatives for an open lagoon. The first is a hard-structural solution and the second consists of a soft solution, a nature-based configuration without a hard structure. The complete design of the structural case can be found in appendix A, design of a stable inlet.

A side effect of an open system that was observed during previous open connections is that the lagoon side of the barrier suffers from erosion (for further information in this aspect see the analysis of the lagoon in chapter 4). To prevent this effect, a design of a bed and a bank protection in the tidal inlet is proposed (section 7).

To make an estimation of the effect of a structural intervention on the adjacent coastline, the sediment transport along the coastline has been calculated (Appendix B). The effects of the sediment transport will be considered qualitatively in the discussion of the different design cases.

6.1.1 Requirements and boundary conditions

The requirements for the whole project are discussed in the previous section, chapter 6.1. The main hydraulic boundary conditions like wave heights, flow velocities and stability of the materials can be found in the corresponding appendices.

6.2 Alternatives Tidal Inlet

Case 1: Permanently Open (hard solution)

The first way to create a stable tidal inlet is by constructing a breakwater near the shore and installing a bed and a bank protection. In figure 73, an impression of a tidal inlet with a breakwater is shown.

The breakwater reduces the wave action and tends to avoid bringing in sediment into the tidal inlet. The tidal inlet should be wide enough for the tide to travel into the lagoon, but narrow enough to prevent the channel from silting up.

Case 2: permanently open (soft solution)

Initial opening
The second solution consists of creating an opening manually with the help of an excavator. The opening should be located around 250 meters west of the vegetated part of the barrier. In this case the tidal inlet is allowed to freely migrate towards the east. The following maintenance steps should be taken to make sure that the system remains open during the whole year.

Maintenance inspections
Every month, when the water level and salinity are measured, the tidal inlet should be inspected. When the inlet is closed by natural processes, it should be dredged with an excavator to reopen the lagoon. If the channel has migrated to the east and is located close to the vegetated stable part of the barrier, a new inlet should be created around the opening location 250 meters to the west of the vegetated part.

A monthly inspection is expected to be enough because in the past the lagoon stayed open for long periods of up to two years (Davies-Vollum, APA reference). This would suggest that the tide and possible human activities inside the tidal inlet could help to maintain the opening.

6.2.1 Design options bank protection

There are several factors that play a role when determining the use of a soft (sand/vegetation based) or hard (rock based) protection in a project. For example, a hard structure is often more expensive and requires more construction time and maintenance. Also, hard engineering disrupts natural processes. As mentioned in the beginning of the project, one of the main objectives is to conserve and maintain the MPL, as stated in the philosophy of the project: 'not only take from the land, but also give back to the land'. For this reason, a soft bank protection is designed.

A soft bank protection should work with the natural environment and it creates areas like wetlands which are important wildlife habitats. Wetlands store flood water and reduce the flow velocities, which is a main cause of bed and bank erosion. Furthermore, wetlands contribute to natural flood protection. If a soft bank protection is used, vegetation is planted along the bank which results in a higher resistance and a reduction of the flow velocity. Also, soft engineering has a more sustainable management strategy than a hard engineering solution, because of its lower economical costs and environmental impacts.

6.2.2 Longshore sediment transport

The potential longshore sediment transport, which travels from the west to the east along the coast of Winneba is in the order of 2.000.000 m3/year (see Appendix B for full estimation). This is most likely an overestimation because a simplified wave climate has been used, but models from the African coastline do show that a potential sediment transport of around 1.000.000 m3/year was found (Ocean and Coastal Management, 2018). This indicates that the potential sediment transport is very high.

Comparing these numbers to the Dutch coast, the net longshore sediment transport near Winneba is around four to eight times larger (Bosboom & Stive, 2015) than for the Dutch coast.
Therefore, the interaction between a breakwater and the coastline should be considered in a further design stage. The effect of the interrupted sediment transport is expected to cause erosion on the eastern side of the breakwater and accretion on the western side, what can compromise the overall stability of the barrier. The longshore sediment transport has been calculated in appendix B, longshore sediment transport.

6.2.3 Floods due to opening

Flood risk is a major driver in the decision to open or not the lagoon. During the fieldtrip, local inhabitants shared their concerns about a potential opening, since they considered that the increase of water level would flood their properties. However, the effects of a hypothetical opening are not clear and further research should be carried out to evaluate them. The combination of hydraulic phenomena such as spring tides, wind setup and heavy rainfall might play a role in extreme high water levels inside the lagoon.

Nevertheless, there is a general agreement among the lagoon inhabitants about the reduction in flood risk due to rainfall, if the lagoon is open to the sea. In the recent years, several lagoon settlements have experimented flooding due to extremely heavy precipitation. Up to now, the most common practice among the population to prevent flooding due to extreme rainfall has been opening the lagoon at the end of the wet season (Davies-Vollum, 2018).

According to the calculations made in section 7, the amplitude of the water level inside the lagoon due to the tide is 0.5 meters, which it is not expected to represent a danger to the settlements included in the spatial planning of the lagoon. Nevertheless, this phenomenon should be addressed in further investigation.

Flood risk may arise in case of illegal construction in the flood plains of the lagoon, specially during dry season. Therefore, regulations in the spatial planning and law enforcement is recommended, in order to avoid risk of flooding in these areas during wet season.

6.3 Discussion of the alternatives

In Table 1, the pros and the cons of the structural and the soft solution are outlined. The relevant requirements and constraints have been put in a table regarding the alternatives to creating a tidal inlet. The interventions are rated with a plus when the solution satisfies a requirement, and a minus when the solution is not completely suitable according to a requirement. The double signs increase the suitability or deficiency of the solution with respect to a requirement.

Requirements	Case 1: Structure Solution	Case 2: Soft solution
People		
Ecosystem	(++) Opening the lagoon will be very beneficial for the ecosystem	(++) Opening the lagoon will be very beneficial for the ecosystem
Legally sound/policy	(++) Once the structure is in place it will maintain it functions for a long time	(-) If there is no money or will to keep the lagoon open it will close again under natural conditions.
Human health	(++) The quality of life will improve when the water quality and ecosystem are stronger	(++) The quality of life will improve when the water quality and ecosystem are stronger
Profit		
Self-maintained system	(+/-) the breakwater will have a long lifetime but requires a large initial investment	(+/-) the opening has to be maintained and regulated but the initial investment is small
Low maintenance	(+) The breakwater won't require a lot of maintenance, but due to the effects of the longshore transport dredging activities might be necessary.	(--) This solution requires monthly inspections and maintenance.
Cost-Effective approach	(-) The initial investment for the breakwater is very high	(+) The initial investment is lower, but the operational costs are larger (more frequent maintenance operations are required)
Planet		
Nature-based solutions	(--) The structure is not nature based and could have a very large impact on the adjacent coast	(++) For this solution the system is kept in a state that also occurs under natural conditions.
Use of local materials	(+) The stones can be ordered from a local quarry	(++) no additional materials are needed for the opening
Ecosystem	(++) Opening the lagoon will be very beneficial for the ecosystem	(++) Opening the lagoon will be very beneficial for the ecosystem
Project		
Adaptability of the interventions	(--) The implementation of hard structures is not easily adaptable	(++) Soft solutions enable fast modifications in the initial plan
Process		
Rational sequence in the implemenation of interventions	(--) High risk due to large initial investment and due to large uncertainty about the effects of the implementation of a breakwater	(+/-) Low investment, but also large uncertainty in the effects of the permanent opening of the lagoon

Table 1 Multi-criteria analysis for the two alternative designs for a tidal inlet

Besides the multi-criteria analysis, two additional aspects should also be considered for the structural and natural opening of the lagoon:

Longshore transport and effect on adjacent coastline

A breakwater will partly block the longshore sediment transport. The coastline will change due to accretion on the west side of the breakwater and erosion on the east side. The rates at which these changes will happen are not known, the consequences are expected to be visible in the short period. Therefore, a solution without blockage of the sediment would be preferable. If a hard structure is designed to keep the tidal inlet open, the effects can be adverse for the long term.

Unknown effects on the ecosystem

The effects of an open connection to the sea (opening of the MPL) are expected to be beneficial for the ecosystem, due to the relieve of pollutants to the open sea. However, lagoon ecosystems can be very sensitive and therefore, further research on the actual effects should be carried out.

In the current stage, the knowledge about the effects of opening the lagoon is scarce. Consequently, a large investment in a hard intervention is not justified in the short term. Opening the system in a natural way and allowing it to function when it is opened is a safer way to observe the changes in the system.

6.4 Final proposal

Considering the beneficial effects of an open system, it is recommended to create a tidal inlet in the barrier. However, because of the unknown effects of the implementation of a hard structure (interaction with the longshore sediment transport and the structure), it is suggested to create a natural opening in the short term. The low initial investment and the limited alteration of the natural state of the lagoon are the main reasons why this option is the preferred one.

However, clear regulations should made on the authoroty to carry out the opening works and implement a maintenance plan. Also a monitoring plan should be implemented to monitor the development of the tidal inlet. We advise to open the lagoon by excavator for a period of 5 years during these years the effects on the lagoon should be monitored. this can be done be collecting regular data on:

- Water quality
- Morphological changes
- Mangrove growth
- Number of species (fish, plants, birds)

According to these data records in the short term, enough information might be available to determine if a structural intervention for a stable tidal inlet is a suitable way to proceed in order to keep the lagoon open.

Additionally, the feasibility of the development of such structure should be analysed by means of a financial model for the entire lifetime of the structure. The financial model should include the capital and the operational expenditures of the breakwater, the bend and the bank protections.

Figure 66 Levee on the Muni-Pomadze site, photo by Ranee Leung

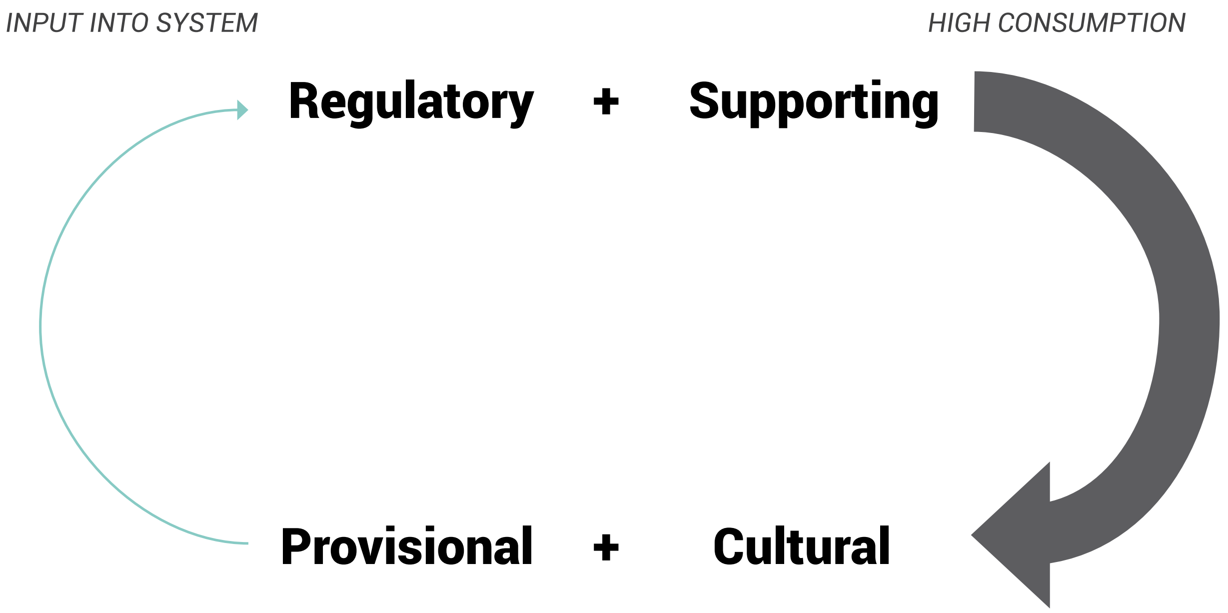
07 Proposal

7.1 Vision

The Future Muni-Pomadze Lagoon

7.2 Concept

Current System



Proposed System

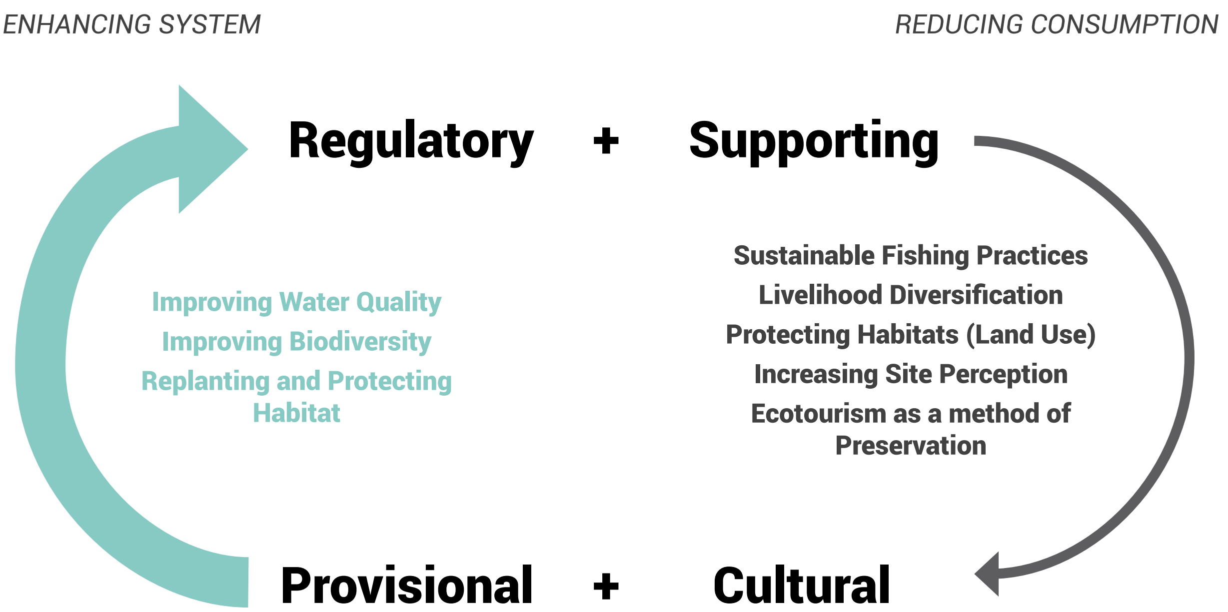


Figure 67 Proposed Concept

Figure 68 Proposed Land Use

7.3 Land-Use

In order to begin enhancing the site to a stable state, the project seeks to establish land uses which focuses on conservation, adaption, and reuse. The design is based on the assumption that the lagoon will be opened, either permanently or seasonally. In order to allow the natural system to grow, the proposal indicates several areas for conservation including the Efutu Conservation Area Extension, the extension of the Yentu Forest Block, new forested lands in the lands resting between the adjacent rivers. To assist in the regrowth of mangroves, the plan indicates replanting areas along the floodplain which should be reserved for planing. On the east boundary, the plan indicates the greenbelt, which provides a physical buffer between the urban area and the lagoon. This greenbelt will provide opportunities for the ecotourism park, children's park, and community funding which will be discussed in the following chapters.

- Built-up Residential
- Open/Agricultural Lands
- Water Bodies
- Floodplain
- Adapted Salt Pans to Mangrove Nursery
- Adapted Salt Pans for Vegetation Growth
- Efutu Conservation Lands
- Children's Park
- Green Belt
- Community Agriculture
- Mangrove Replanting
- New Forested Lands
- Sewage Line
- Constructed Wetland
- Ecotourism Infrastructure

Figure 69 Proposed Strategies

- Built-up Residential
- Open/Agricultural Lands
- Water Bodies
- Floodplain
- Adapted Salt Pans to Mangrove Nursery
- Adapted Salt Pans for Vegetation Growth
- Efutu Conservation Lands
- Children's Park
- Green Belt
- Community Agriculture
- Mangrove Replanting
- New Forested Lands
- Sewage Line
- Constructed Wetland
- Ecotourism Infrastructure

7.4 Strategies

In addition to the land use designations on the site, the project proposes a number of strategies to enhance the natural system and to provide sustainable livelihoods for the community. Firstly, on the west end of the site, ecotourism and cultural uses are combines in order to conserve and stimulate regrowth projects within the areas. Routes are connected from the Egyasimanku Hill to the Yentu Block forest in order to create a hiking network for visitors. The Southern section of the site contains the tidal opening with bridge access over it. The rest of the southern area contains the beach/dune bank where the existing fishing community

1. Ecotourism Base (Hotels and Base Information)
2. Tidal Opening
3. Efutu Conservation Lands Extension
4. Yentu Block Forest Extension
5. Mangrove Replanting Area
6. Boating Dock
7. Butterfly and Bird Sanctuary
8. Forested Lands
9. Community Farming Area
10. Entry Park
11. Re-opened Salt-Pans
12. Recycling Plant (Abutting Plastic Capturing Mechanism)
13. Salt-Pans adapted for mangrove nursery and experimentation
14. Children's park
15. Constructed Welands along Sewage lines
16. Retail and Restaurant Area
17. Flood Erosion Protection

is located. As noted in strategy 17, Flood erosion protection is used in order to protect the bankand the community from future flow changes. To the Northern section of the site where there is currently open space and pasture lands, the project proposes to plant a forested area, but also include a butterfly and bird sanctuary within the area in order to promote tourism, but also avoid development in this dry area of the lagoon. To the east, several strategies make up the "Greenbelt", a buffer used to inhibit development from the encroaching urban area. Firstly, the park will provide an official entrance for visitors who will access the park by roads. This area of the park will include a visitors centre and retail areas as well as recreational pathways and a fishing dock. Also included within this area will be a continuation of the natural filtration systems found on the site already. All of the sewage lines which connect to the lagoon will be filtered using these new, soft systems. To the north of this area, the filteration system will also provide nutrients for the community farming activities which will be expanded throughout the project. Moving to the south of the greenbelt, there is the existing placement of the Salt Pans.These pans are no longer in use, but provide an ideal structure for plant life which thrives in a high saline environment, due to their elevated structure providing shallow water and small openings. Here the project proposes that a section of the pans be converted into nurseries for the mangroves which can allow the community to test ideal mangrove species in the area before planting, as well as grow the seedlings in a calm environment. These strategies will be discussed in greater detail in the following sections.

7.5 Supportive Strategies: Water

Figure 70 Open situation of the lagoon (Google Earth, May 2016)

During extreme events and in the case the lagoon is open, the tidal effects and the evacuation of rainfall waters are expected to generate high velocities in the tidal inlet that connects the sea to the lagoon, due to the flow constriction in this section. Moreover, an inner channel is formed close to the bank on the lagoon side of the sand bar (Figure 70). Large flow velocities are expected to occur in the outer bend of the inner channel, which is adjacent to the sand bar. Consequently, the sand bar is being eroded.

As explained in the Analysis section, several rows of palm trees stabilize the stretch to the East of the tidal inlet, due to the presence of large and long roots that attach the trees to the soil. However, during the field trip it was noted that some of the palm trees were toppled (Figure 92), due to the recent narrowing of the sand bar on the lagoon side (almost 2 meters). Also, the barrier had developed steep profiles and a berm, which are clear signs of erosion. To avoid this phenomenon, it is desired to build a soft bank protection in this location which consists of a vegetation cover layer.

In this section, the extreme flow velocities in the bend are quantified, by assuming an extreme event that combines high tide and heavy precipitation (10-year return period), during wet season.

Design of the protection elements in the tidal inlet

In Appendix E, the extreme flow velocities in the bend are calculated, by assuming an extreme event that combines high tide and heavy precipitation (10-year return period), during wet season. The flood velocity in the tidal inlet is 3.7 m/s. The bed and the banks of the tidal inlet should be protected against the load caused by the flow. Since the velocities are high, a hard protection consisting of a granular filter is proposed for the tidal inlet (Figure 71, Figure 72).

In Figure 73, a top view of the tidal inlet is shown, where it is included the bed protection, the bank protection and the breakwater.

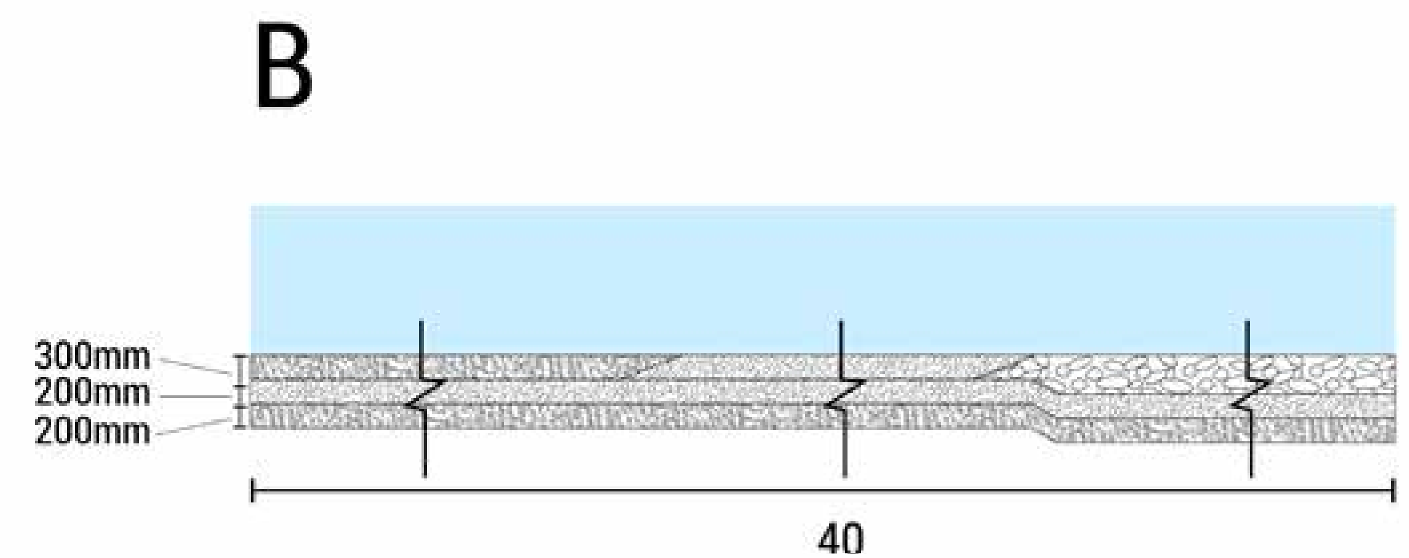


Figure 71 Longitudinal section of the bed protection of the tidal inlet

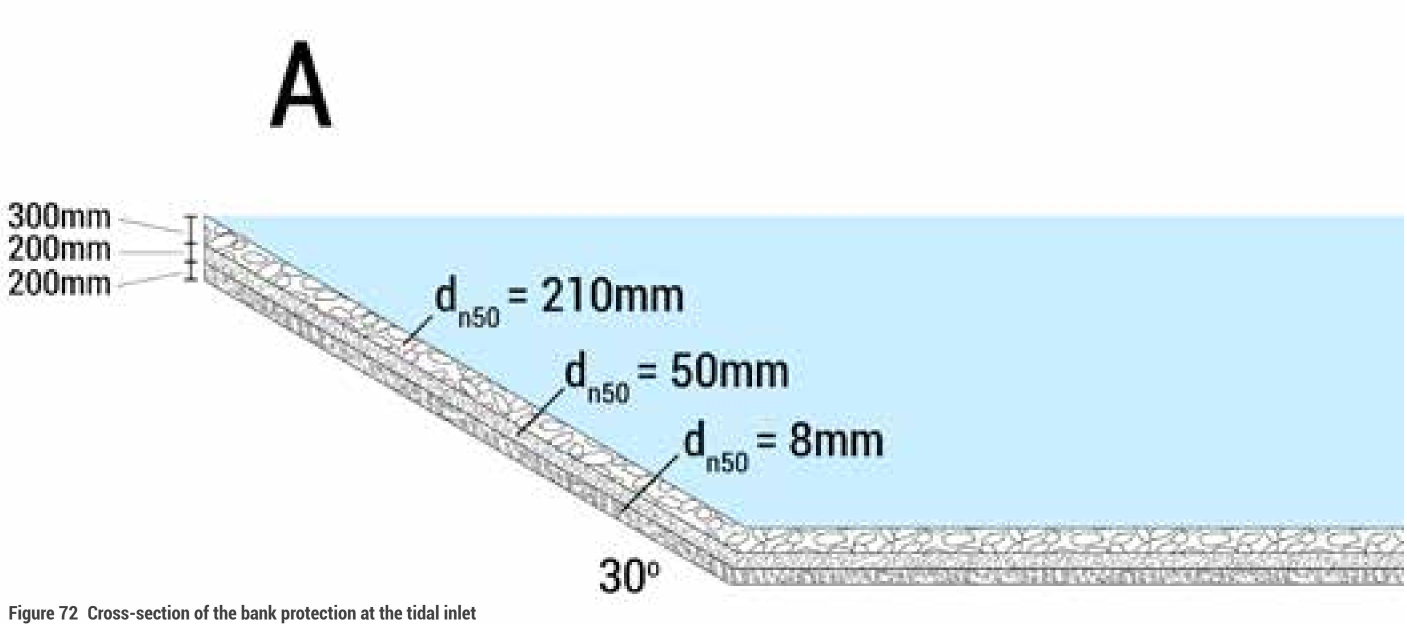


Figure 72 Cross-section of the bank protection at the tidal inlet

Design of the protection elements in the bend

In Appendix B, the calculation of the flow velocities caused by a 10-year return period precipitation in the bend is shown. The resultant velocity in the bend is 1.2 m/s. In this case, a soft bank protection is sufficient to withstand the flow loads. The bank protection in the bend consists of reinforced vegetation.

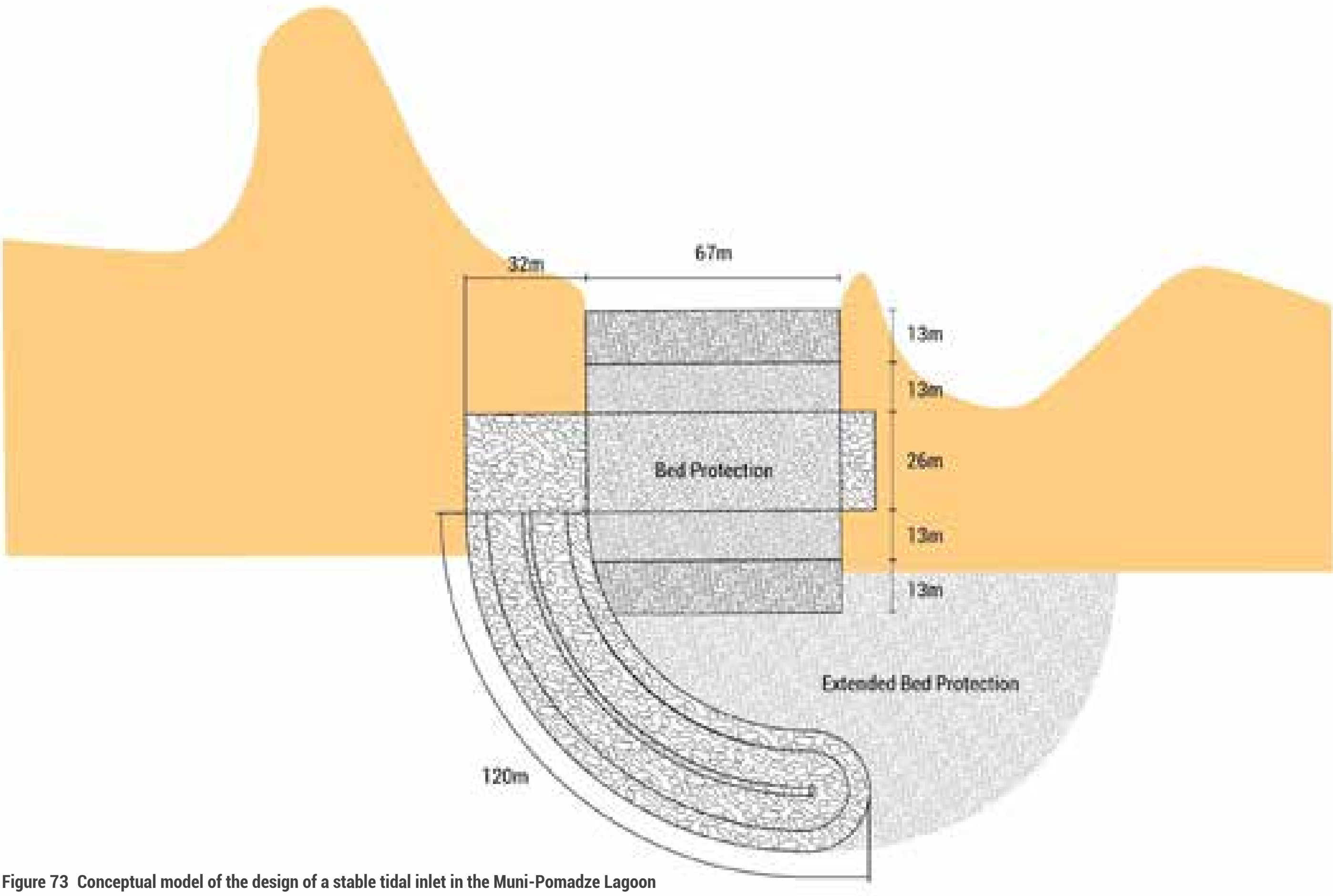
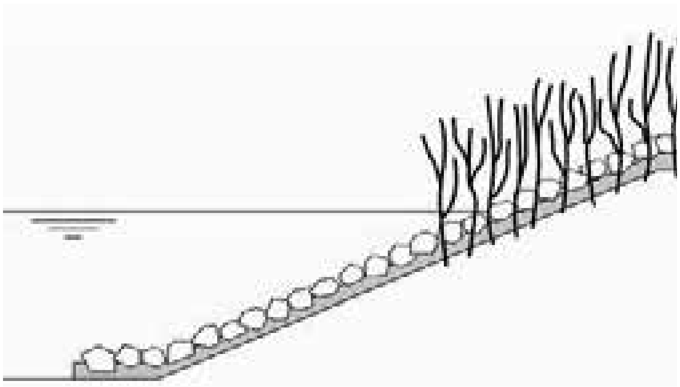


Figure 73 Conceptual model of the design of a stable tidal inlet in the Muni-Pomadze Lagoon

The reinforced vegetation consists of three parts: a mat, vegetation and rocks (Figure 75). The mat is made of a local tree which can resist salty water. The rocks are obtained from nearby quarries. Rocks of dn50 = 1 cm should be enough to resist the load according to Shields, but the same type of rocks as used in the bed protection in the tidal inlet will be placed (LMA 10-60, dn50 = 21 cm), in order not to hinder the growth of the vegetation, while keeping the mat in place. The layer thickness will consist of one rock layer (21 cm).



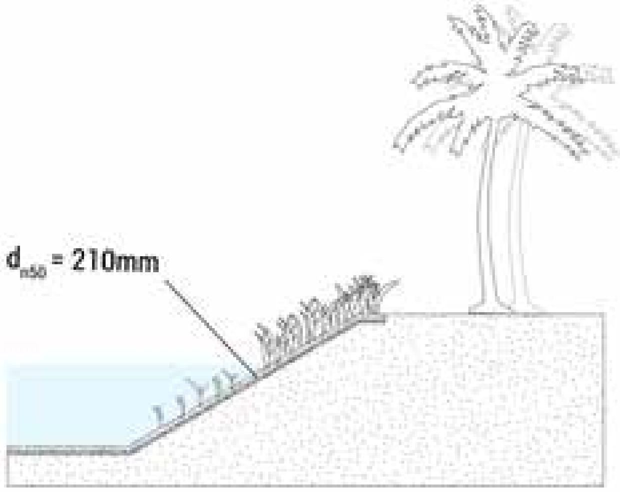


Figure 75 Shait

Figure 74 Example of a bank protection (Schiereck, 2012) (l), schematic overview of the reinforced mat (Schiereck, 2012) (r).

7.5.1 The Nature Based Solution for Water Quality

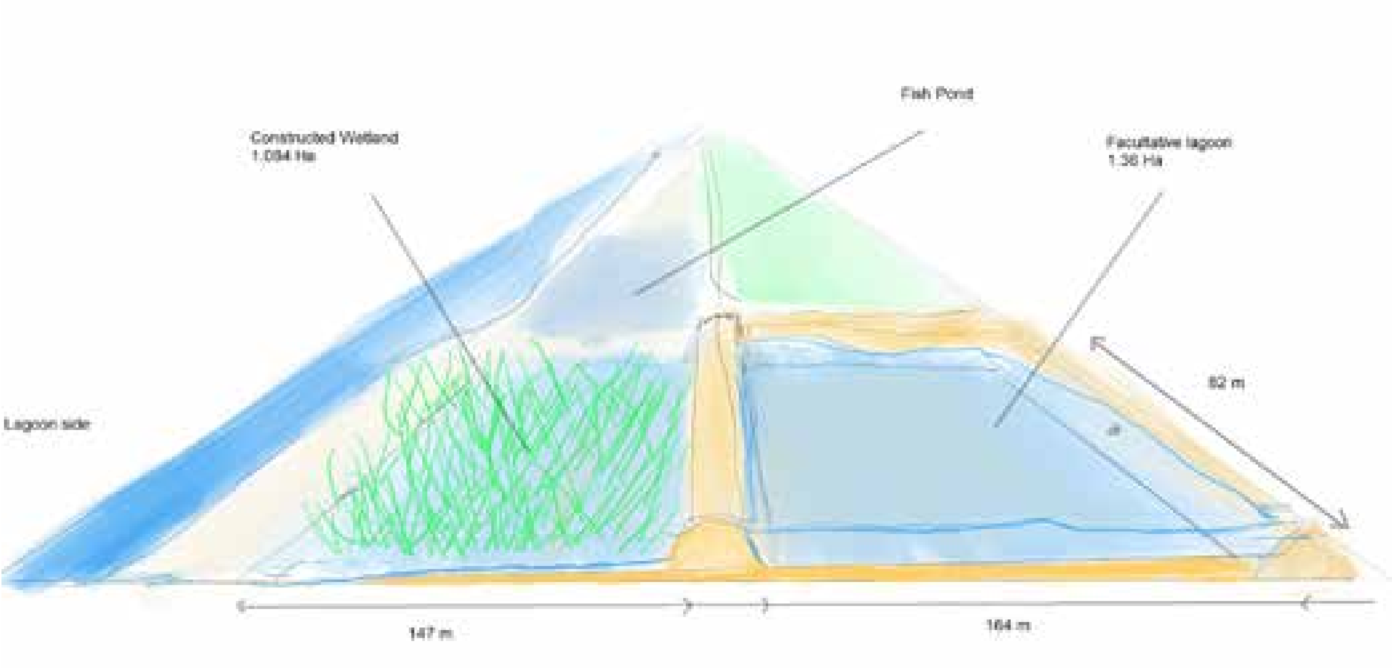


Figure 76 Nature based solutions: constructed wetlands and facultative lagoon/pond in the Muni- Pomadze area

The contaminated water in the lagoon will be improved in two stages. The first stage is the facultative lagoon. The function of this system is to treat the raw wastewater. The constructed wetlands are used as the second stage which will improve the effluent water quality of the facultative lagoon before discharging it into the lagoon water.

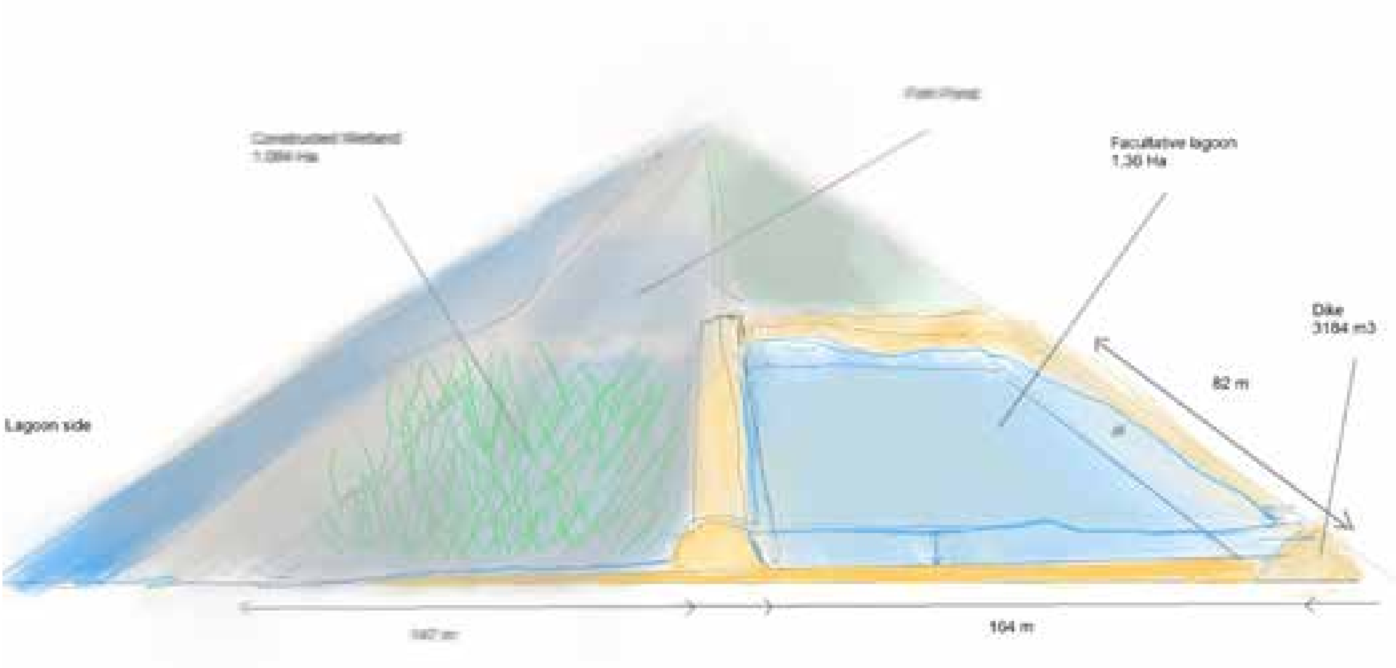


Figure 77 Facultative lagoon/pond in the Muni- Pomadze area.

Facultative Lagoon

Before the wastewater flows to the constructed wetlands, a simplified facultative pond will be implemented based on the East Kolkatta wetlands. This system reduces the wastewater discharge to prevent overloading in the simplified constructed wetlands. The facultative pond is based on the principle of an anaerobic and aerobic reactions. There is less need for maintenance and operation. Besides that, the tropic conditions are also suitable for those ponds for the degradation of certain water pollutants such as Nitrate and organic matter. The effluent discharge of the facultative water flows into the constructed wetlands by using gravity.

Principle of Facultative Lagoon

Photosynthesis and aerobic respiration by the phototrophic organisms and algae are the main processes on the water surface level. Sunlight and CO2 provide the energy for the algae to produce oxygen in the photosynthesis process while the aerobic bacteria consume this product. The aerobic bacteria use this oxygen to degrade the dissolved organic matter in the wastewater in the respiration process. Therefore, the aerobic bacteria and algae are collaborating with each other to degrade the dissolved organic matter (Von Sperling, 2007)

On the bottom of the lagoon, there is less sunlight and oxygen. Furthermore, the suspended solids such as soluble organic matter which flows through the facultative lagoon will settle down in the bottom of the lagoon. Those particles will be decomposed by anaerobic organisms into sludge. This will result in sludge which can be removed in the dry season and can be used for agriculture purposes.

The degradation of pollutants in this facultative lagoon depends on certain factors such as the temperature and the depth of this lagoon. An increase of temperature will also increase the degradation of pollution. The depth is important for the anaerobic bacteria (no oxygen zone) to decompose it and is assumed to be 1.5m.

The Design of the Facultative Lagoon

The dimensions of the facultative pond are calculated by using the data of the total influent concentration of pollutants and the surface loading rate based on (Von Sperling, 2007) and (Mara, 2003) as shown in Apendix D.

The dimensions of the Small Dike Isolating the Pond

The dike dimensions are based on the pond dikes calculations (FAO, 1992). The dike is assumed to have a slope of 1:1.5 while freeboard height is assumed to be 0.5m in order to prevent flooding of the pond in the wet season. The volume of sand/clay which has to be implemented is 3183 m3 for the two ponds. The pipes which connect the facultative pond and the constructed wetlands are assumed to be 0.75 m to avoid clogging due to sludge accumulation.

Constructed Wetlands in General

A nature-based solution is using simplified constructed wetland has many benefits. The purification of contaminated water is one of the benefits of using the constructed wetlands. Vegetation such as Typha Latifolia (cattail) and Wool grass assimilate pollutants such as phosphorus chemicals, Ammonium, Nitrate, organic and inorganic matter. Those pollutants are converted into harmless chemicals for example by denitrification of the denitrifying organism and the plant. The local reed vegetation Typha (known as cattail) in combination with Typha Australis will be used to purify the wastewater of the urban areas. Typha Latifolia has a removal efficiency of 44 percent for nitrate and 23 percent for nitrite as a result of a study in Tanzania (Kaseva, 2004). Degradation of several bacteria in wastewater has also been found in this study. The biodiversity is Besides that, this vegetation lowers the temperature of the effluent and an increase of dissolved oxygen. Furthermore, accretion is also created due to the decay of vegetation in anaerobic situation. The increase of the soil due to the decay of vegetation will be around 0.1-2 cm per year (Mara, 2003).

Simplified Constructed Wetlands Designing and Dimensioning

The implementation of simplified constructed wetlands is loosely based on the free water surface constructed wetland. The constructing wetlands are based on the illegal sewage point discharge. The north-west part of the lagoon area does not have a high concentration of pollution caused by the agriculture. According to the study ' (Tiakor, 2015), the nitrate and Biochemical Oxygen Demand (BOD) concentrations are lower than the water quality standard for the surface water. Therefore, the constructed wetlands are not implemented on the North-West of the Lagoon.

Illegal wastewater flows from Winneba are calculated by estimating the wastewater of the household using the average water consumption of each person. The average water consumption is 76 litre/d per person which is based on a study in Accra (Badsha, 2016). However, it is stated by the Wildlife Division that Winneba discharges the wastewater into the sea. Therefore, estimation has been made for the informal sewer discharge. An observation has been made that the soil type has been considered as clayey sand in this area. This information is needed to calculate the area of the constructed wetland and the facultative pond. The dimension calculations are based on the (UN-habitat, 2008) in the appendix.

Constructed Wetland	Dimensions	Unit	Note
Discharge	1679	m^3/d	2 wetlands
Surface Area	10.835,00	m	1 wetland
Depth	0,7	m	1 wetland
Length	147,2	m	1 wetland
Width	73,6	m	1 wetland
Retention time	19	d	1 wetland

Table 2 Dimensions of the constructed wetlands

Maintenance

The constructed wetlands does not need considerable amount of maintenance, because the wetland plant communities are self-maintaining. However, visual inspection is needed every year to maintain the quality of the constructed wetlands and facultative ponds (UN-habitat, 2008). The maintenance of facultative ponds are also less. Sludge removal has been done every decennium (Von Sperling, 2007).

7.5.2 The effects of opening the lagoon on the ecological environment

It is proposed to open the lagoon to prevent further degradation of the biodiversity. This solution has a substantial impact on different kind of topics in the MPL. The opening will change the water quality, the current wildlife, vegetation and people in this area. Therefore, it is a solution that is considered as a complex system which depends on many factors.

Effect on nutrients and salt concentration

The opening of the lagoon has been analysed in different type of regions. For example, the Salgados Lagoon and Foz do Almargam Lagoon are analysed for one year. (Coelho et al., 2015) concluded that the nutrient concentration such as organic material (BOD) and inorganic material (COD) and other water chemicals accumulated in the observed Salgados lagoon, were discharged and the salinity increased in the opened situation. However, there an increase of Nitrogen-related chemical was still observed in this lagoon due to the urban and agricultural wastewater in the nearby area.

This is also the case for the Muni-Pomadze Lagoon, where two illegal sewage points from the urban area are discharging in the lagoon. The nitrate concentration was substantial high in the northern area between the two illegal sewage points which is nearby the urban areas of Winneba.

The opening does help to reduce the pollution in the lagoon however, the urban water pollution should also be considered.

Impact of Constructed Wetlands

An increase of salinity changes the dynamic of the biodiversity in the lagoon. The implementation of certain constructed wetlands with specific species can be inefficient for pollutant removal under changing salt-conditions. Typha latifolia cannot germinate under a high salinity concentration. For example, the growth of the Typha Latifolia seedlings are inhibited when the salinity of the water is 30 - 40 ppt (Sanchez-Garci E.A. et al., 2017)

7.5.3 Impact on fishes

The Muni Pomadze lagoon is a habitat for three kind of fish species. The Sarotherodon melanotheron fish is the dominant species in this lagoon. Tilapia and Liza Falcipinnis are the two other species in this lagoon. (Korangten.K et al., 2000). It is stated by the local fishermen that the fish species are common in the lagoon when the lagoon is opened during the wet season. Furthermore, it is observed that the dead fish species such as Sarotherodon melanotheron fish were found in a closed lagoon. Therefore, the biodiversity will increase when the lagoon is opened during wet season.

7.6 Livelihood Diversification

As a part of the supportive ecosystem services, an attempt to diversify the livelihood opportunities for the lagoon dependant population has been proposed. These will help in reducing the resource pressure on the site and increase the focus on conservation efforts.

Recycling Unit

The aim of the constructed wetlands is to filter out all the solid and chemical waste in the water. During the site visit it was noticed that the city has virtually no garbage management system and most of the plastic lands up in the water and eventually on the beach. Hence the wetlands have been designed to catch the floating plastic waste which can then be transplanted to a recycling unit constructed on site for sorting and be processed to make other products. The process would require man power to clean the wetland screen, manage the recycling unit and the post processing of the waste. The unit will be privately leased and managed which would bring in the funds for its construction and generate profit. A similar initiative was seen in Accra where a recycling unit was located on the banks of the Odaw River.

Another livelihood opportunity is to create craft industries or products from the waste by capacity building in the local population as producers. The communities can practice this in the lean season and market it in the city and other cities along the coast. (Holt & Littlewood 2017)

Figure 78 Recycling Plant in Accra (Asmeeta Das, 2019)

Figure 81 Construction with Plastic Bottles (Source : https://www.africanglobe.net)

Figure 80 Locally made screen for trapping plastic (Source : https://themindunleashed.com)

Figure 79 Recycled Plastic Mats (Source : https://theglobalgrocery.wordpress.com)

Handicrafts and Temporary Retail

New community-based livelihoods can be introduced by the active non-governmental organisations and the authorities in the area through skill development workshops. This approach already exists in the area but at a very small scale. The abundance of natural materials like coconut shells and leaves along with the existing skill of weaving mats can be used to produce different products. On the site visit we noticed that the villagers at the edge of Winneba city were weaving coconut leaf mats to make boundary walls for their houses. This skill can be channelized to creating marketable products which can be sold in the city markets.

Additionally with the predicted rise in tourists, spaces for temporary informal markets have been allotted on site (see section 7.6.1). This can help people earn additional revenue in the tourist season making them less dependant on the lagoon for their livelihoods. These markets can be regulated in a way that priority is given to the communities which practice agriculture or fishing on the site. The handicrafts initiatives can also be marketed in these areas. The people would need skill development workshops to fit into the different roles needed for the supply chain of the products. The aim should be to make the whole process a community based one. (Gordon, Pulis, 2010)

Figure 82 Local Marketplace in Ghana (Asmeeta Das, 2019)

Figure 84 Coconut leaf weaving (source : https://youronevoicecanmakeadifference.wordpress.com/education/)

Figure 83 Coconut leaf weaving (Asmeeta Das, 2019)

7.6.1 The Growing Trend of Community Eco-tourism in Ghana

Several crucial questions to address are how to design a community based eco-tourism strategy and what are the key considerations? Along with, how does eco-tourism impact the growth and conservation of the lagoon?

Ecotourism is an effective measure to assist in "resources while promoting socio-economic development and empowerment of local communities" ("Emerging ecotourism in Ghana makes headway | Ghana 2017 | Oxford Business Group," 2017). This has been evident in many successful case studies within Africa that range from Kenya's Maasai Mara National Reserve, Gabon's Loango National Park and Botswana's Okavango Delta. The sector of ecotourism within Ghana and especially the Muni-Pomadze Ramsar site has high potentials. The socioeconomic development and benefits to the conservation of protected areas have been heavily studied and implemented. It is also a form of tourism to assist in reducing "environmental impacts, contribute to environmental protection, enhance interaction between tourists and local people, and improve the economic and social well-being in host communities"(Appiah-Opoku, p.501, 2011).

One of the main goals is to develop a community based eco-tourism strategy while contributing to local livelihood enhancement and enriching the nature conservation in the Muni-Pomadze site. Within the element of establishing sustainable tourism is to also maintain and grow ecological processes. In addition, there is an important consideration to the widespread conflicts between the protected areas and those who reside within the immediate vicinity of these sites.

7.6.2 Application and Active Involvement of Traditional Beliefs and Knowledge: Eco-tourism Management and Enriching Forest Reserves

As the livelihoods in these communities can often conflict with the biodiversity conservation in protected areas, the use and expansion of the protected Yenku Nature Reserve could restrict local people's access to the natural landscapes while attracting ecotourists to these resources.

The Kakum National Park in Ghana is deemed as a successful model in the conservation of a national park in Ghana but within its operation, it has negatively affected the rural livelihoods of villages within vicinity of the park (Appiah-Opoku, p.501, 2011). The initial model was to protect the rainforest, promote ecotourism and environmental education and promote economic development in villages surrounding the park. However, the danger of introducing alternative economic activities to the area such as beekeeping, woodcarving and snail farming which are not indigenous in nature to the area is failure. Most of the activities were abandoned and the locals did not have adequate financial resources for these activities. The introduction of new community-based ecotourism is to utilize existing local activities that would attract tourists while generating revenue. The adoption and development of the type of livelihoods needs to heavily involve the local communities, especially in the decision-making process. Successful cases of adopting the knowledge can be seen in the case study in the New Zealand shared governance model outlined in chapter 5.

In the development and expansion of the eco-tourism initiative, the local community would need to be heavily involved as well as managerial assistance from the Ghana Wildlife Division of the Forestry Commission, private investors and NGOs. In safeguarding conservation practices, an allocated staff team would enforce and carry out anti-poaching patrols. Additional community outreach would be required with educational campaigns to dissuade poaching.

By explicitly stating the potential of concrete benefits of conservation with the communities within the Muni Pomadze area, there will be a stronger justification for the sustainable management of the site. It is a strong incentive to receive community support for any new development and site protections. If these benefits are not clearly outlined, there will be little attention from these communities to assist in the protection of these natural resources.

7.6.3 Eco-tourism Potentials and Joint Education Initiatives

What are the current eco-tourism potentials on the site? And are these linked to the lagoon?

Majority of the physical and cultural attributes of the Muni-Pomadze site contribute to a potential in establishing an income-generating and educational nature reserve (Gordon et al., 2000).

Several principles need to be included in the development of the eco-tourism on the site including:
- Respecting the sociocultural, traditional values, heritage and authenticity of communities
- Promoting equity in the distribution of economic costs and benefits among the community and tourism developers

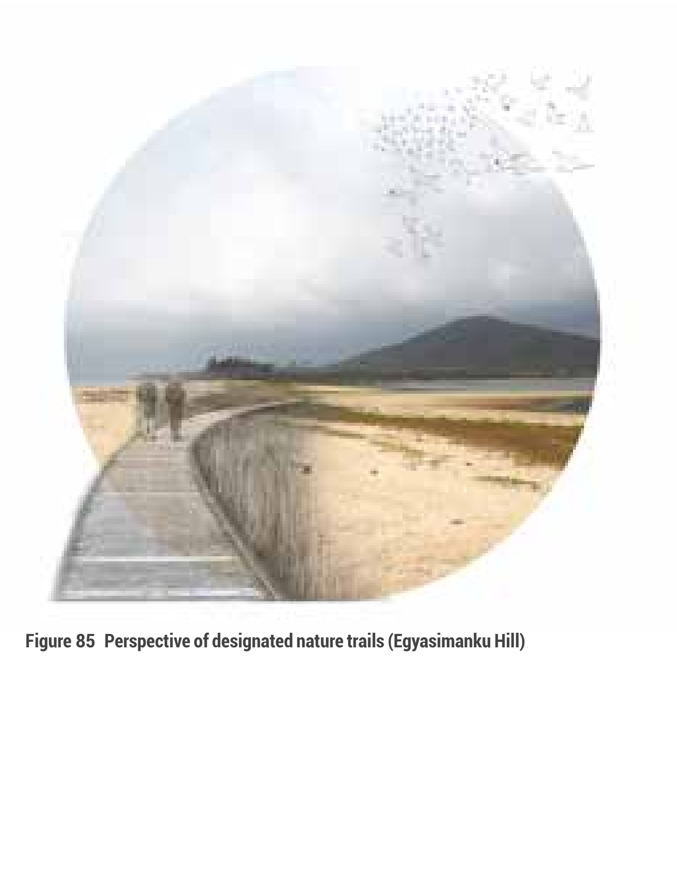


Figure 85 Perspective of designated nature trails (Egyasimanku Hill)

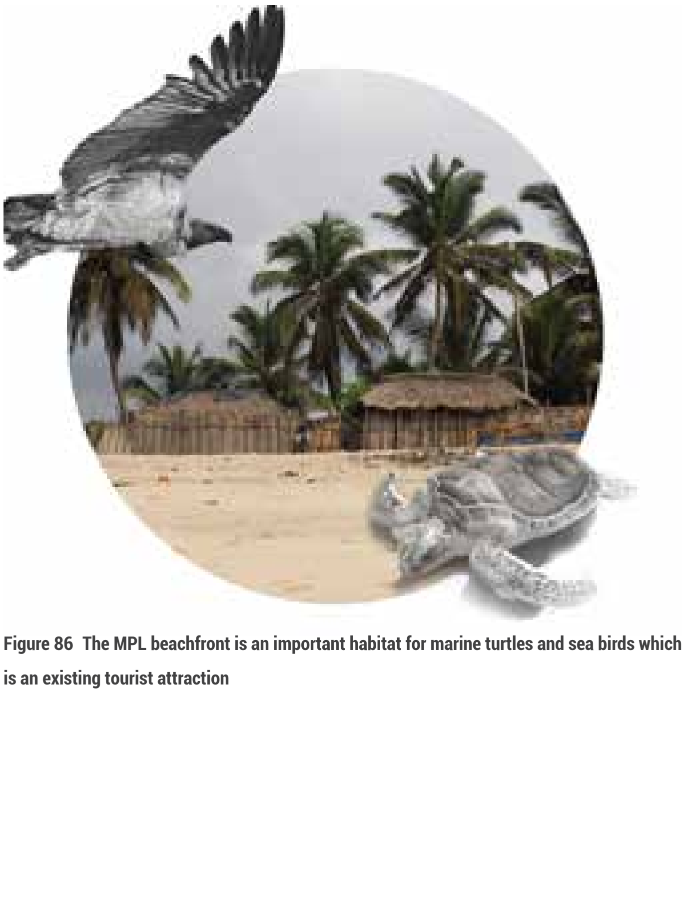


Figure 86 The MPL beachfront is an important habitat for marine turtles and sea birds which is an existing tourist attraction

7.6.4 Proposed Development

In figure 87, the spatial locations of the proposed developments are marked along with the following proposals:

- Development of clear demarcated nature trails and clearings. To establish these routes, careful planning and site observations would be required before determining exact the locations for tourists. In addition, monitoring programmes would need to be developed and maintained (Gordon et al., 2000) with the assistance of community involvement.
- A secondary network with restricted vehicle access for the Wildlife Division needs to be established for the monitoring programme.
- By designating local guides as an alternative means of income, the perpetuation of the rich culture of the Effutu people would be passed on ("International Partnership for the Satoyama Initiative » Community sacred forest in the Effutu traditional area, Central region, Ghana," 2019.) The traditional area should also be protected as it is a strong part of their culture in the last 300 years.
- The creation of routes would be comprised of boardwalks, viewpoints, docking areas of small boats and small recreational zones. This would also heavily involve the input the local community while reinforcing education and the passing down of indigenous knowledge of the site
- New development with tourist amenities (eco-lodges) would be restricted to a small area to decrease the encouragement of tourism infrastructure encroachment

7.6.5 Enhancing and Expanding Forest Reserves: Continued Habitat Preservation and Conservation of Heritage Values

Presently there are two protected areas which are the Yenku A and B Forest Reserves which occupy 10% of the site (Gordon et al., 2000). The expansion of the forest reserve should contain similar indigenous vegetation found along the borders the lagoon to the west and north. The surveyed area contains thickets of shrubs and small trees with the species (primarily Azadirachta indica, Zanthoxylum xanthozyloides, Elaeophorbia drupifera, and Lonchocarpus cyanescens, Securinega virosa, Chromolaena odorata, Clausena anisota, Cissus arguta). Other dominant species include: Andropogon gayanus, Fimbristylis ferruginea, Heteropogon contortus, Vertiveria fulvibarbis, Panicum maximum, and Sporobolus pyramidalis). The area already has a strong collaboration with the Asafo Company (local warrior groups). Already trained in tree plantations, the restoration of indigenous trees will help restore degraded ecological zones. This will help with the ecological integrity and communal forest landscape. Additional benefits includes the stabilization and increase of the bushbuck population which is by the Effutu people during their annual Aboakyir festival. The impacts of securing a strong habitat area in the replanting and growth of these designated areas can empower communities to take better of their environment and utilize resources more efficiently.

Sea Turtle & Sea Birds Conservation

One of the primary tourist attractions in the area are the marine turtles that nest on the sandy shores. The area is also a habitat of over 48 species of water birds (estimated population of 23,000) and a diverse set of 75 butterfly fauna.

7.6.6 Private Investors

The expansion of the forest reserves can also benefit from Ghana's existing aid packages from the Climate Investment Funds' Forest Investment Programme which is currently set at $24m packaged backed by a $10m loan from the Climate Investment Funds' Forest Investment Programme and $14m from the African Development Bank. The current funds aim to restore degraded forest reserves and assist in forest plantations.

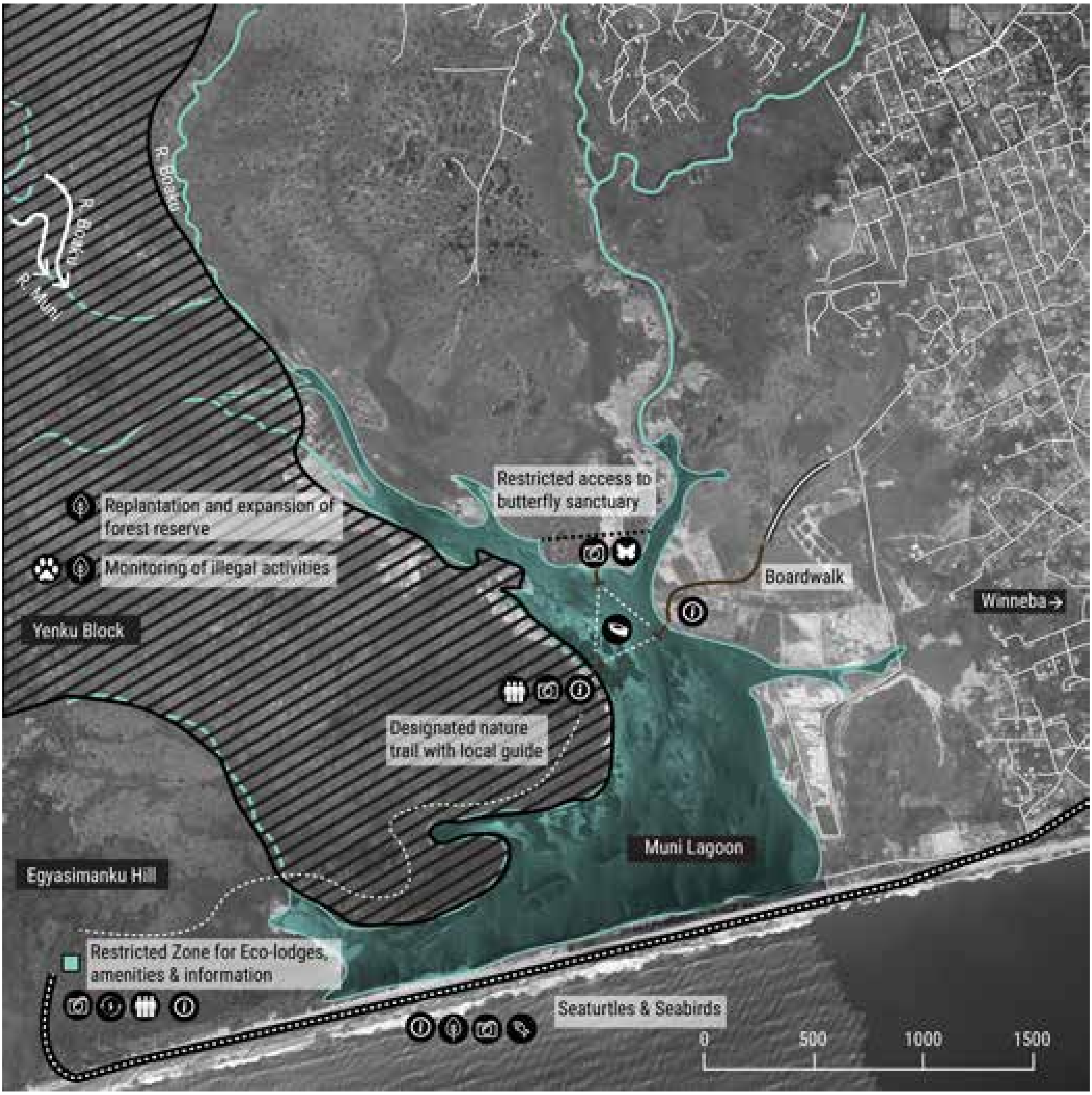


Figure 87 Proposed eco-tourism amenities

The current investors and level of involvement range from:

- The Swedeu Township who are invested in creating leisure, relaxation and residency for tourists
- The Ghana Tourism Authority are seeking to enhance tourism potential and to also shape the image of the area
- The Ocean's club wants to develop an attractive and beautiful location for tourists. The group is also ready to develop a portion of the lagoon (Mankwaadze Hill)
- NGO Involvement - Friends of the earth are focused on environmental conservation. They will continue to assist in the planting mangroves and coastal cleaning practices
- Municipality of Winneba aims to help protect and conserve wetland, increase tourism (birdwatching) and continue coordination amongst communities and organizations
- Wildlife Division aims to protect vulnerable species and assist in monitoring illegal activities

7.7 Green Belt Design

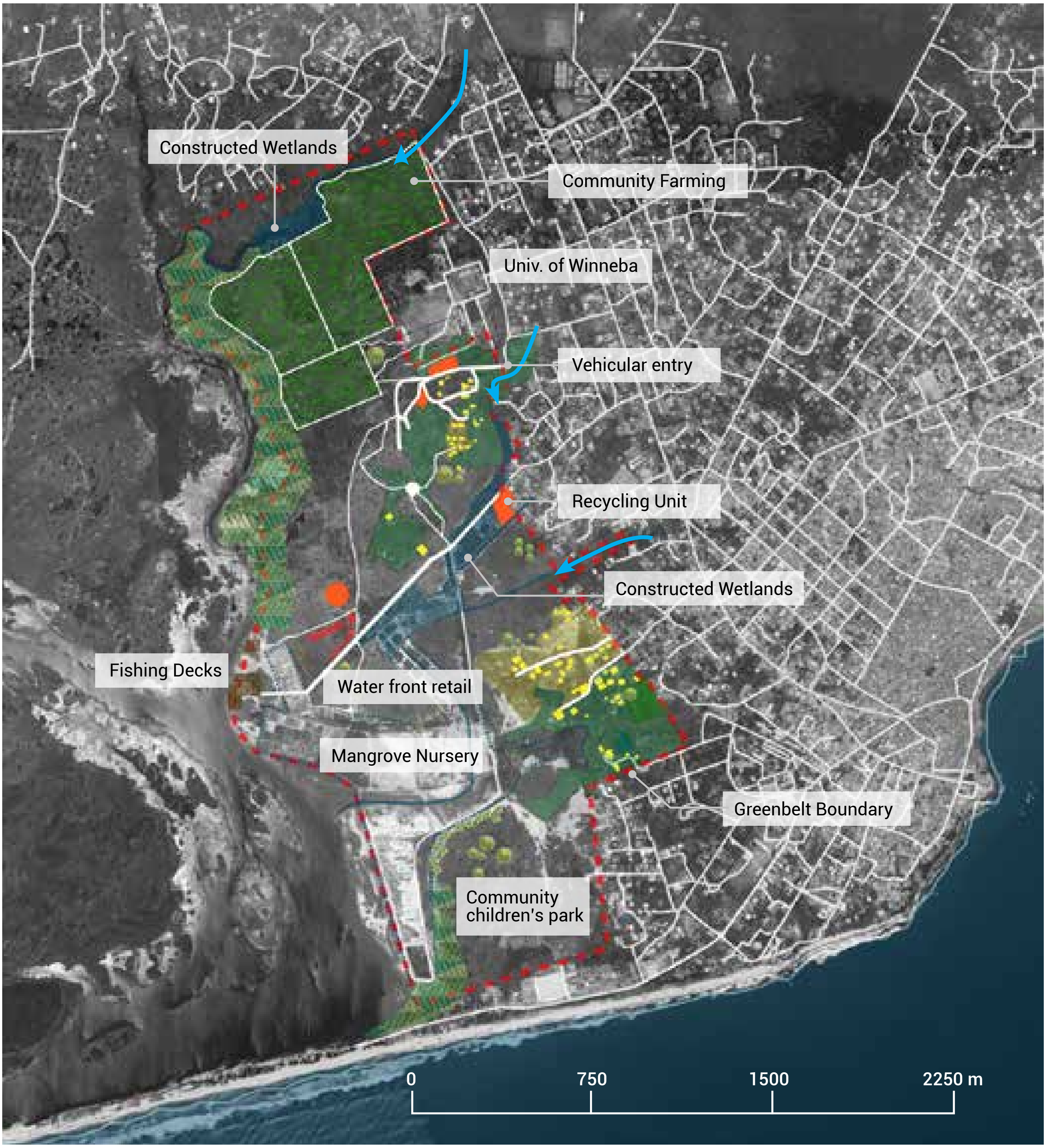


Figure 88 Proposed Green buffer - Dry Season

Figure 89 Proposed Green buffer - Dry Season

The Green belt has been designed to limit the city encroachment into the lagoon area. The belt acts as a city park with various functions spread over an area of 3.6 kilometre square. It acts as a breather for the growing city and provides many ecosystem services like air purification and recreation spaces.

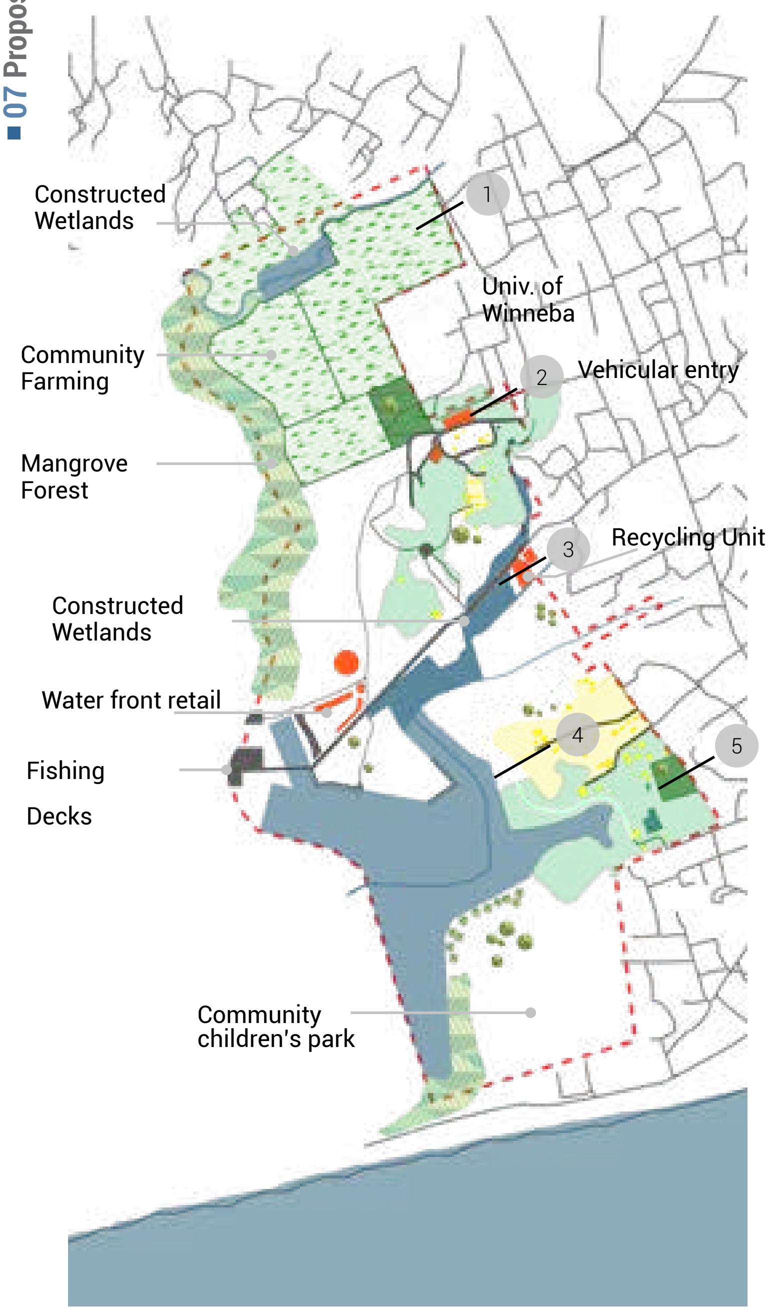


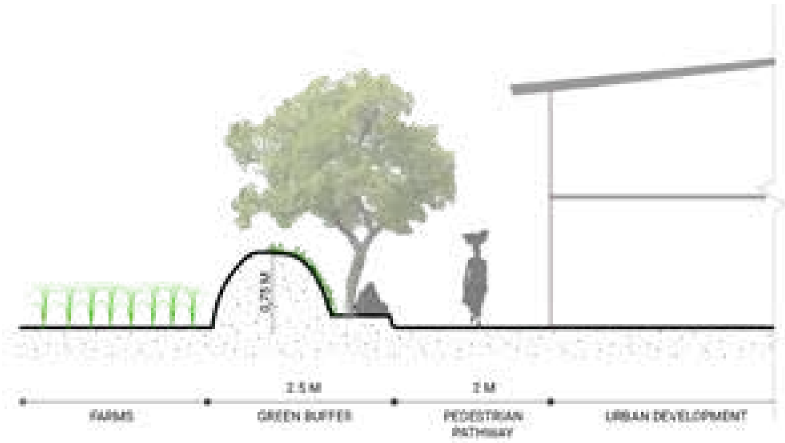
Figure 90 Proposed Green buffer - Boundary Conditions

The belt runs along the western edge of the city, incorporating some of the built areas (marked in yellow) within its limits. It follows the Seoul Green Belt model (see Case Studies 5.3) of governance and is classified as a regulated open space. New permanent construction is prohibited unless sanctioned by the Lagoon Authority (see Governance 8.1).

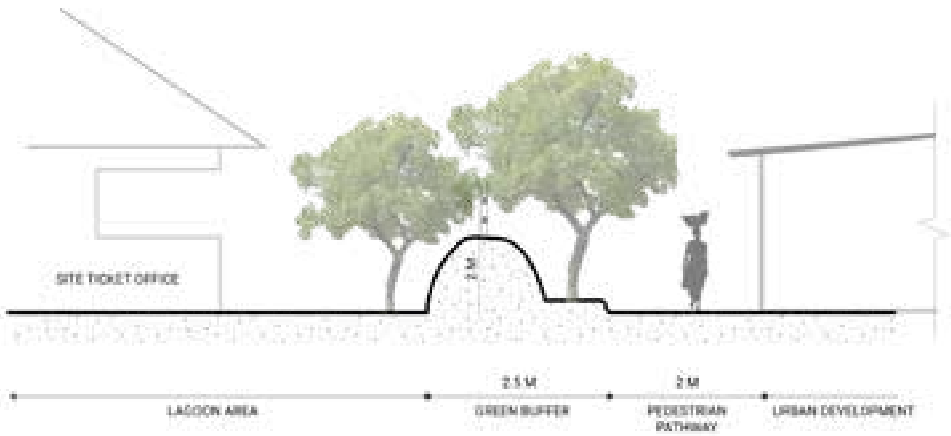
- **Access** : A single vehicular access into the belt area and further into the Lagoon area has been designed to monitor the movement on the site. This is a gated and ticketed entry for tourists. Some of the original pedestrian pathways have been maintained to allow the community to navigate the site for their needs. However these pathways have high visibility to avoid illegal activities in the area.

- **Integrated Design** : The constructed wetlands and the waste streams have been integrated into the design of the park. The wetlands filter catch the floating waste through a locally made wooden or bamboo screen. The waste is then taken to an on-site recycling plant which has been introduced to process the city;s garbage. The residual sewage is treated through bio re-mediation, aerobic and anaerobic processes to produce manure for the bordering community farms and food for the fish in the consequent fish pond. (Details in 7.8.1) The proposed area also borders the University on the northern side and an existing park called the Advance park on the southern edge. The area bordering the University is next to a football field and has been left open for the use of the students for recreational activities. The Advance Park is currently used for the Masquerade festival and also seamlessly continues into the site.

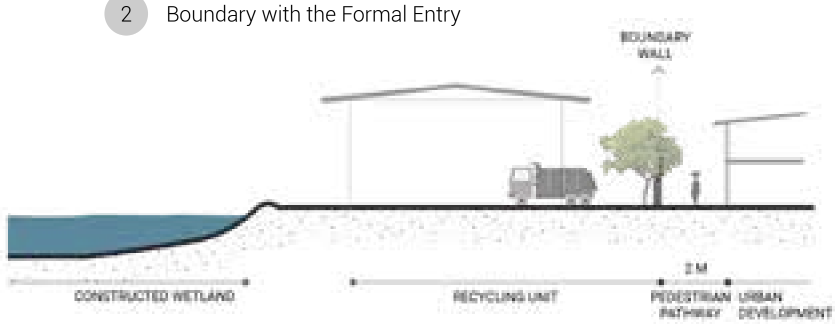
- **Urban Areas** : There are two clusters of existing buildings on the site (marked in yellow). These must be clearly defined and demarcated by the authorities and strict regulations must be put on their expansion. They can coexist with the Green Belt but need to abide by the conservation guidelines of the area.



1 Boundary with the Community Farms

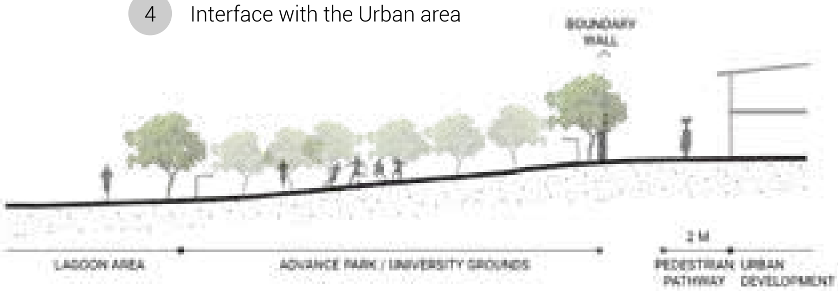


2 Boundary with the Formal Entry



3 Boundary with the Recycling Plant

4 Interface with the Urban area



5 Interface with the Advance Park

Boundary Conditions

The boundary design of the Green Belt, along the settlement, changes as per the boundary conditions. Varying from natural mounds to boundary walls wherever required, the aim is to channelize the entry to the site and restrict construction.

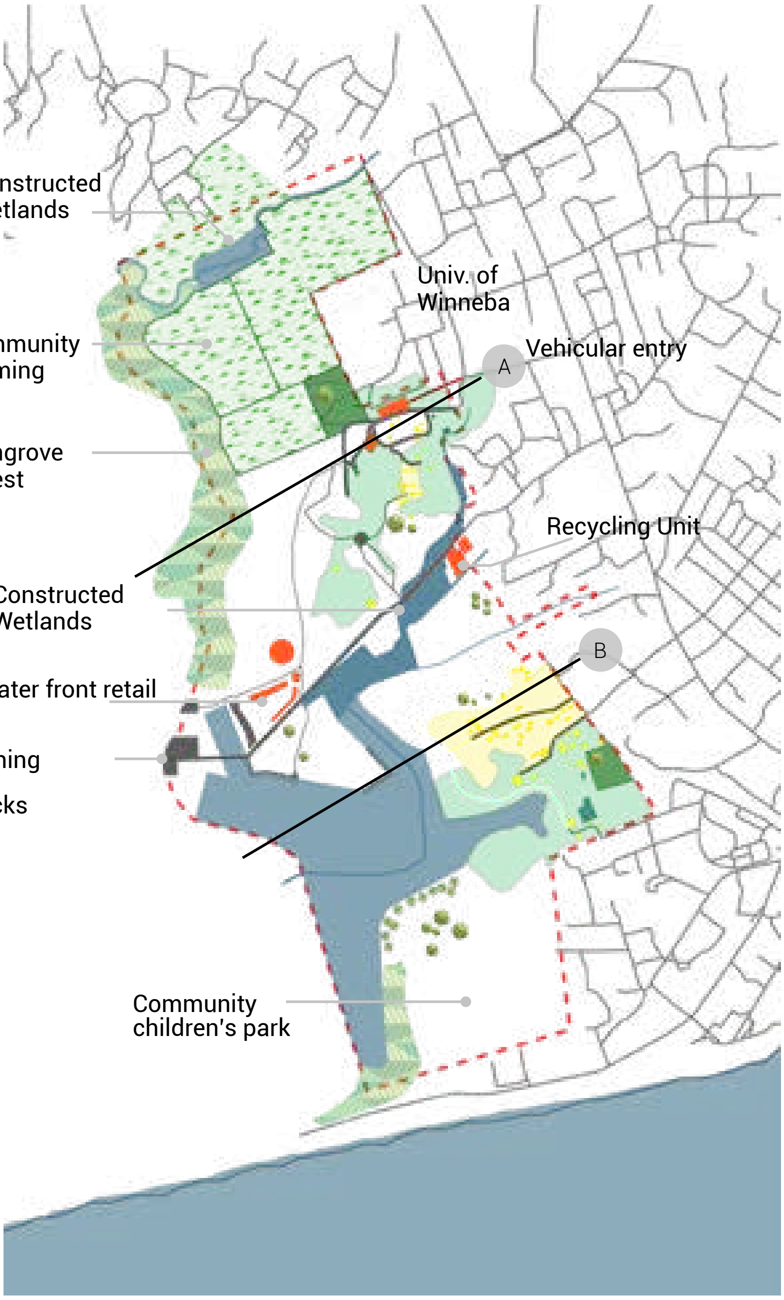
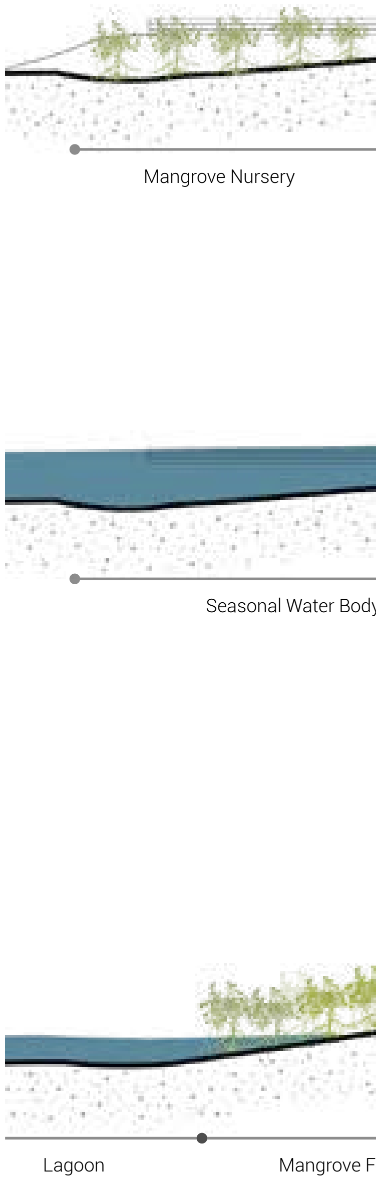
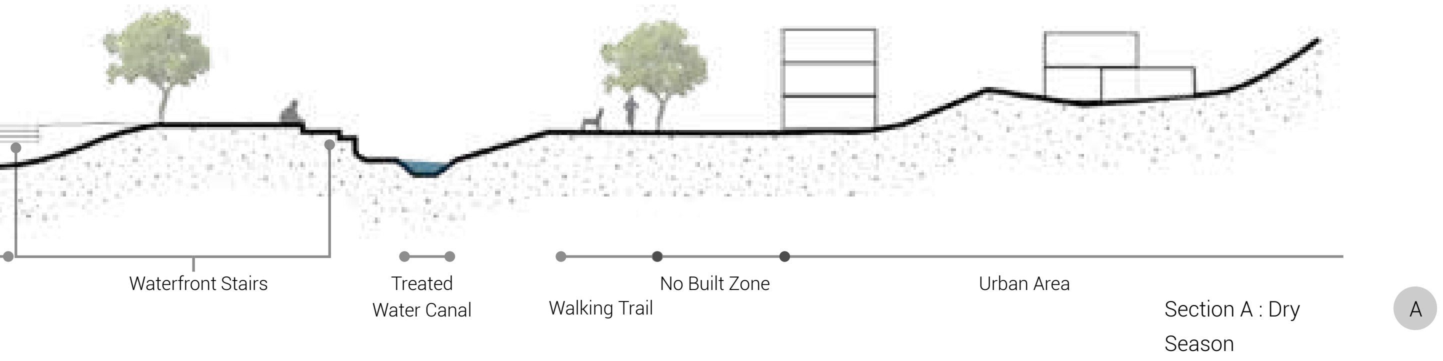
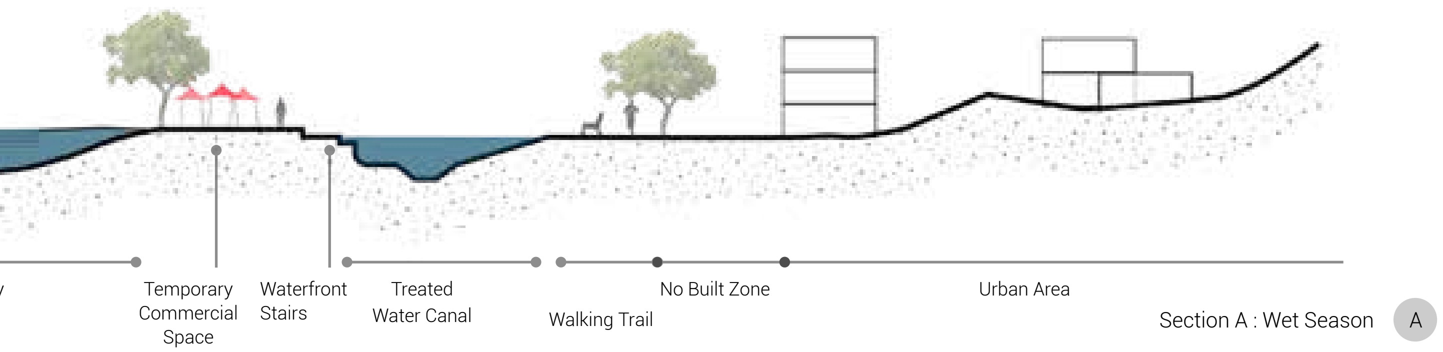
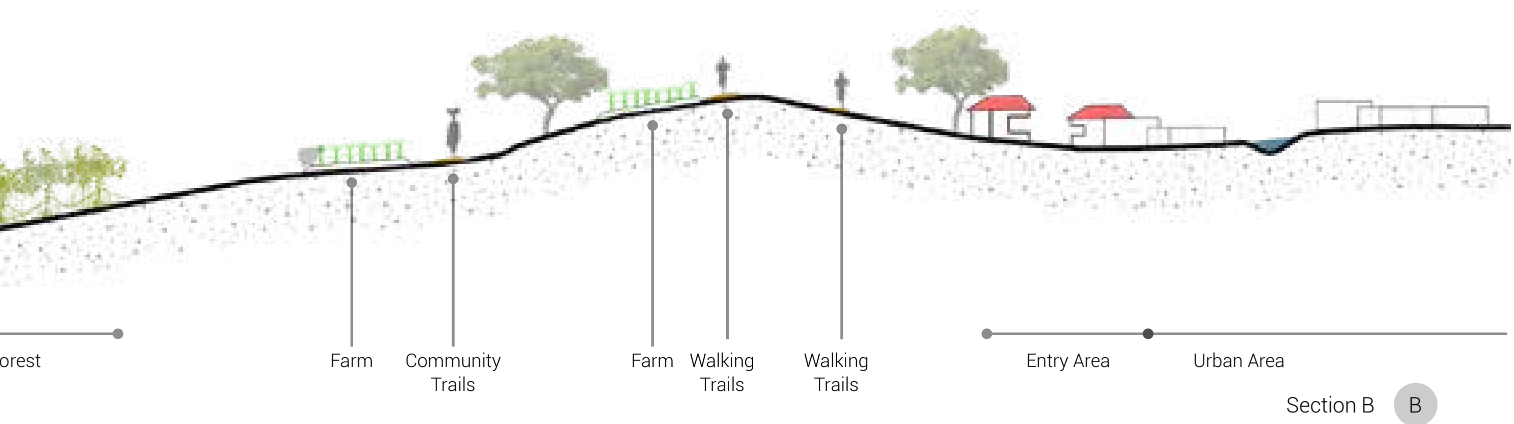


Figure 91 Proposed Green buffer - Cross Sections









The design responds to the seasonal change in the water body. The salt pan areas are used as a nursery for the mangrove plants in the dry season and are replanted in the forest areas during the wet season when the pans flood with rain water. The area then becomes a recreational space and can host temporary commercial activities by the local population.

The walking trails on the site are to be demarcated using natural stones and materials on site. Paving can be avoided and the tasks can be carried out by the communities themselves. A community children's park has been zoned next to the fishermen village and the main access to the beach as a visible and safe public space with direct access to the water in the wet season.

7.7 Biodiversity - Mangrove Forests

Sufficient sediment supply and fresh water supply is the key of mangroves restoration. Currently, the restoration of mangroves inside the Muni-Pomadze lagoon suffered from erosion and water quality degradation. This situation could be mitigated by the construction of wetland for water purification and the building of permeable structures. There are many research being done using the permeable structures to help the restoration of mangroves. Since 2015, BwN program has been building permeable structures, together with locally-formed community groups, in three villages in Demak District, namely Bedono, Timbulsloko, and Surodadi (Tonneijck et al., 2015).

Local materials like bamboo and branches could be used to build the permeable structures in Muni-Pomadze lagoon. Those permeable structures functioning like the artificial "root" will dissipate the strong tidal energy, reduce the impact of disasters, such as flooding and help the accumulation of sedimentation. By applying the permeable barriers to reduce erosion and catch the sedimentation, the implementation will help young mangrove forests grow and expand. This process has been successfully implemented in Java, Indonesia, where it has also supported community development by protecting both the land and the shrimp farms (Winterwerp et al., 2014).

Figure 92 Growth of natural mangroves and sedimentation accumulation behind the location of Permeable Structures in Timbulsloko Village. Photo by Apri Susanto Astra

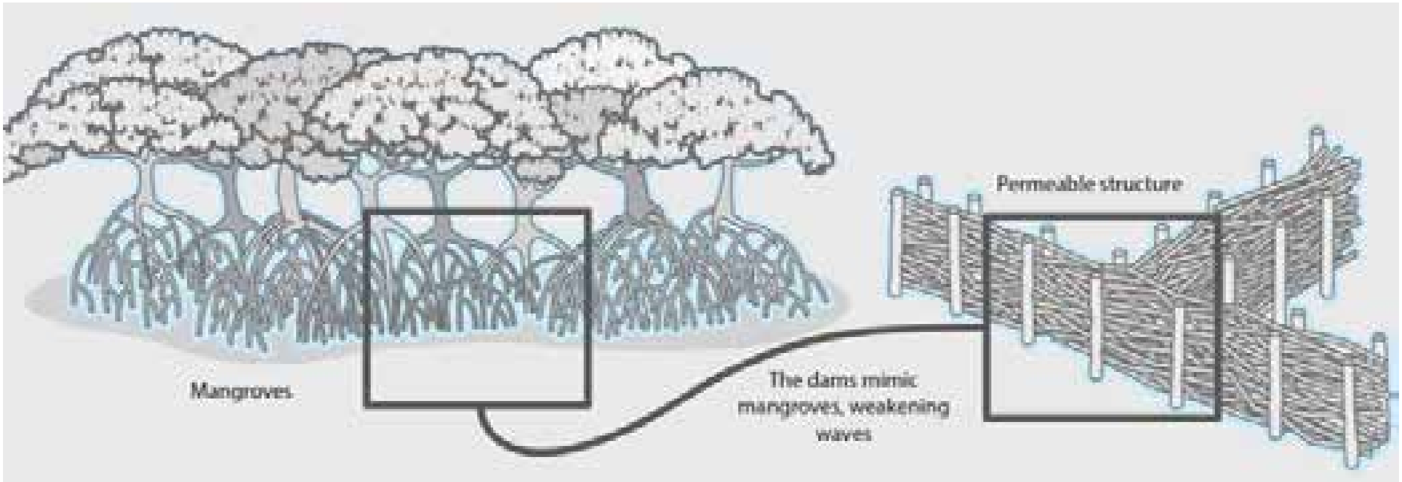


Figure 93 Permeable structures mades of bamboo and branches (https://makeasmartcity.com/2016/06/16/permeable-dams/).

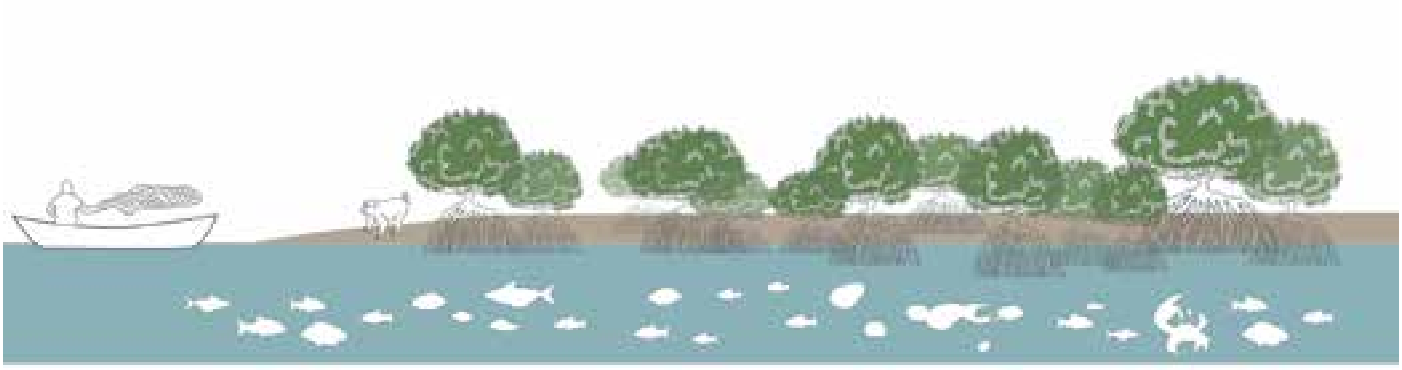


Figure 94 Cross Section of Mangrove Restoration (Danyan Lui, 2019)

7.8 Salt Pan Adaption

To the south of the greenbelt plan, there is the existing placement of the Salt Pans. These pans are no longer in use, but provide a ideal structure for plant life due to their elevated structure providing shallow water and small openings. Within the abandoned Salt Pans and marshes of Rochefortand Brouage, France, the area has seen an influx of vegetation which can survive within the soil salinity and the flooding duration of the solar salt pans (Bouzillé, Kernéis, Bonis & Touzard, 2001). Within Madagascar, the Honko Community Based Mangrove Reserve has also seen a growth in magroves and sea grass within their abandoned salt plans. Of course the climate in Ghana is significantly different to such examples, but the premise of using non-invasive plants which thrive in salinated soil and can withstand shallow flooding could be used as method to redevelop these salt pans.

For this reason the project proposes that a section of the pans be converted into a nursery for mangroves to grow before being replanted elsewhere on the site. Not only could this provide a local and simple production of mangroves, but i also could provide as a testing site to see how species react within the calmer environment in comparison to the rest of the lagoon.

Figure 95 Vegetation on abandoned salt pans at Salines de Llevant Mallorca Spain

Figure 96 Honko Community Based Mangrove Reserve: Abandoned Salt Pans Photo by Honko Community Based Mangrove Reserve Management

7.9 Provisional - Livelihoods

Provisional services on the site are primarily the livelihood opportunities which are directly dependant on the site. The proposal attempts to create sustainable practices for these livelihoods to reduce the exploitation of the site by the communities.

Constructed Wetland Farming and Fishing

The farm lands present on the site have been demarcated in the Green Belt Design. The design proposes that the land is clubbed and cooperative farming is practiced. The land ownership remains with the current owners but they are restricted from selling it to a third party as per policy provisions by the Lagoon Authority. Further, the community cultivates the land collectively and reaps the profit as per their land share. This allows them to gain a higher yield and avoids over exploitation of small parcels of land. Further, it averts the current and future challenge of small unproductive land holdings.

In order to limit the exploitation of the lagoon resources, a constructed wetland has been placed in close proximity to the farms. The water from the wetlands can be used for irrigation after its purification phase and the sludge from the sewage can act as the organic manure. This reduces the use of chemical pesticides. The model aims to act as a pilot for the farming practices of the region, hoping to inspire other farmers by gaining high yields.

A similar model is also used for fishing in the fish ponds constructed or formed after the constructed wetland. As cited in the case study (5.1), these ponds not only provide livelihood opportunities through controlled aquaculture, but also help in the purification of water. Having controlled ponds for fishing will also reduce the fishing activities in the lagoon, giving the fish population time to recuperate.

Figure 97 Cooperative Farming also a way for Women Empowerment (http://bassiounigroup.com/cooperating-on-cooperatives/)

Figure 98 Fields irrigated with waste water in Kolkata, India (Source : World Health Organization)

Figure 99 Fishing in Wastewater in Kolkata (Source : India Water Portal)

Figure 100 Levee on the Muni-Pomadze site, photo by Ranee Leung

08 Roadmap

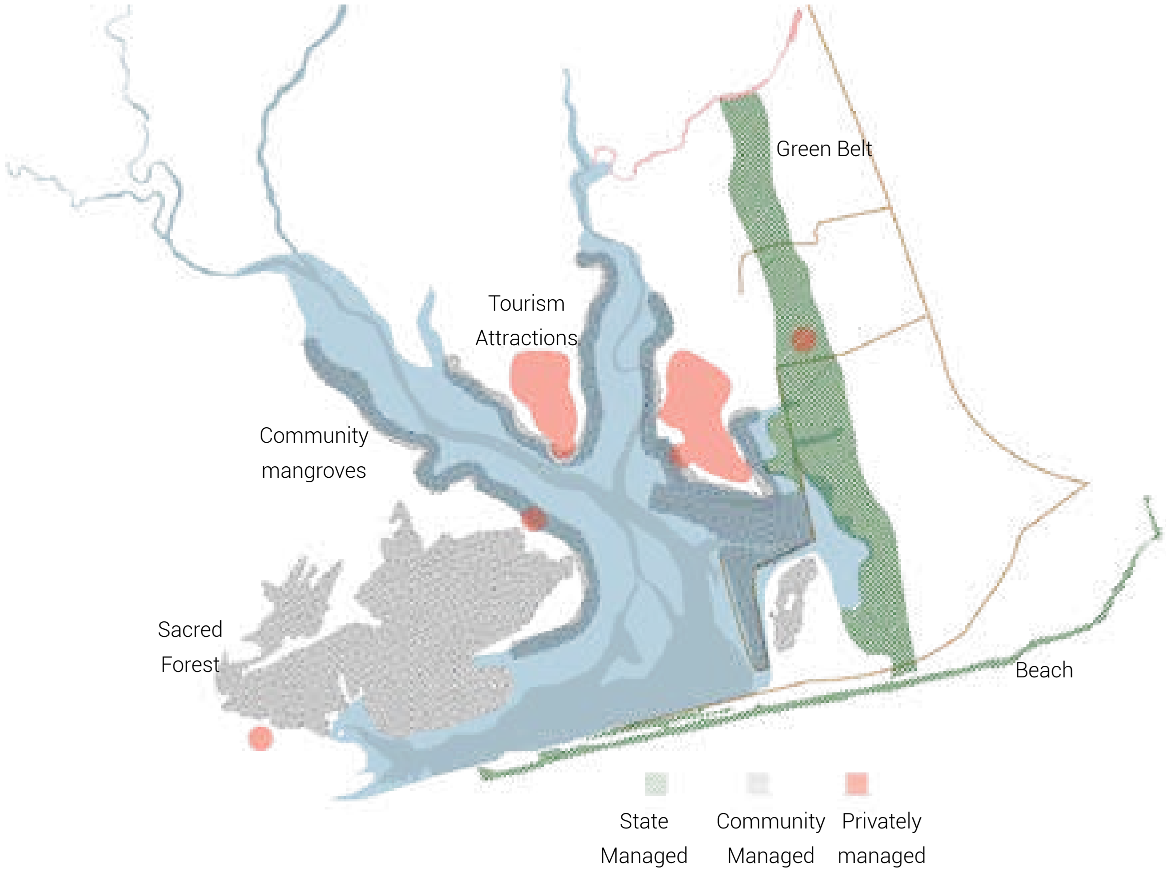


Figure 101 Area Based Management of the Lagoon

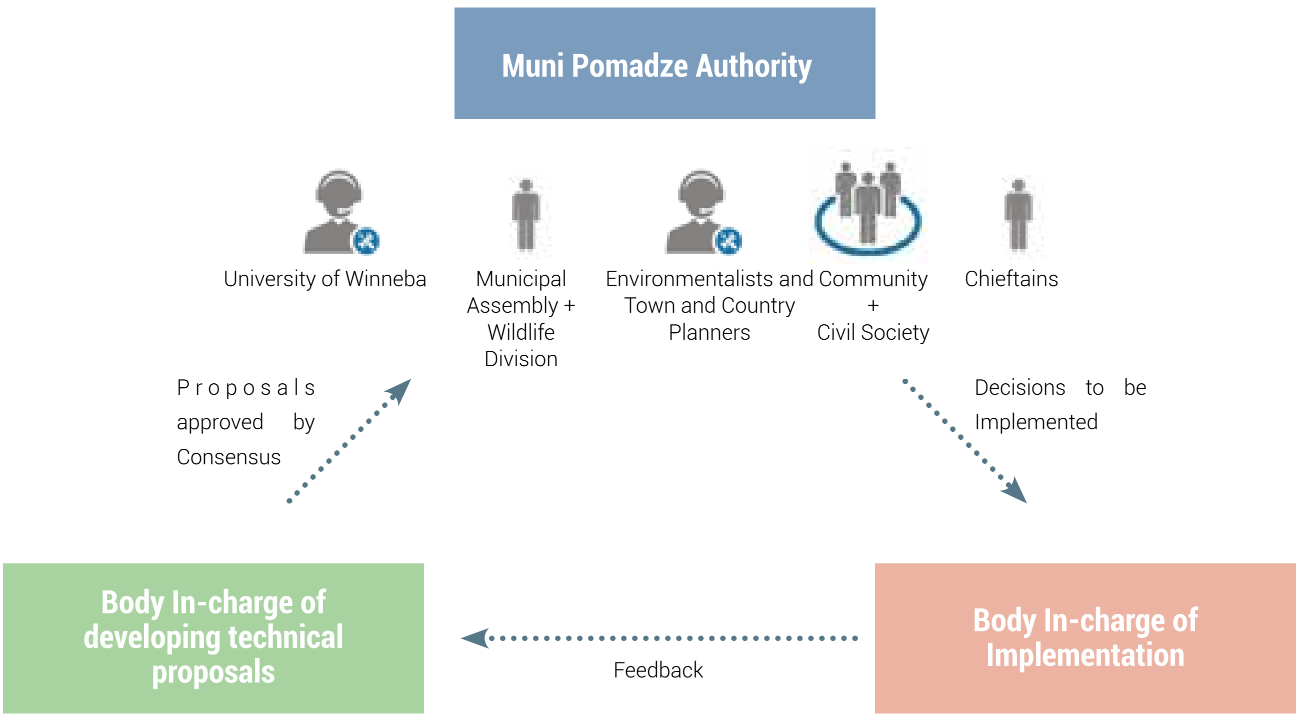


Figure 102 Shared Governance structure

8.1 Governance for Conservation

Conservation by area-based management

Conservation is a dynamic phenomenon, dependant on internal and external circumstances and "human institutions" like human values, knowledge and skills and policies and practices. Throughout history many human cultures have had different mechanisms of maintaining their relationship with the natural environment. While some societies have failed miserably, some have been able to maintain a mutually beneficial relationship with nature.

For example, throughout villages in West Africa, dedicated families or clans are devoted to conservation practices and maintaining the spiritual relationship between the people and the land. They are considered to be the original inhabitants of the land and are responsible for the management of the land.

While this practice brings a feeling of ownership to the community, it needs to be altered towards the needs of the stakeholders and dynamics of the current situation. Contemporary conservation has to cater to the interest of the civil society, private parties as well as the state authorities. Integrating these interests with the indigenous functions and knowledge of the site can prove to be a successful model for the Muni-Lagoon.

The strong influence of the Traditional Chieftains of the communities on the land management and decision-making, indicates the underlying prevalence of the traditional practices and beliefs of the society. This combined with the interests of the private stakeholders and the municipality can be used to generate area functions like the tourism initiatives and the municipal gardens to incidentally conserve the area as a secondary consideration. This makes the stakeholders accountable for maintaining the land and does not hold a single body responsible for conservation.

Source : Feyerabend, Dudley, Lassen et al, 2013

Shared Governance / Collaborative governance
Moving towards indigenous governance

The International Union for Conservation of Nature (IUCN) and the Convention on Biological Diversity (CBD) both recognise four broad governance types for protected areas. They range from a top down approach by the government to complete power to the local communities and the indigenous people to manage the resources. What is essential in all the types is the importance of the ecosystem services for the the conservation process.

For the Muni-Pomadze Lagoon, it is feasible to have a Shared Governance or 'Collaborative Governance' which is iterative in nature and in the long run moves towards complete governance by the indigenous people of the land. The Shared Governance model is based on mechanisms which share the authority and accountability among several formal and informal actors. It proposes that while the decision making power remains in the hands of one body or committee, the body is required to, by law or policy, to inform and consult the other stakeholders at the time of planning and implementation.

In order to tailor-make this model for this site, this research proposes a joint committee of representatives of all the stakeholders to be created exclusively for the management of the conserved area and its surroundings. This body must contain democratic representation from the Chieftains, local communities, Wildlife Division, A Rocha and other NGO's working in the area, University of Winneba, Town and Country Planning Department, environmentalists and the relevant private investors. The committee will be the decision making body and wil ensure the participatory processes are carried out for the implementation of any intervention on the site or which might have an influence on the site.

The implementation or enforcement bodies are to be from the civil society to ensure that the process is bottom-up. Similar initiatives on other Ramsar Sites like the New Zealand case study (refer 5.2) can be reffered to for operational tips.

8.2 Roadmap

To sum up, the interventions that are proposed in this project can be brought together into three main categories: Spatial, Governance and Community awareness. Below (Figure 103), the specific interventions related to each category are listed.

Spatial	Initial Investment	Revenue Return	Key Actors Responsible + Investors
1. Creation of the natural embankments	$		Community-based initiatives with State funding
2. Opening of the Lagoon	$		State initiative
3. Breakwater	$$		State funding
4. Constructed Wetlands	$	$$	Community-based initiative
5. Plastic Recycling Plant	$$	$$	Private enterprise
6. Planning of Forest, Park and Sanctuary			Effutu Municipality
7. Construction of the Park	$$	$$	Wildlife Division + Community
8. Eco-tourism: maintaining the existing situation			
9. Eco-tourism: Connecting to full vision	$	$$	Private Enterprises
10. Salt pan use for mangrove nursery / removal of dikes	$		NGO's + Community

Governance	Initial Investment	Revenue Return	Key Actors Responsible + Investors
11. Formation of the Authority			Municipality + Wildlife Division + NGO's
12. Vision and Goals document: making	$		Muni - Pomadze Authority
13. Vision and Goals document: implementation	$		Muni - Pomadze Authority
14. Conservation Policies			Muni - Pomadze Authority + Forestry Comm.
15. Joint- research Programmes	$	$$	University + MP Authority + NGO
16. Open House of Projects			Muni - Pomadze Authority
17. Enrichment strategy			Muni - Pomadze Authority
18. Site Analysis	$$	$$	University + MP Authority + International Research Organisation

Community awareness	Initial Investment	Revenue Return	Key Actors Responsible + Investors
19. Planting of Mangroves	$		NGO's + Community with state or public funds
20. Collection of Traditional knowledge	$		NGO's + University
21. Participatory Learning			NGO's with State funding
22. Skill development	$$	$$	NGO's with international NGO funding
23. Workshops and Capacitation (Educational drives)	$		NGO's with international NGO funding

Figure 103 Proposed interventions

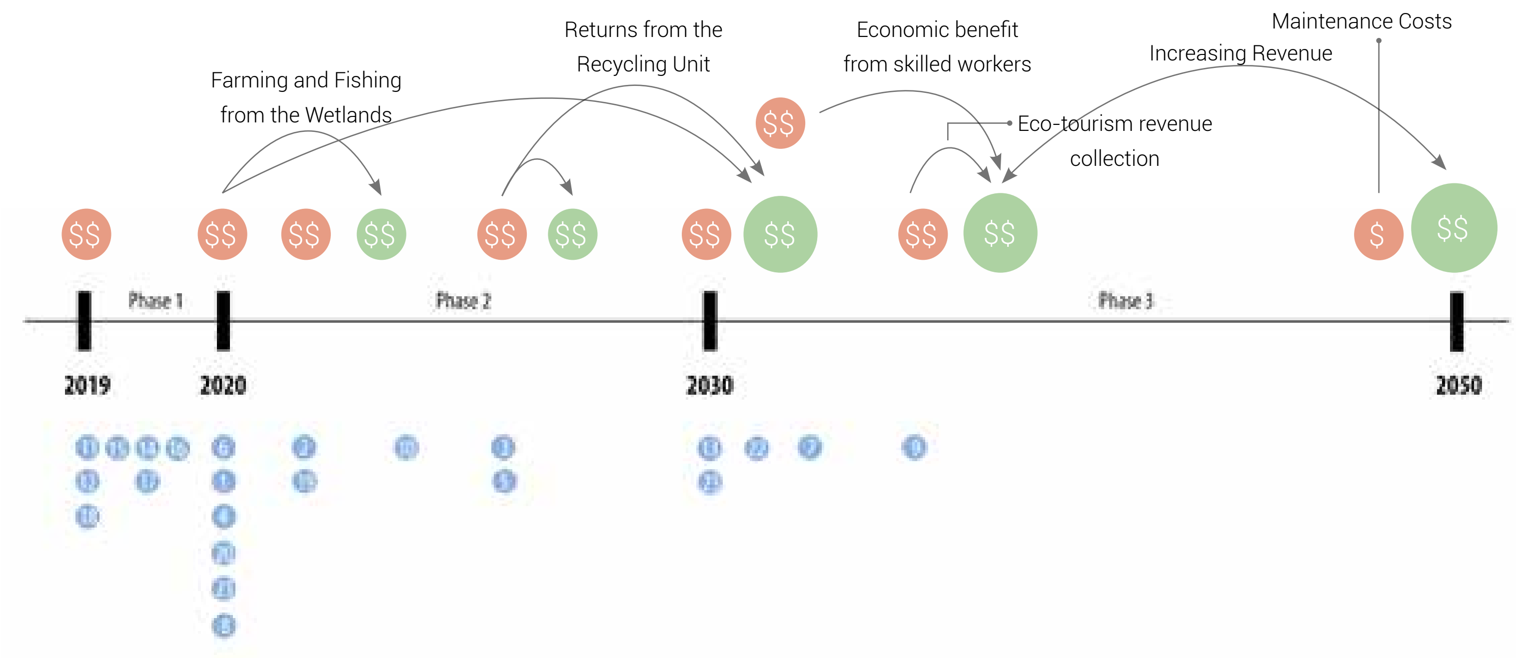


Figure 104 Roadmap Timeline

Phase 1.0 Representing the vision

Before starting with the construction phase, the internal and external stakeholders need to cooperate to form the new Muni-Pomadze Committee. It is essential that the new formed authority comes up with a vision for the development of the lagoon, which should be oriented towards the conservation of the lagoon and for the future benefits of the community. Based on a thorough site analysis and the proposals given in this report, the design phase is developed.

Furthermore, the new committee will strongly be involved in establishing all the necessary plans by 2020, such as creating conservation policies for MPL, strategies to enrich the ecology of the lagoon and having joint research programs with the university to create awareness and educate the community. The participation of the community will also be promoted by creating open house projects for the possible design of the park or any other project suggestion for the benefit of the site.

Phase 2.0 Short-term goals (period 2020-2030)

In 2020, the construction phase will start. The execution of the short term interventions is carried out until 2030 in several steps:

Step 1:
- Creation of the nature-based stable embankments: Before the opening of the lagoon, the existing bank must be stabilized and protected against erosion.
- Constructed Wetlands
- Planning of the Forest, Park and Sanctuary: The design of these facilities is based on the gathered traditional knowledge and participative design within communities.

Step 2:
- Opening of the Lagoon: The lagoon is opened by the use of light machinery (excavator). Maintenance operations are carried out with a frequency of three to five years.
- Planting of mangroves: Community education about mangrove types and planting.

Step 3:
- Salt Pan Use for Mangroves Nursery: education/re-purposing

Step 4:
- Breakwater construction: only in the long-term, if a financial model suggests that a permanent solution is effective in restoring the lagoon ecology.

A monitoring campaign is necessary to gather real data about the changes in the coast morphology. Based on the general laws of physics that explain the coastal phenomena, a coastal model must be developed for the area of study. When the sample of real data is statistically significant, the results of the model simulation can be compared with the real data in order to calibrate and validate the model.

The validated model can be used to estimate the morphological effects caused by the breakwater in a longer period. The changes in the morphology of the

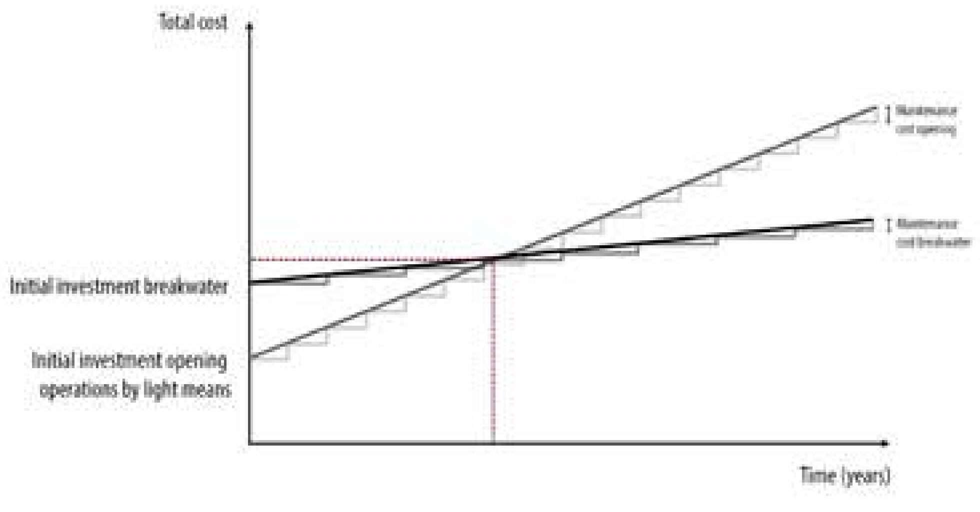


Figure 105 Development of the cost in time of the breakwater and the opening of the lagoon by excavator.

opening can also be analysed. Based on these effects, a feasibility study can be carried out to evaluate which of the two alternatives is more viable. The construction of the breakwater supposes larger capital expenditures and lower maintenance costs, while opening the lagoon by light means (excavator) entails low capital expenditures but large maintenance costs.

- Plastic Recycling Plant: Initiatives from foreign investor, NGOs and communities.

Phase 3.0 Long-term goals (period 2030-2050)

Step 5:

- Implementation enforcement of the vision
- Community workshops: Educational drives and ownership exercises.

Step 6:

- Skill development
- Construction of the Park: (bordering Winneba & Muni-Pomadze)

Step 7:

- Eco-tourism: Once the biodiversity is flourishing, the whole concept of eco-tourism can be improved from the existing situation and the vision can be fully integrated. Propositions for eco-tourism are routes/viewing decks/boardwalks, hotels, amenities and recreation corridors held by private and public investors.

Figure 106 Levee on the Muni-Pomadze site, photo by Ranee Leung

09 Reflection and Conclusions

9.1 Relevance

Wetlands, specifically coastal lagoons, are extremely productive natural systems which are vital to both local and global ecosystems. These environments have the ability to support and create numerous ecosystem services which regulate and support the natural environment, as well as provide necessary resources for the local community. Yet, these services are at risk, especially when considering their rapid decline in most regions of the world. Improper planning of human activities and over-exploitation of the surrounding natural resources have damaged the biodiversity and the natural processes which occur in these areas and have placed the balance of ecosystem services at risk. These services are an essential element for the existence of surrounding communities, yet have still been exploited beyond capacity.

With the Muni-Pomadze Lagoon as our case study, the research project sought to identify an approach to manage and enhance these coastal lagoons in an increasingly challenging climatic and political context. Considering the complexity of the issues, the project chose an interdisciplinary and collaborative approach to produce a holistic solution for the site. Further, it uses the principles of Nature-Based Design and the 4-P framework (People, Planet, Prosperity, Space and Project) to guide and reflect on the design. In order to develop the final recommendations for the site, the project built upon the concept of ecosystem services in order to create a set of interconnected strategies which could equalize the imbalance between declining regulating/supporting services and increasing provisional/cultural practices. Rather than framing ecosystem services as a consumptive opportunity, the project introduced an element of ecosystem participation, where the community could improve supportive and regulatory services whilst reducing provisional and cultural services. The research has identified strategies to achieve this. Such strategies included options for a tidal inlet, mangrove/vegetation restoration, eco-tourism generation, governance recommendations, and general land use strategies to protect and improve the services on site. These designs outlined in the document build upon the scientific knowledge of coastal lagoons through the lens of urbanism, landscape architecture, civil engineering, hydraulic engineering and water management.

While the project intends to add to the theoretical knowledge of sustainability and coastal lagoons, it also has contributed to the body of knowledge which has been available for the Forestry Commission and the Municipal body of Winneba. This data is an accessible starting point to take action within the Muni-Pomadze lagoon, which has the ability to become a case study for the successful management of a coastal lagoon along the West African Coast.

9.2 Discussion

Following our methodology, the solutions are based on our interdisciplinary knowledge which addresses the issues in the Muni Pomadze Lagoon. However, some implications during the process have been noticed.

Analysis

Several measurements and small interviews were taken during the fieldwork to gain insight into the problems of MPL and the suitable nature-based solutions in this area. However, some factors are difficult to point out what the issues are in the MPL. This leads to uncertainty of whether or not the implementations do have an actual beneficial impact. The time limit and the lack of good data are one of the factors which would have an influence on certain decisions.

Interdisciplinary approach

It was difficult to come to an agreement for one solution between all the possible ideas and perspectives during this research. Therefore, a more thorough process is needed to guide coordination between an interdisciplinary project. During the process, some interdisciplinary solutions have been found. Furthermore, the solutions are based on different types of disciplines which are mainly focused on water quality, urbanism and hydraulic structures. Yet, the knowledge about the biodiversity of MPL is limited. Therefore, the effects of the nature-based solutions on the MPL on the ecological environment are uncertain as well, although some considerations and assumptions are made. Involvement of different disciplines such as ecology, policy management could provide a better insight.

Feasibility of the implementation

The nature-based solutions are soft approaches for the local community. Cost-effective solutions are chosen to improve the ecological environment.

The benefits of using nature-based solutions are depending on the situation and preferences of the local community. They might prefer another implementation which causes a rupture in our strategy to address the MPL. However, the implementations of our nature-based solutions can also be implemented separately or be applied in combinations with other alternatives.

9.3 Conclusions & Recommendations

The purpose of taking the Muni-Pomadze lagoon as a case study was to gain insight on how to address issues facing coastal lagoons and adjacent communities with an interdisciplinary approach. As mentioned prior in the report, this is formulated in our main research question: ***How can a coastal lagoon be ecologically conserved and enriched by integrating natural processes and anthropic processes for the future?***

As an effort to develop strategies to ecologically conserve and enrich the MPL, several considerations need to be accounted in order to integrate natural and anthropic processes. The analysis clearly dictates that the dominant threats to the MPL are from urban encroachment, overfishing, waste and water pollution from the urban settlements and other climate related issues. In addition, there is a lack of communication and clear hierarchy of the governing system with the MPL. The project aimed to approach these outlined issues with nature-based contextual solutions. At the same time, the design intent strived to keep provisional ecosystem services and as a key consideration to plan for more sustainable livelihood patterns. These identified threats could be a key component in applying a similar methodology in analyzing and formulating strategies to comparable lagoon locations in Ghana or other developing nations.

Coastal lagoons are unique ecosystems are attractive for human settlements due to the provisional services they offer. It was found essential to keep these services as a key consideration and to further plan them to increase their supportive value. Further, following a nature-based technical approach resulted in producing contextual solutions with minimal input and high long term gains for the lagoon as well as the dependant communities. This was done through employing technical solutions to restore the health of the water and the surrounding biodiversity while integrating the current and alternate livelihoods of the directly dependant communities to avoid further exploitation. The research advocates that community involvement and bottom-up initiatives are the key to a successful conservation plan. The case studies revealed that the community initiatives are the most effective and economic method to conserve natural resources, provided they are given ownership and responsibility of the area. In order to integrate the natural and anthropic processes, it was essential to define these processes and identify all the relevant stakeholders. Stakeholder management was found to be a key point of intervention for the MPL case.

Collaboration Between Stakeholders and Execution of Projects
Stakeholder collaboration and the ambiguity in their responsibilities was seen to be as one of the major underplayed issues on the site. In order to resolve several of the pressing issues on the site, it became apparent that initiatives would be closely intertwined with the involvement of stakeholders and local communities. Culturally rich developing nations would need context specific and nature-based solutions that would resonate with the community. This would assist in integrating and a conscious effort from the communities alongside low-maintenance processes. However, future collaborations with the local stakeholders, university and governmental institutions would be needed to develop precise solutions. In addition, it is essential to create initiatives for participatory planning and to create an ownership model for conservation. Sectoral collaboration and a formation of authority for the MPL would facilitate communication and execution of projects in a more efficient manner rather than ad-hoc initiatives. It is strongly recommended that an action plan should be developed by using solutions as a guiding framework.

Based on the lessons learned from other case studies, it is essential that when determining a model and execution of community based eco-tourism, extensive stakeholder meetings are required in any decision-making process before executing projects. A key aspect is to have transparency and promotion of a fair distribution model alongside benefits and equity for the community. If these requirements are not met before the launching of the project, it will become extremely challenging and difficult to execute any projects proposed in the report.

Limitation of Data and Repercussions of Opening the Lagoon
The primary physical intervention that is needed to enrich the existing ecological condition of the lagoon includes creating an opening to allow for a connection to the ocean. As previously stated in the analysis, this would enable several positive effects to the ecosystem and socio-economic condition of the area. However, additional and more in-depth scientific data would be needed in order to understand the full extent of the repercussions of opening the lagoon. First, only a small sample of contaminated water in the MPL was measured in the dry season to gain insight about the current issues. A proper investigation would require several samples over an extended period. Second, there would need to be a comparison between the variations in data between the wet and dry season. Third, the lack of data and equipment to survey the area complicates the results in determining the exact location and indication of the source of pollution in the lagoon. Fourth, the proposal to expand the wetlands and integrating a natural water filtration would need to be monitored to see the changing levels in water quality and biodiversity.

A future recommendation for the project is that data should be monitored every month before creating effective solutions to address the water pollution. By initiating a regular monitoring system, further insights and conclusions could be made on the behavior of the system. This is fundamental in providing working knowledge towards a more permanent solution for the future. Additional future recommendations for the project would need to include in-depth site investigations and creation of models to understand the morphological changes, sediment transport and water level changes inside the lagoon. For example, modelling the sediment transport along the coast in the event of introducing breakwater could provide validation on introducing this system. The second would be a coastal modelling of the tides to verify the amplitude of the water level inside the lagoon. The results from this would determine if the opening of the lagoon would jeopardize the sediments located within the water body.

Due to the limited scope of the project, the maintenance, operation and cost of the nature-based solutions should also be analyzed to see the feasibility of executing the project. If the strategies and interventions were to be replicated to another site, every location would need to have this requirement due to the varying environmental and socio-economic conditions per site.

Interdisciplinary Approach

The over exploitation of natural resources and degradation of the wetlands is a worldwide issue which cannot be tackled with a mono-disciplinary approach. It is essential to identify the prevalent issues and handpick the expertise required to achieve sustainable solutions. The interdisciplinarity approach makes the solutions much more efficient and holistic leaving less space for error and ignorance.

Figure 107 Levee on the Muni-Pomadze site, photo by Ranee Leung

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Figure 108 Levee on the Muni-Pomadze site, photo by Ranee Leung

Appendix

Appendix A, Design of a stable tidal inlet, breakwater design

To ensure a permanent opening between the ocean and the MPL a design for a breakwater in combination with a bank and bed protection is proposed as one of the alternative solutions. This appendix will provide a preliminary deterministic design based on limited available data, estimations and filed observations. The data that is missing is estimated based on literature or field observations. For this design there was no geotechnical data available. Therefore it is assumed that the geotechnical properties are good enough to build the structure. In further stages of the design a geotechnical survey should be done.

Location

The location of the opening will be on the eastern part of the barrier separating the lagoon and the ocean. The bathymetry of this location can be found in Figure 109 The depth profile perpendicular to shore has been obtained using the information from (Navionics, 2018) and can be found in Figure110

Figure 109 Coastal Bathymetry in front of the barrier (Navionics, 2018)

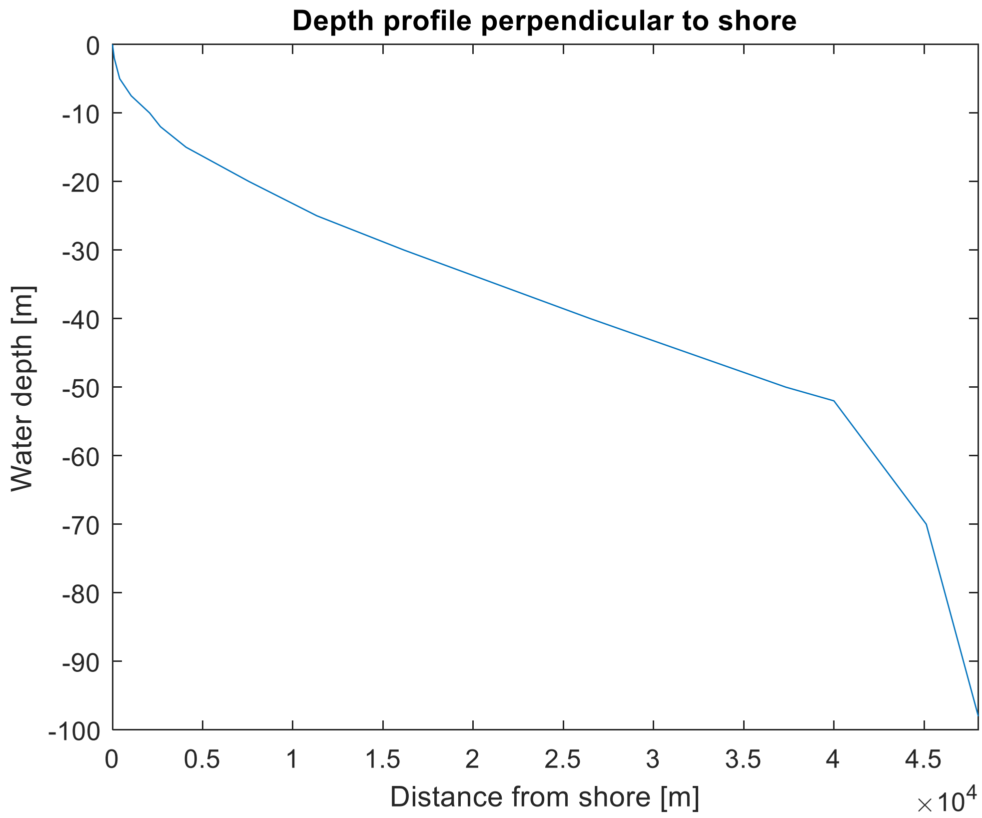

Figure 110 Depth Profile of the coastal area perpendicular to the shore (164 deg North)

Design of a stable tidal inlet

The design of a stable inlet consists of the following parts: the channel, breakwater, bank protection and protection against scour. The basic design criteria for the design are given in the next section.

The channel

The channel enables the connection between the MPL and the ocean. The depth, the length and the profile should be designed in such a way that there is no accretion within the channel to prevent sediment to accumulate which might lead to a closure. For the design there are two scenarios that determine the boundary conditions that have to be considered for the design:

- Dry season scenario: the tide is the only source of discharge through the tidal inlet.
- Wet season scenario: The volume discharged through the inlet is combination with the tide together determine the discharge.

To prevent accretion the flow through the tidal inlet should be sufficiently high. As a result the bed and the banks in the tidal inlet should be protected against erosion.

The breakwater

A breakwater is needed to prevent waves and sediment from moving into the channel of the inlet. The breakwater is constructed from rocks which can be obtained from Eastern Quarries Limited near Accra or another quarry nearby. A typical rubble mount breakwater consists of an armour layer made of large rocks and a core from rock of a smaller diameter. The breakwater can be permeable as long as the wave transmission is low enough that it does not have an effect on the sediment transport inside the channel. The boundary conditions for the breakwater are the highest significant wave height, angle of incidence and peak period.

Protection against scour

To prevent scour behind the bed protection inside the channel a scour protection should be designed. The scour protection can be made from rocks.

Boundary conditions

The boundary conditions at the structure can be calculated from the offshore wave climate. The offshore wave climate has been obtained from (Waveclimate.com, 2019). Both satellite observations that have been converted to wave conditions and wave data from a model have been used.

Wave data at the breakwater

To find the significant wave height (H_s), the 2% exceeded wave height ($H_{2\%}$) and the offshore wave length (L_{0m}) offshore the wave data from (Waveclimate.com, 2019) had to be obtained. The input that has been used on waveclimate.com is presented in table 1. The location that was given to find the wave data in front of the Ghanaian coast, see also figure 3 to see the presence of altimetry data.

Parameter	Value
Offshore location	5° 17'N, 0° 26'W
Offshore model point	5° 00'N, 0° 30'W
Size of offshore area for satellite data	200x200 km

Table 3 Input to collect wave data on (Waveclimate.com, 2019)

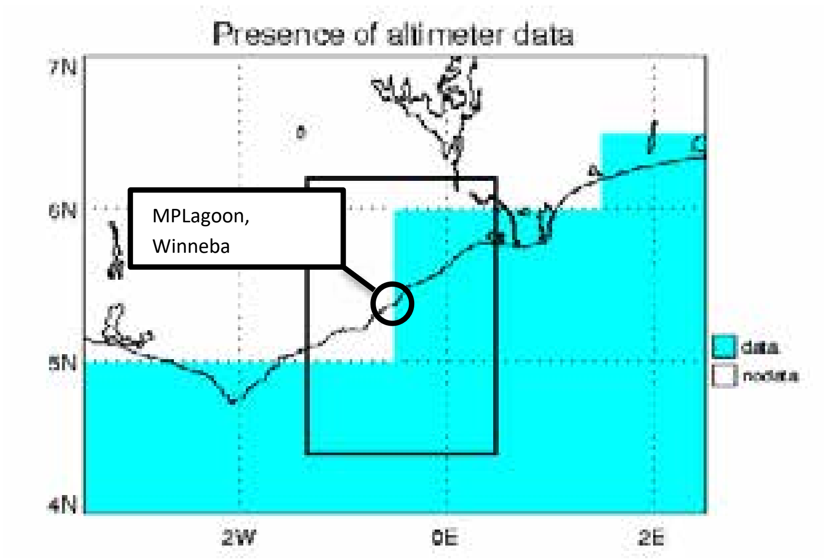

Figure 111 Location of Data (Waveclimate.com, 2019)

Significant wave height

The monthly significant wave height satellites can be found in the following table, the colours indicate the height of the value, the blue cells can have a value below 0.04 and red gives the highest percentage of occurrence.

Lower H_{s0} [m]	Upper H_{s0} [m]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.0	0.5	3.9	2.2	1.2	0.6	0.3	0.1	0.3	0.1	0.3	0.3	0.8	3.2
0.5	1.0	48.6	35.4	25.6	15.5	7.5	3.2	3.9	3.2	4.7	10.8	19.2	42.7
1.0	1.5	42.6	55.9	62.7	60.6	57.0	41.0	39.9	40.8	47.9	59.4	59.9	48.4
1.5	2.0	3.9	5.7	9.3	20.7	28.9	45.7	44.9	44.0	36.6	26.1	17.8	4.7
2.0	2.5	0.5	0.5	0.8	1.9	5.0	8.5	9.3	9.7	8.6	3.0	1.7	0.6
2.5	3.0	0.2	0.2	0.3	0.6	0.9	1.1	1.5	1.8	1.7	0.3	0.4	0.5
3.0	3.5	0.2	0.1	0.1	0.2	0.4	0.3	0.2	0.3	0.3	0.2	0.2	0.1
3.5	4.0	0.0	0.1	0	0.0	0.0	0.1	0.0	0.0	0.0	0	0.1	0.0
4.0	4.5	0	0	0	0.0	0	0.0	0.0	0.0	0.0	0	0.0	0.0
4.5	5.0	0	0	0	0	0	0	0	0	0	0	0	0
total		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 4 Monthly occurence (%) of significant offshore wave hight H_{s0}[m] (Waveclimate.com, 2019)

From these measurements it is clear that the highest offshore significant wave height is in the category H_{s0} = 4 - 4.5 meters, the coloured cells have a value of 0.0 because these waves occur less the 0.04%. However these waves are normative for the design of the breakwater. The results found from this table are for deep water conditions, and therefore they should be converted to near shore conditions at the breakwater.

Mean period and wave length

To obtain the wave length, the mean offshore period T_{m0} must be known. There is not enough data available to find this from the satellite imagery and therefore the wave model computations from waveclimate.com have been used (Waveclimate.com, 2019), see table 4 . It should be noted that the modelled range of occurring significant wave heights is smaller than the observations from satellite. The highest waves (range 2.5 – 3.0 m) have a period ranging from 8 to 13 seconds, and generally the highest wave heights have a mean period between 9 and 12 seconds.

		Lower T_{m0} [s]	03	04	05	06	07	08	09	10	11	12	13	14	15	
Lower H_{s0} [m]	Upper H_{s0} [m]	Upper T_{m0} [s]	04	05	06	07	08	09	10	11	12	13	14	15	16	total
0.0	0.5		0.0	0	0	0	0.0	0.0	0.0	0	0	0	0	0	0	0.0
0.5	1.0		0.0	0.0	1.1	6.0	9.8	6.9	2.2	0.5	0.1	0.0	0.0	0.0	0	26.7
1.0	1.5		0	0.0	0.9	6.1	16.0	18.4	10.7	4.3	1.2	0.2	0.0	0.0	0	57.8
1.5	2.0		0	0	0.0	0.5	2.1	3.7	4.0	2.4	0.9	0.2	0.1	0.0	0	14.0
2.0	2.5		0	0	0	0.0	0.0	0.2	0.3	0.4	0.2	0.1	0.1	0.0	0	1.4
2.5	3.0		0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0	0.0
3.0	3.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total			0.0	0.1	2.1	12.7	27.9	29.1	17.3	7.6	2.4	0.6	0.2	0.0	0.0	100.0

Table 5 Table of offshore significant wave height [H_{s0}] and corresponding mean wave period [T_{m0}] data based on model computations from (Waveclimate.com, 2019)

For the design purpose a mean period of 12 seconds is used because this value has the highest percentage of occurrence in the range of significant wave height between 3.0 and 3.5 meters. This value is also chosen because longer waves cause more damage and are therefore normative in the design. It can be noted that 99.2 % of the waves have a mean offshore period of 12 seconds or less so there is only a 0.8 % chance that the waves will be longer.

Direction of the waves

The direction of the waves in deep water is important for the alongshore sediment transport as well as for the design of the breakwater. The results from the model computations (Waveclimate.com, 2019) can be found in table 4.

		Lower [deg N]	105	115	125	135	145	155	165	175	185	195	205	215	225	235	
Lower H_{s0} [m]	Upper H_{s0} [m]	Upper [deg N]	115	125	135	145	155	165	175	185	195	205	215	225	235	245	total
0.0	0.5		0	0	0	0	0	0	0	0	0.0	0.0	0.0	0	0	0	0.0
0.5	1.0		0	0.0	0.0	0.0	0.0	0.0	0.7	8.7	13.0	3.8	0.4	0.0	0.0	0	26.7
1.0	1.5		0	0.0	0.0	0.0	0	0.0	1.7	15.4	25.9	12.7	2.0	0.2	0.0	0	57.8
1.5	2.0		0	0	0	0	0.0	0.0	0.6	4.1	5.9	3.0	0.4	0.1	0.0	0	14.0
2.0	2.5		0	0	0	0	0	0	0.1	0.6	0.5	0.2	0.0	0.0	0	0	1.4
2.5	3.0		0	0	0	0	0	0	0.0	0.0	0.0	0.0	0	0	0	0	0.0
3.0	3.5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total			0.0	0.0	0.0	0.0	0.0	0.0	3.0	28.7	45.3	19.8	2.8	0.3	0.0	0.0	100.0

Table 6 Table with significant wave height [H_{s0}] and direction [deg N] (Waveclimate.com, 2019)

From these observations it can be found that the dominant wave direction is around 190 [deg N]. And the direction for the highest waves is spread between 115 and 235 degrees north.

Nearshore transformation

A nearshore transformation is necessary to transform the offshore wave data to the near shore situation. There are several effects that happen when the waves approach the shore. For this preliminary design the following processes have been taken into account:

- Shoaling
- Wave breaking
- Refraction

Shoaling

To calculate the increase of the wave height due to shoaling the formula for shoaling has been used (Bosboom, Stive, 2015, p. formula 5.7).

$$H_s = \sqrt{\frac{1}{\tanh(kh)}\frac{1}{2n}} * H_0$$

Where the wave number k is calculated using:

$$k = \frac{2 * \pi}{L}$$

The wave length is found iteratively by using the dispersion relation (Bosboom, Stive, 2015, p. formula 3.22)

$$\omega = \sqrt{gk\tanh(kh)}$$

The dispersion relation can be rewritten to find the wave length. The wave length is found using a starting value of 10 and 1000 iterative steps.

$$L = \frac{gT_{m0}^2}{2\pi} * \tanh(\frac{2\pi}{L * h})$$

The ratio between the group velocity and the higher phase velocity is called n and can be calculated using the following formula (Bosboom, Stive, 2015, p. formula 3.26)

$$n = 0.5\left(1 + \frac{2kh}{\sinh(2kh)}\right)$$

Wave breaking

When the waves start shoaling and the depth decreases the waves will at some point become too steep and start breaking. The breaking process in shallow water can be calculated using the breaker index γ (Bosboom, Stive, 2015, p. formula 5.19).

$$\gamma = \left[\frac{H}{h}\right]_{max} = \frac{H_b}{h_b} = 0.88$$

First the significant wave height after shoaling is calculated. When the maximum breaker index is exceeded the value of the significant wave height becomes $0.88 * h_b$.

Refraction

As the depth decreases the waves start to refract towards the depth contours. This effect can be calculated by using Snell's law (Bosboom, Stive, 2015, p. formula 5.8). To calculate this, the wave velocity (c) also has to be calculated by rewriting the dispersion relation (Bosboom, Stive, 2015, p. formula 3.23).

$$\varphi_1 = \text{asin}\left(c * \frac{\sin(\varphi_0)}{c_0}\right)$$

$$c = \frac{gT}{2\pi}\tanh(kh)$$

Results nearshore transformation

The wave transformation has been performed using Matlab, the code can be found at the end of this appendix. The results are represented in figure 4 showing the bathymetry, angle and significant wave height. Also the design conditions for each depth are given in table 5.

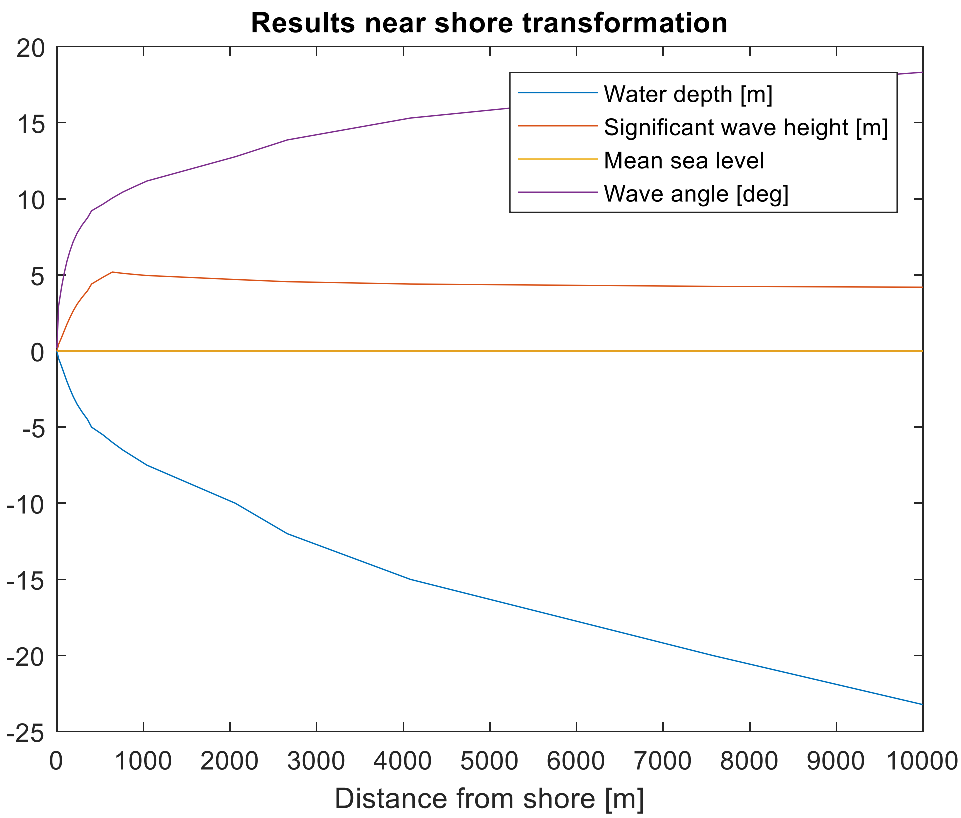

Figure 112 Results from near shore transformation

From the results the boundary conditions for the maximum significant wave height at a certain depth can be found. For a water depth of 2 meters a significant wave height of 1.76 meters is found.

Water depth [m]	Significant wave height [m]	Wave length [m]	Direction [deg]
0.50	0.44	26.51	2.96
1.00	0.88	37.41	4.18
1.50	1.32	45.71	5.11
2.00	1.76	52.66	5.89
2.50	2.20	58.73	6.58
3.00	2.64	64.19	7.19
3.50	3.08	69.17	7.75
4.00	3.52	73.77	8.27
4.50	3.96	78.06	8.75
5.00	4.40	82.08	9.21
5.50	4.84	85.88	9.64
6.00	5.19	89.49	10.05
6.50	5.10	92.92	10.44
7.00	5.03	96.19	10.81
7.50	4.96	99.32	11.17
10.00	4.70	113.30	12.76
12.00	4.55	122.89	13.86
15.00	4.40	135.35	15.30
20.00	4.25	152.36	17.28
25.00	4.16	165.96	18.88
30.00	4.12	177.04	20.19
40.00	4.11	193.62	22.18
50.00	4.16	204.83	23.54
52.00	4.17	206.58	23.75
70.00	4.29	217.14	25.05
100.00	4.43	223.22	25.80
3200.00	4.50	224.83	26.00
4000.00	4.50	224.83	26.00

Table 7 Results from near shore transformation

Breakwater design

A rubble mount breakwater typically consists of an armour layer and a core from smaller material. In between the core and the armour layer usually a filter layer is constructed. The structure has a certain free board, which is the distance between the highest water level and the crest of the breakwater. The armour layer at the sea side is usually supported by a tow to prevent scour. A cross sectional design of the breakwater can be found in figure 113.

Armour layer

For the stability of the rocks in the armour layer, the formula from van der Meer (J.P. van den Bos, H.J. Verhagen, 2018, p. 86)will be used to find the diameter d_{n50}.

$$\frac{H_s}{\Delta d_{n50}} = c_{pl} P^{0.18} \left(\frac{S}{sqrt(N)}\right)^{0.2} \left(\frac{H_s}{H_{2\%}}\right) * \xi_m^{-0.15} \quad (For\ plunging\ waves)$$

$$\frac{H_s}{\Delta d_{n50}} = c_{pl} P^{-0.13} \left(\frac{S}{sqrt(N)}\right)^{0.2} \left(\frac{H_s}{H_{2\%}}\right) * sqrt(\cot(\alpha)) \xi_m^P \quad (For\ surging\ waves)$$

To find out if the formula for plunging or surging waves should be used, the surf similarity parameter has to be calculated with the following formula (J.P. van den Bos, H.J. Verhagen, 2018, p. 82).

$$\xi_m = \frac{\tan(\alpha)}{\sqrt{s_{m0}}}$$

$$s_{m0} = \frac{H_s}{L_{0m}}$$

The results with the wave data at the toe (depth of 2 meter) can be found in table 6.

H_{s0}	T_{m0}	Slope	Iribarren number
4.5	9	1:3	1.8
4.5	12	1:3	2.4

Table 8 Results to find if plunging or surgin waves occur

From the calculation of ξ_m it is clear that the waves at the breakwater are plunging and therefore the formula for plunging waves is applied to determine the nominal stones diameter (d_{n50}) of the armour layer.

Parameters

In table 7, the specific data to calculate the required stone size of the armour layer can be found.

Parameter	Value	Source
Delta [-]	1.65	Relative density, typical value found in literature
c_{pl} [-]	8.7	Fit coefficient (J.P. van den Bos, H.J. Verhagen, 2018, p. 86)
c_s [-]	0.08	Fit coefficient (J.P. van den Bos, H.J. Verhagen, 2018, p. 86)
P [-]	0.5	Permeability parameter: Typical value for a breakwater with a permeable core (G.J. Schiereck, H.J. Verhagen, 2016, p. 197)
S [-]	8	A damage level of 8 is typical for a breakwater in the ultimate limit state (J.P. van den Bos, H.J. Verhagen, 2018, p. 86)
Cot(alpha)	0.3	A slope of 1 in 3 is chosen for this design
ξ_m	$\xi_m = \frac{\tan(\alpha)}{\sqrt{s_{m0}}}$ $s_{m0} = \frac{H_s}{L_{0m}}$	(J.P. van den Bos, H.J. Verhagen, 2018, p. 82)
H_s [m]	1.76	From near shore transformation
$H_{2\%}$ [m]	2.94	Using the value for $H_{1\%} = 1.67*H_s$ (J.P. van den Bos, H.J. Verhagen, 2018, p. 36)

Table 9 Parameters and their value

Results/conclusion

Using the van der Meer formula for plunging waves a d_{n50} of 0.47 meters is found. For the final design a stone class HM_A 300 – 1000 should be used for the outer layer. This corresponds to a range of 300 – 1000 kg, which can be ordered from a local quarry. A layer thickness of $2*d_{n50}$ = 1.2 meters is necessary on the front side.

Design of the crest height and freeboard

The crest height is based on the formula for overtopping of waves over a breakwater (J.W. van der Meer, N.W.H. Allsop, T. Bruce, J. De Rouck, A. Kortenhaus, T. Pullen, H. Schüttrumpf, P. Troch, B Zanuttigh, 2018, p. 174).

$$\frac{q}{\sqrt{g * H_s^3}} = 0.1035 * \exp\left[-(1.35 * \frac{R_c}{H_s * \gamma_{f,overtopping} * \gamma_{\beta,overtopping}})^{1.3}\right]$$

$$\gamma_{\beta,overtopping} = 1 - 0.0063|\beta|$$

Parameters

A maximum overtopping q = 0.1 [m^3/m/s] is considered acceptable for the design of a breakwater without a road. All the parameters used to calculate the crest height are shown in table 8.

Parameter	**Value**	**Source**
Dir [deg]	5.89	From near shore transformation
Storm water level [m CD+]	0.3 + 1.2 = 1.5	Wind setup (assumption) + Highest Astronomical Tide (HAT) (assumption)
H_s	1.76	From near shore transformation
Max. overtopping q [m^3/m/s]	0.1	Typical value for ultimate limit state (J.P. van den Bos, H.J. Verhagen, 2018)
g	9.81	Standard value used in literature
$\gamma_{f,overtopping}$ [kg/m^3]	0.40	Typical value for double permeable rock layer (J.W. van der Meer, N.W.H. Allsop, T. Bruce, J. De Rouck, A. Kortenhaus, T. Pullen, H. Schüttrumpf, P. Troch, B Zanuttigh, 2018)

Table 10 Parameters to calculate the crest height of the breakwater

Results

Using the formula for overtopping a free board (R_c) of 0.85 meters is found. The crest height can be calculated by adding the HAT and wind setup.

The crest height of the breakwater is:

$$Crest\ height = 0.3 + 1.2 + 0.86 = 2.4\ [m\ CD+]$$

Armour layer on the rear side

As a preliminary design and due to the lack of data a symmetrical breakwater will be designed. Within the design it is assumed that the same armour layer as the front of the breakwater will be sufficient. Hence the thickness of 1.2 meters and a d_{n50} = 0.59 meters.

Core and filter layer

To make the breakwater less permeable and more economic, it is common to apply a filter layer and a core of finer material than the armour layer. To design these layers the filter rules for a geometrically closed filter will be used to make sure that the core material cannot migrate through the armour layer.

The design is based on the rule of thumb for the ratio between stone (G.J. Schiereck, H.J. Verhagen, 2016) sizes:

$$\frac{dn_{50,top}}{d_{n50,filter}} = 2 - 3$$

Filter layer

Applying the mentioned rule, a filter layer with a diameter of 21 cm should be sufficient because the ratio is 2.8. This is a stone class LM_A 10 – 60 with a range of 10-60 kg. A layer thickness of 1.5*d_{n50} = 0.32 m should be sufficient (G.J. Schiereck, H.J. Verhagen, 2016, p. 360).

Core material

For the core, the same filter rule is used, which results in a d_{n50} of 9.7 cm (stone class CP90/250 and has a range of 90/250 mm).

Width of the crest

For simplicity the top layer will be constructed from the same material as the armour layer. To create a stable top at least 2*d_{n50} is needed for stability reasons. Therefore a crest width of 2 meters will be applied.

Toe structure

The toe is important for stability of the armour layer, as well as to prevent scour from the return currents of the waves on the breakwater. To keep the design simple, the toe will be constructed of the same material as the armour layer. The basic rule for the dimensions of the toe are a height of 2*d_{n50} and a width of 3*d_{n50} (J.P. van den Bos, H.J. Verhagen, 2018, p. 94).

Design of the cross section

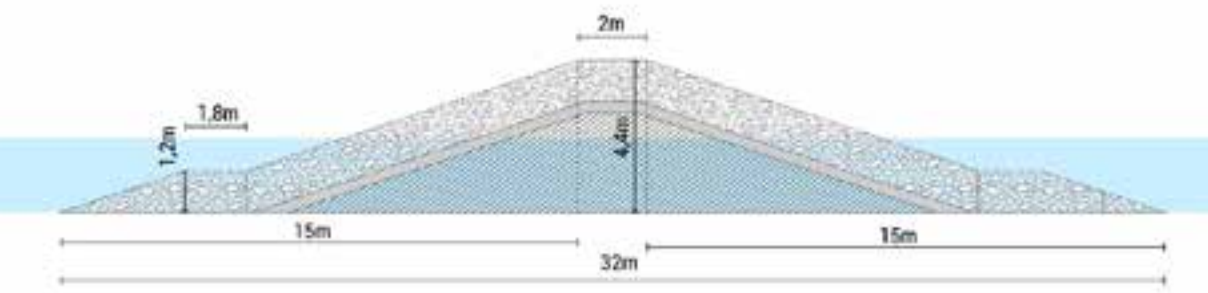

Figure 113 Cross section of the breakwater design

Top view

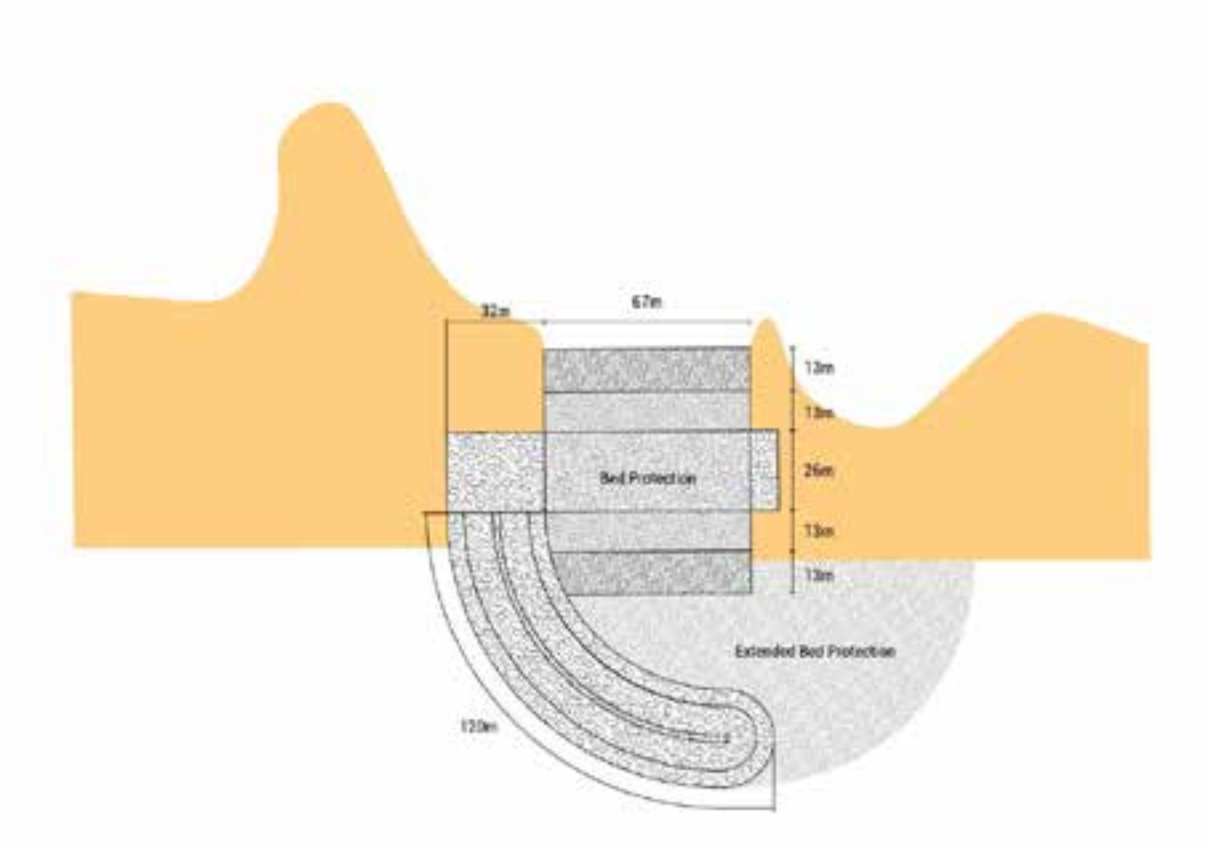

Figure 114 Top view of the breakwater

Artistic impression of the breakwater and coastal area

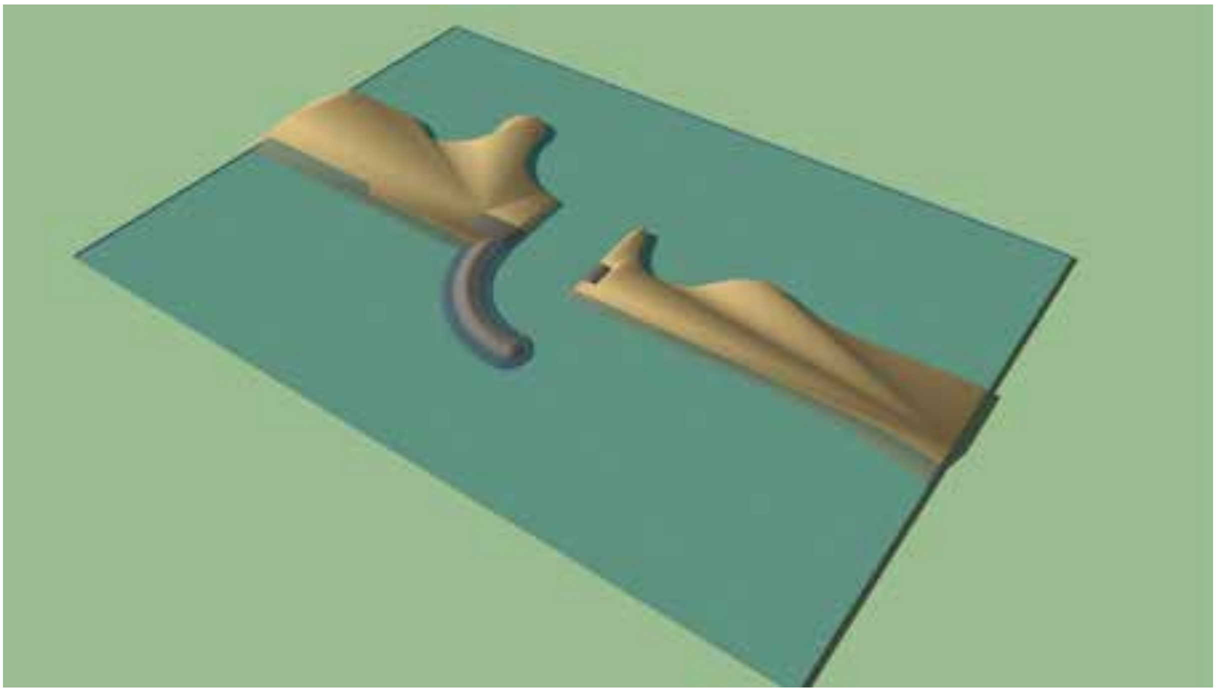

Figure 115 Artistic impression of the barrier and the breakwater

Appendix B, Longshore transport

To estimate the effect of a stable opening with a breakwater on the adjacent coastline and the interaction between a structure and the coast the alongshore sediment transport due to waves has to be estimated.

CERC Formula

There are two effects that need to be considered. First the waves induce a longshore current which is the main driver for the transport of the sediment (Bosboom, Stive, 2015, p. 345). The longshore current is driven predominantly by breaking waves which approach he coast under an angle.

The second effect on the longshore transport is the increase of the suspended sediment due to the waves. The orbital motion causes the magnitude of the bed shear stress to vary over each wave cycle and creates two peaks. During these peaks the shear stress on the bed is highest and sediment is mobilized. The other effect of the breaking waves is the increase in turbulence in the water column which brings suspended sediments into the upper parts of the flow.

To determine the potential bulk (total) sediment transport (S) in the breaker zone, the CERC formula can be used as a first estimate (Bosboom, Stive, 2015, p. 350).

$$S = \frac{K}{\big(16(s-1)(1-p)\big)}\sqrt{\frac{g}{\gamma}}\,sin(2\varphi_b)H_b^{2.5}$$

The parameters used to calculate S can be found in table 1.

symbol	Parameter	Value	Source
K [-]	(Coefficient for CERC formula)	$\left(\frac{1}{\sqrt{2}}\right)^{\frac{5}{2}}$	Typical value when using the significant wave height (Bosboom, Stive, 2015, p. 350)
s [-]	(Relative density)	$\frac{\rho_s}{\rho_w} = 2.59$	Calculated using ρ_s and ρ_w
P [-]	(porosity)	0.4	Estimation based on (Bosboom, Stive, 2015, p. 259)
g [m/s^2]	(gravity constant)	9.81	Assumption, typical value in literature
γ [-]	(breaker parameter)	0.78	(Bosboom, Stive, 2015, p. 350)
φ_b [deg]	(Angle of incidence	-	Variable, see next section
H_b [m]	(significant wave height)	-	Variable, explanation in next section
ρ_s [kg/m^3]	(density sand)	2650	Assumption, based on (Bosboom, Stive, 2015, p. 258)
ρ_w [kg/m^3]	(density sand	1025	Assumption, typical value used in literature

Table 11 Parameters used to estimate the bulk sediment transport

Significant wave height and angle

To make an estimation of the bulk sediment transport the table with wave data derived from waveclimate.com is used. Because the CERC formula only takes into account the significant wave height and the angle at the location where breaking starts the data can be divided in 4 ranges of significant wave height that occur. In combination with the percentage of time they occur the yearly sediment transport can be estimated.

Wave data

For the wave data the average value of each significant wave height has been used, see table 2. The full wave data can be found in table 2. To determine the wave height at the breaking point the same formula for shoaling and wave breaking have been used as in appendix A (design of a stable opening, section nearshore transformation). The resulting significant wave height at the breaking point ($H_{s,b}$) can be found in table 2.

	T_{m0} [s]	02	03	04	05	06	07	08	09	10	11	12	13	14	15	
Lower H_s [m]	Upper H_s [m]	03	04	05	06	07	08	09	10	11	12	13	14	15	16	total
0.0	0.5	0	0.0	0	0	0	0.0	0.0	0.0	0	0	0	0	0	0	0.0
0.5	1.0	0	0.0	0.0	1.1	6.0	9.8	6.9	2.2	0.5	0.1	0.0	0.0	0.0	0	26.7
1.0	1.5	0	0	0.0	0.9	6.1	16.0	18.4	10.7	4.3	1.2	0.2	0.0	0.0	0	57.8
1.5	2.0	0	0	0	0.0	0.5	2.1	3.7	4.0	2.4	0.9	0.2	0.1	0.0	0	14.0
2.0	2.5	0	0	0	0	0.0	0.0	0.2	0.3	0.4	0.2	0.1	0.1	0.0	0	1.4
2.5	3.0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0	0	0	0.0
3.0	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total		0.0	0.0	0.1	2.1	12.7	27.9	29.1	17.3	7.6	2.4	0.6	0.2	0.0	0.0	100.0

Table 12 Table of significant wave heigh and corresponding mean wave period, data based on model computations (Waveclimate.com, 2019)

Angle

To determine the angle for each range of significant wave height the same data from waveclimate.com has been used as in section: appendix A.

	[deg N]	105	115	125	135	145	155	165	175	185	195	205	215	225	235	
Lower H_s [m]	Upper H_s [m]	115	125	135	145	155	165	175	185	195	205	215	225	235	245	total
0.0	0.5	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0	0	0	0.0
0.5	1.0	0	0.0	0.0	0.0	0.0	0.0	0.7	8.7	13.0	3.8	0.4	0.0	0.0	0	26.7
1.0	1.5	0	0.0	0.0	0.0	0	0.0	1.7	15.4	25.9	12.7	2.0	0.2	0.0	0	57.8
1.5	2.0	0	0	0	0	0.0	0.0	0.6	4.1	5.9	3.0	0.4	0.1	0.0	0	14.0
2.0	2.5	0	0	0	0	0	0	0.1	0.6	0.5	0.2	0.0	0.0	0	0	1.4
2.5	3.0	0	0	0	0	0	0	0.0	0.0	0.0	0.0	0	0	0	0	0.0
3.0	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
total		0.0	0.0	0.0	0.0	0.0	0.0	3.0	28.7	45.3	19.8	2.8	0.3	0.0	0.0	100.0

Table 13 Table with significant wave height and direction (Waveclimate.com, 2019)

For each range of significant wave heights the corresponding value for the angle has to be estimated. To do so the centre of gravity (Wikipedia, 2019) of the different directions for a certain wave height has been calculated. The results can be found in table 2. For the nearshore transformation the same formula for refraction has been used as in appendix A .

Results

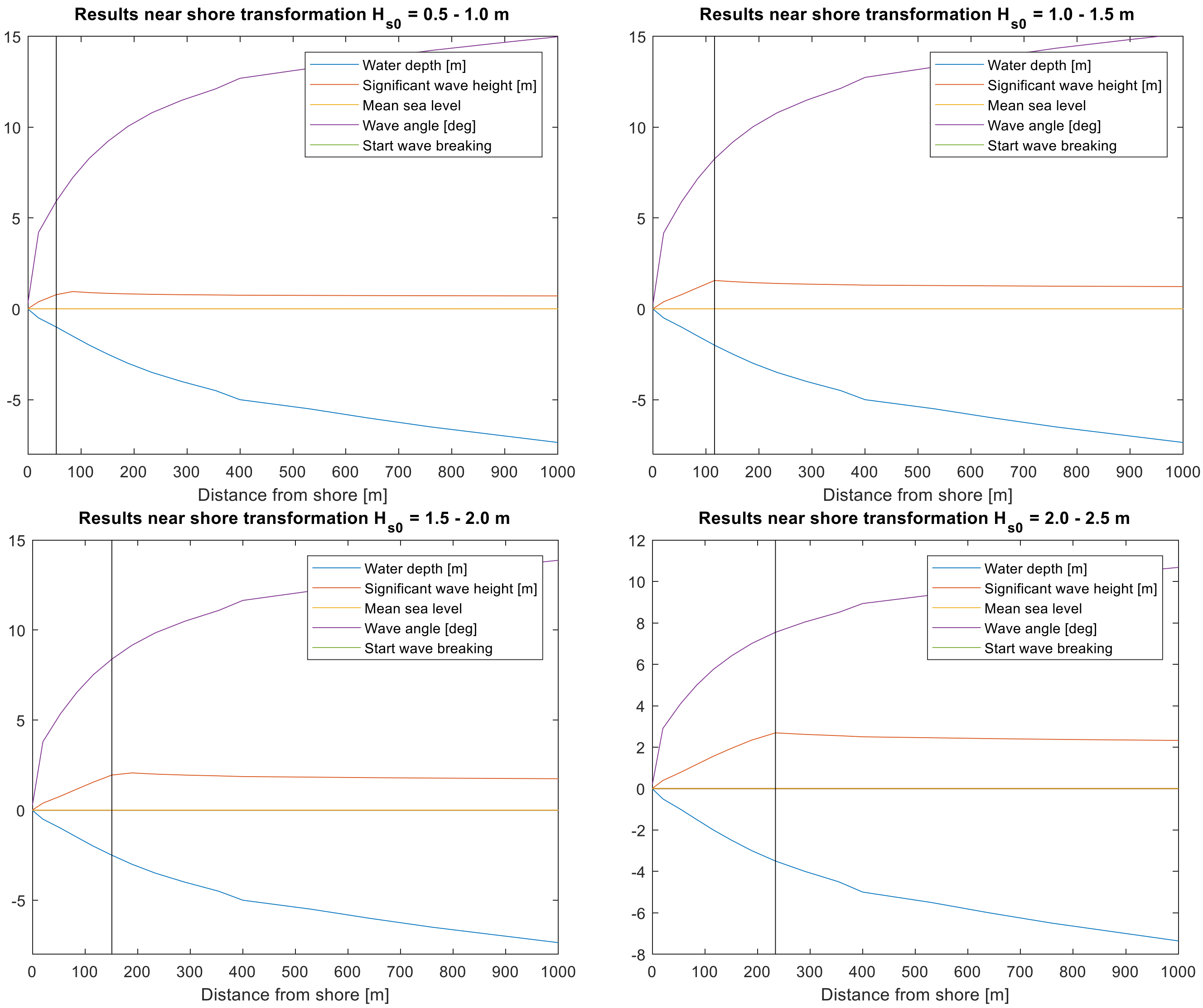

Figure 116 Results from nearshore transformation to find relevant data at the point of breaking

Range of H_{s0} [m]	Mean H_{s0} [m]	Offshore Angle phi_0 [deg]	Percentage of occurrence [%]	Offshore mean period T_{m0} [s]	Significant wave height at breaking point $H_{s,b}$ [m]	Angle at breaking point phi_b [deg]	Potentials sediment transport S [m^3/s]
0.0 – 0.5	0.25	200	-	-	-	-	-
0.5 – 1.0	0.75	187	26.7	7.5	0.78	5.9	0.01
1.0 – 1.5	1.25	190	57.8	8.5	1.6	8.3	0.08
1.5 – 2.0	1.75	189	14.0	9	2.0	8.4	0.15
2.0 – 2.5	2.25	185	1.4	10	2.7	7.5	0.30
2.5 – 3.0	2.75	185	-	-	-	-	-

Table 14 **Results and input values for CERC formula**

The total sediment transport per year can be calculated by multiplying the sediment transport for each range of significant wave height with the corresponding percentage of occurrence. This gives the total sediment transport per second, to find the yearly potential bulk sediment transport this should be multiplied with the number of seconds in a year (365*24*60*60).

$$(0.01 * 0.267 + 0.08 * 0.578 + 0.15 * 0.14 + 0.3 * 0.014) * 365 * 24 * 60 * 60 = 2.3 * 10^6\ m^3/yr$$

Conclusion

From the CERC formula and wave data we find that there is a potential yearly longshore sediment transport from west to east of around $2*10^6$ m^3 per year. This is a very rough first estimate and it is probably an overestimation, other models also gave a estimation of around $1*10^6$ m^3 per year (Ocean & Coastal Management, 2018). However, this calculation provides an insight in the fact that the potential sediment transport due to waves is very large (around 2 to 4 times as much when compared to the Dutch coast (Bosboom, Stive, 2015, p. 360). This could also help to explain why the tidal entrance migrates because there is an abundance of sediment delivered and deposited on the western side of the tidal inlet. Also it might explain the closing of the tidal inlet, when the forcing of the tide and run of through the tidal inlet are low there is enough sediment transported to fill the entrance channel.

Appendix C
Water quality in Muni-Pomadze Lagoon

	A	B	C	D	E	European Water Quality Standards
pH	8,22	8,1	8,17	8,09	8,05	7-9
NO3 (ppm)	50	30	30	10-20	1	50
NO2 (ppm)	0,15-0,3	0,3-1	0,3	10	0-15	<10
Salinity (ppt)	12,3	11,4	1,4	11,7	11,2	0,5-30 (for brackish water)
Temperature	30,3	30	30	28,8	30,6	30

Table 15 Water quality in the Muni-Pomadze Lagoon`

Appendix D

Constructed Wetlands and Facultative Lagoon calculations

```
#A is surface area of wetlands
#Q discharge [m^3/d]
#CW manual *t uit pagina 196
#n is porosity clayey sand https://www.geotechdata.info/parameter/soil-porosity.html
#Calculations based on kinetics of primary clarifier

T=28
k20=0.282
d=0.75
n=0.37
Cin=50
Cout=10

kT=k20*1.06**(T-20)
kbod=kT*d*n

Q=1679.4213569024391
A=Q*(log(Cin)-log(Cout))/kbod
HRT=(A*d)/(0.5*Q)
b=sqrt(A/2/2)
l=2*b
print ('Surface Area of Constructed Wetland:',A)
print ('HRT is',HRT)
print('Width is ',b)
print ('Length is',l)
21670.797/2
```

```
Surface Area of Constructed Wetland: 21670.796870324702
HRT is 19.355592431813644
Width is  73.6050216872543
Length is 147.2100433745086
```

```
#https://iwaponline.com/sites/default/files/ebooks/9781780402109.pdf
from pylab import *
#design facultative pond
#surface area loading is determined
#40 g BOD per person per day
Q=1675.4213569024391
D=1.5
T=28
pop=55331
Winarea=13120000
Lagarea=11.97E4
WinLag=5430000
Ls=350*(1.107-(0.002*T))**(T-25)                      #surface loading rate

pc=(Lagarea + WinLag)/Winarea
L=40E-3*pc*pop                                        #influent total BOD5
A=L/Ls                                                #Area of facultative pond in ha
V=A*D*10000
HRT=V/Q
print ('Area of facultative pond in ha :',A)
print ('Retention time: ',HRT)

#assumption length/width ratio =2
b=sqrt((A*10000)/2/2)
l=2*b
print ('length of one facultative pond',l)
print ('width of one facultative pond',b)

#Removal of effluent soluble BOD

K=0.091+2.05E-4*Ls
kt=K*1.05**(T-20)
S=Ls/(1+(kt*HRT))
#Removal of particulate BOD
PBOD=80*0.35
#Total
print ('Amount effluent in mg/l',PBOD+S)
print('removal efficiency',(Ls-(PBOD+S))/Ls)
```

```python
#Construction height of Dike around the facultative pond
#(SA=settlement allowance), DH=design height, F= freewaterboard, CH= construction heigth
#http://www.fao.org/tempref/FI/CDrom/FAO_Training/FAO_Training/General/x6708e/x6708e06.htm

F=0.5
SA=15
DH=1.5
CH=DH/((100-SA)/100)
print ('Construction heigth:',CH)

#slopewidth
SW=1.5*CH
Basewidth=(2*SW)+1
print ('Basewidth', Basewidth)

#Volume of Area
Adike=SW*CH+(1*CH)
print ('surface area of dike dwarsdoorsnede', Adike)
Vdike=Adike*l + Adike*b
print ('Clay/sand Volume of dike for two ponds in m^3 ',Vdike*2)
```

```
Area of facultative pond in ha : 2.7191921005088247
Retention time:  24.280860113136977
length of one facultative pond 164.89973082757987
width of one facultative pond 82.44986521378954
Amount effluent in mg/l 108.75587016030187
removal efficiency 0.7523442885631026
Construction heigth: 1.7647058823529411
Basewidth 6.294117647058823
surface area of dike dwarsdoorsnede 6.435986159169551
Clay/sand Volume of dike for two ponds in m^3  3183.8771480480664
```

APPENDIX E

Flow velocity in the Tidal Inlet

The following initial data has been used (Table 16)

g [m/s^2]	9.81	Acceleration due to gravity
h_{prec} [mm]	130	Precipitation in 6 h for 10-year return period event (Witteven+Bos, 2019)
T_{storm} [h]	6	Storm duration (Voorendt, 2016)
A_b [ha]	1000	Wet lagoon area (Davies, 2018)
f_{runoff} [-]	0.33	Run-off factor (USGS, 2018)
R [m]	1.25	Tidal range in the Winneba coast (Tides Chart, 2019)
T_{M2} [h]	12.42	Period of the principal lunar constituent M2 (Bosboom, 2018)

Table 16 Open situation of the lagoon (Google Earth, May 2016)

The first effect that will be quantified is the discharge through the tidal inlet due to the tide. The tide at Winneba has a semidiurnal character, with two high and two low tides per day. The period of the tidal wave corresponds to the principal lunar constituent (M2).

To calculate the discharge due to the tide in a simplified way, it is checked if the small basin approximation applies in this case. The condition that should be satisfied is:

$$\frac{l_b}{L_{M2}} \leq \frac{1}{20}$$

l_b is the length of the lagoon, which is approximately 5 km (Google Earth). L_{M2} is the length of the tidal wave:

$$L_{M2} = cT_{M2}$$

Since the tidal wave is considered a relatively long wave, shallow water conditions apply and the wave celerity is:

$$c = \sqrt{gd}$$

where d is the depth, assumed 4 m in the Winneba coast (Navionics, 2019). The wave celerity is 6.3 m/s. The resultant L_{M2} is 280 km and therefore the condition to assume the shallow water approximation applies ($0.02 \leq 0.05$).

According to the small basin approximation, it can be assumed that the water level in the lagoon is equal in all locations. The amplitude of the discharge in the tidal inlet ($\hat{Q}_b$) can be calculated as (Labeur, 2014):

$$\hat{Q}_b = \omega A_b \hat{\zeta}_b$$

where ω is the wave frequency, which is $\omega = \frac{2\pi}{T_{M2}} = 1.4 \cdot 10^{-4}\ rad/s$. $\hat{\zeta}_b$ is the wave amplitude inside the basin, which is $\hat{\zeta}_b = r\hat{\zeta}_s$, being $\hat{\zeta}_s$ the tidal amplitude at the sea, which is half of the tidal range (0.625 m) and r is the response factor (amplitude ratio). The response factor depends on the resistance and the inertia of the wave. Inertia becomes important if $\frac{\omega_0^2}{\omega^2}$ is close to 1, where ω_0 is the eigen frequency of the basin:

$$\omega_0 = \sqrt{\frac{gA_c}{l_{inlet}A_b}} = 3.43 \cdot 10^{-3}\ rad/s$$

with A_c the cross-sectional area of the tidal inlet (Figure 7 , 240 m^2) and l_{inlet} the length of the inlet (20 m). Computing, $\frac{\omega_0^2}{\omega^2} = 1.7 \cdot 10^{-3}$ and it can be concluded that the inertia is negligible.

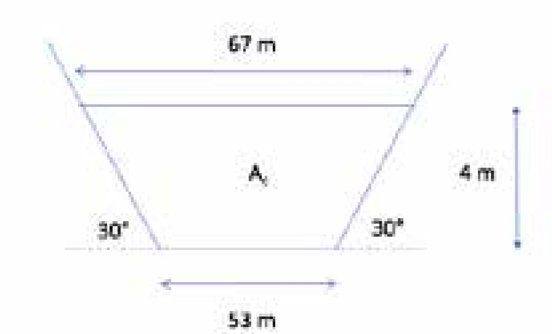

Figure 117 Cross-sectional area of the tidal inlet

The wave resistance is characterized by the factor χ, which is:

$$\chi = \frac{1}{2} + \frac{c_f l_{inlet}}{R}$$

where c_f is a friction coefficient and R is the hydraulic radius of the cross section. Nevertheless, since the tidal inlet is very short, the second term of the expression can be neglected and $\chi = 0.5$. Therefore, the amplitude of the tidal wave inside the lagoon is only reduced due to the losses at the tidal inlet.

Accordingly, the response factor can be calculated as follows (neglecting inertia):

$$r = \frac{1}{\sqrt{2}\Gamma}\sqrt{-1+\sqrt{1+4\Gamma^2}}$$

where:

$$\Gamma = \frac{8}{3\pi}\chi\frac{{A_b}^2\omega^2\hat{\zeta}_s}{{A_c}^2 g} = 0.93$$

Then, $r = 0.8$ and $\hat{\zeta}_b = 0.5\ m$. Implementing this value in the formula to calculate the amplitude of the discharge, it is obtained $\hat{Q}_{tide} = 705\ m^3/s$.

The discharge in the inlet due to the tidal effects is enhanced by the extreme rainfall event. According to precipitation records obtained from rainfall stations in Accra, the 10-year return period precipitation (p) ascends to 130 mm in 6 h (Witteveen+Bos, 2019). The catchment area of the lagoon system (A_{catch}) is 90 km^2 (Davies, Zhang, & Agyekumhene, 2018). Assuming a heavy precipitation event of 6 hours of duration (T_{storm}), the volume of rainfall ($V_{rainfall}$) to be evacuated through the tidal inlet during the described extreme event is:

$$V_{rainfall} = A_{catch}T_{storm}f_{runoff}p = 3.9\cdot10^6\ m^3$$

where f_{runoff} is the runoff factor, which gives the fraction of rainfall that reaches the lagoon eventually (USGS, 2019). Assuming that the rainfall is evacuated immediately after it drops (6 h), the additional discharge in the tidal inlet due to precipitation is:

$$\hat{Q}_{rain} = 181\ m^3/s$$

Hence, the total discharge in the tidal inlet is:

$$\hat{Q}_b = \hat{Q}_{tide} + \hat{Q}_{rain} = 886\ m^3/s$$

Thus, the velocity in the inlet can be calculated as follows:

$$u_{inlet} = \frac{\hat{Q}_b}{A_c} = 3.7\ m/s$$

Flow Velocity in the Bend of the Inner Channel

The cross section of the bend is schematized as shown in the figures below

Figure 118 Top view of section AB of the bend (google earth)

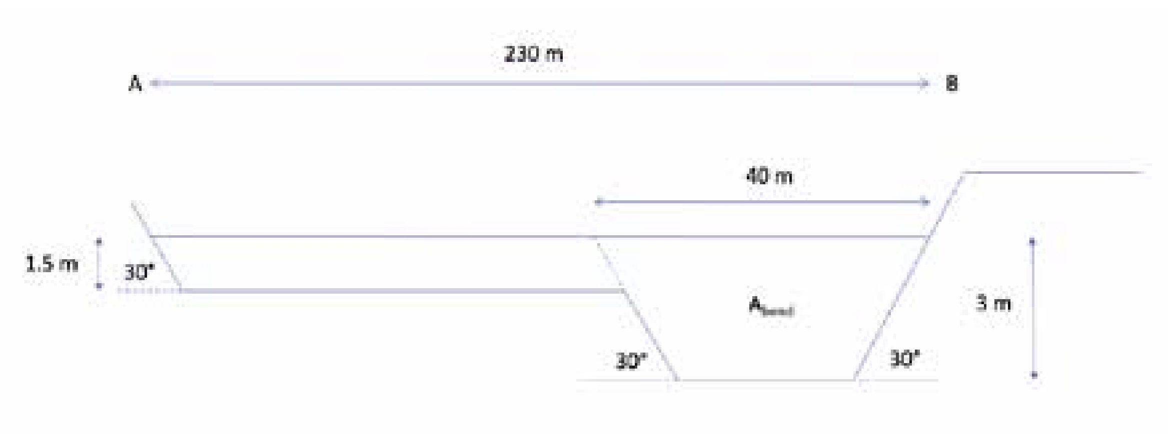

Figure 119 Schematization of the cross-section AB of the bend (not to scale, distances obtained from google earth)

To calculate the flow velocity in the bend, it is assumed uniform flow. Hence, the Chézy equation can be applied:

$$u_{bend} = C\sqrt{Ri}$$

where C is the Chézy coefficient, defined as (White-Colebrook, 1939):

$$C = 18log_{10}\frac{12R}{2d} = 75\ m^{1/2}/s$$

where d is the diameter of the soil grains (assumed 1 mm for medium sands) and R is the hydraulic radius

$$R = \frac{Wet\ area\ section}{Wet\ perimeter\ section} = 2.51\ m$$

Due to the lack of information about the bathymetry in the area of study, it is assumed that the slope (i) of the channel bed is 10 cm per km. The resultant flow velocity in the bend is $u_{bend} = 1.2\ m/s$.

Design of the Bed Protection (Tidal Inlet)

The high flow velocity in the tidal inlet (averaged over the depth) that has been previously calculated (3.7 m/s) can lead to erosion of the bed on the tidal inlet. This effect is undesired for the stability of the tidal inlet and the breakwater. The flow accelerates in the tidal inlet. Hence, the flow is not uniform at this location, due to the constriction.

The formulation proposed by Shields (1936) is applicable under uniform flow conditions. However, it has been proved empirically that it can also be applied in accelerated flow (Schiereck, 2012). Therefore, Shields is used to calculate the required diameter of the stones to protect the bed of the tidal inlet:

$$d_{n50} = \frac{u_{inlet}^{\ 2}}{\psi_c \Delta C^2}$$

where Δ is the relative density of the rocks (1.65) and ψ_c is the Shields parameter (assumed 0.03). Since C depends on d_{n50}, an iterative calculation is carried out to obtain the value of these parameters. After five iterations, C and d_{n50} converge to 35 $m^{1/2}/s$ and 21 cm, respectively.

This rock size corresponds to the manufactured rock type LM_A 10-60 (EN13383), which has a mass of 10 to 60 kg and $d_{n50} = 21\ cm$. The thickness of the armor layer of the bed protection is:

$$t_{armor} = 1.5 d_{n50} = 32\ cm$$

The total length of the bed protection is (van der Waal, van Driel, & Verheij, 1991) ten times the depth at the inlet (4 m), times 2 (upstream and downstream of the inlet, which makes a total of 80 m.

The bed protection is divided into three parts. The type of stone used varies when increasing the distance from the inlet:

- **From 0 to 13 m away from the inlet (stretch A)**: first type of rock
  - Class: LM_A 10-60
  - $d_{n50} = 21\ cm$
  - 10-60 kg

- **From 13 to 26 m away from the inlet (stretch B)**: second type of rock ($\frac{d_{n50}}{2.5} = 8.4\ cm$).
  - Class: CP63-180
  - $d_{n50} = 9\ cm$ (manufactured rock size, layer of at least 20 cm)
  - 63/180 mm

- **From 26 to 40 m away from the inlet (stretch C)**: third type of rock ($\frac{d_{n50}}{5} = 4.2\ cm$).
  - Class: CP45-125
  - $d_{n50} = 6.4\ cm$ (manufactured rock size, layer of at least 20 cm)
  - 45/125 mm

In order to ensure permeability and stability in the bed protection, a geometrically closed granular filter is placed underneath the armor. The conditions that must be fulfilled are:

- $\frac{d_{15F}}{d_{15B}} > 5$ (permeability)

- $\frac{d_{15F}}{d_{85B}} < 5$ (stability)

where d_{15} and d_{85} is the sieve diameter which is passed by 15% and 85% of the mass of grains, respectively. The sub index B and F correspond to the filter and the filter layer, respectively. Applying these conditions, the following sizes of the armor and the filter are found, for the respective stretches

Stretch A	d_{15}	d_{85}	d_{n50}	thickness
Armor	-	-	210 mm	32 cm
Filter layer 2	30 mm	60 mm	50 mm	20 cm
Filter layer 1	5 mm	10 mm	8 mm	20 cm
Existing sand layer	-	-	1 mm	-

Table 17 Dimensions of the armor and the filter layers of the bed protection in the tidal inlet (stretch A)

Stretch B	d_{15}	d_{85}	d_{n50}	thickness
Armor	-	-	90 mm	20 cm
Filter layer 2	30 mm	60 mm	50 mm	20 cm
Filter layer 1	5 mm	10 mm	8 mm	20 cm
Existing sand layer	-	-	1 mm	-

Table 18 Dimensions of the armor and the filter layers of the bed protection in the tidal inlet (stretch B)

Stretch C	d_{15}	d_{85}	d_{n50}	thickness
Armor	-	-	64 mm	20 cm
Filter layer 2	30 mm	60 mm	50 mm	20 cm
Filter layer 1	5 mm	10 mm	8 mm	20 cm
Existing sand layer	-	-	1 mm	-

Table 19 Dimensions of the armor and the filter layers of the bed protection in the tidal inlet (Stretch C)

A sketch of the bank protection is shown below (Figure 120)

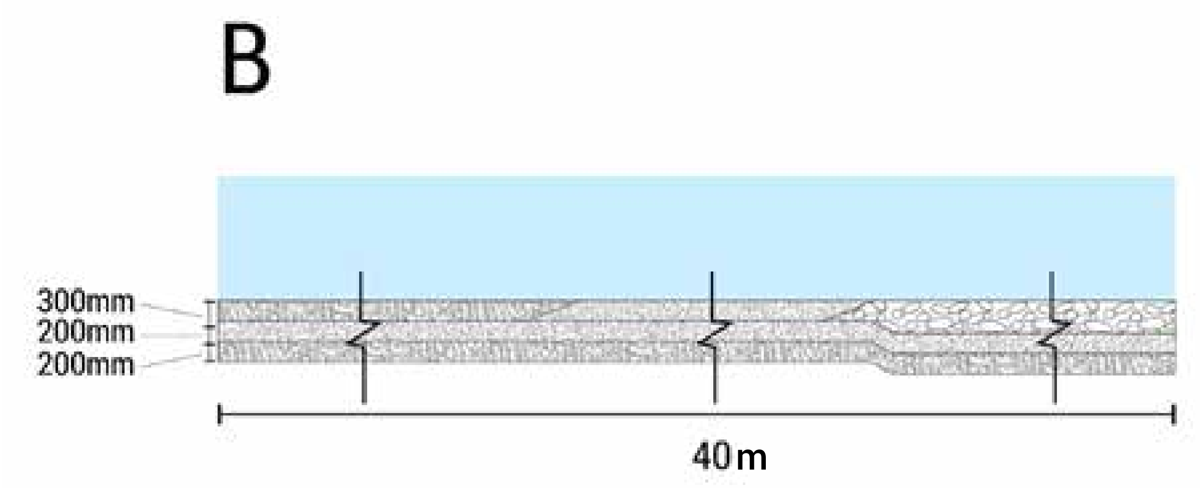

Figure 120 Longitudinal Section of the bed protection of the tidal inlet

Design of the bank protection (tidal inlet)

In Figure 20 it is shown the cross-section of the tidal inlet and its dimensions. The design flow velocity in the tidal inlet has been previously calculated (3.7 m/s). For the bank protection in the tidal inlet, the Shields formulation is used as well. Nevertheless, in this case the slope plays a role in the stability calculation. The required nominal diameter of the rocks of the bank protection is:

$$d_{n50} = \frac{u_{inlet}^2}{K_s \psi_c \Delta C^2}$$

where K_s accounts for the influence of the slope in the stability (Schiereck, 2012):

$$K_s = \sqrt{1 - \frac{sin^2(\alpha)}{sin^2(\phi)}} = 0.63$$

where α (30 degrees) is the slope angle and φ is the angle of internal friction of the sand, which is assumed 40 degrees (Voorendt & Molenaar, 2016).

The required d_{n50} to protect the bank is 29 cm. The manufactured size of rock is 34 cm, which corresponds to the rock type LM_A 40-200 (EN13383). The thickness of the armor layer is $1.5\,d_{n50}$, which is 52 cm. The banks will be protected over a length of 20 meters. In Figure 121 an example is shown of a bank protection for a tidal inlet.

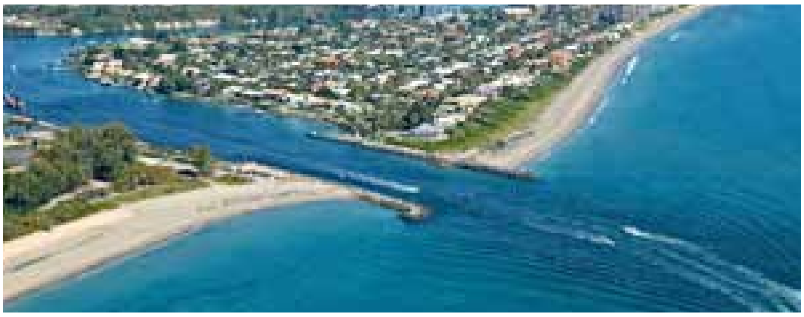

Figure 121 Tidal inlet including a bank protection (Sease 2019)

For the banks, a geometrically closed filter is also required. The filter layers underneath the armor layer are the same than for the bed protection (Table 19)

In the figure below (Figure 122) a cross-section of the bank of the tidal inlet is shown.

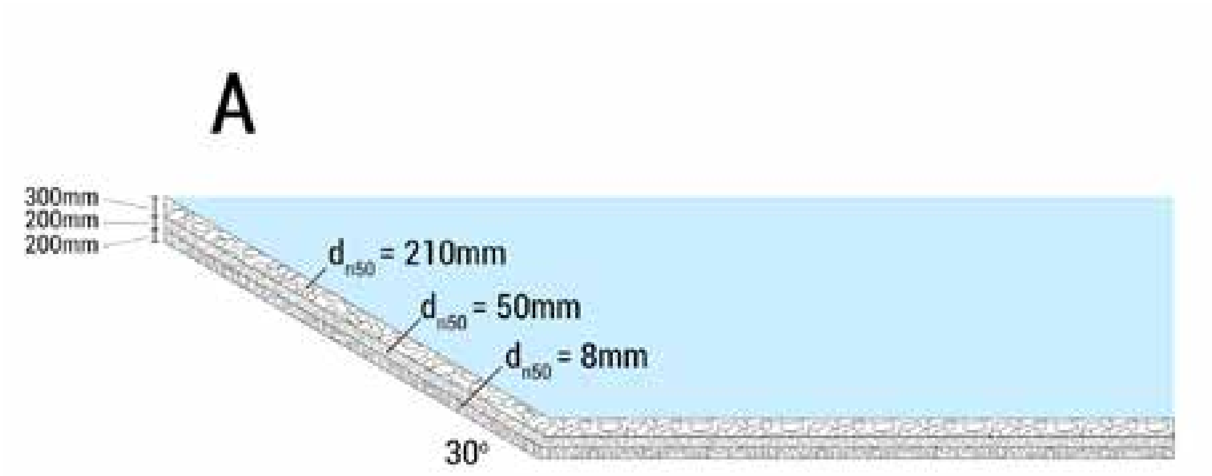

Figure 122 Cross-section of the bank protection of the tidal inlet.

Design of the Bank Protection (Bend)

During opening periods, the flow erodes sand of the barrier between the lagoon and the sea. As shown in Figure 40, the erosion in the bend is clearly visible and even some trees have fallen into the lagoon. A solution to prevent erosion is placing a bank protection, which will guarantee the stability of the bank.

Types of bank protections

Two types of bank protections can be distinguished: hard and soft. Banks often must be protected against currents or waves. If the loads of the waves are significant, often a hard structure is required. If the loads of the waves are low, a soft solution will be sufficient to prevent erosion effects. In Figure 123 and Figure 124, two examples of the different types of bank protections.

Figure 123 Example of a hard bank protection using rocks (Government of Bangladesh, 2019)

Figure 124 Example of a soft bank protection using anchored trees (SAFCA, 2019)

Design of the Soft Bank Protection

As mentioned during the site studies there are no waves inside the lagoon, which means the bank protection in the bend will be subjected only to flow loads. As mentioned before, a soft protection will be used to protect the bank at the bend.

It is known that under water usually the vegetation decreases the load on the subsoil, but it does not increase the resistance against erosion. Vegetation increases the friction, what leads to a reduction of the load due to flow velocities. Above the water, roots increase the strength of the soil. This is only the case when vegetation is dense (e.g. mat). To obtain the best design solution, a combination of both characteristics is required. Therefore, for the MPL reinforced vegetation will be used (Figure 127).

The reinforced vegetation consists of three parts: a mat, vegetation and rocks (Figure 127). The mat is made of a local tree which can resist salty water. The rocks are obtained from nearby quarries. Rocks of dn50 = 1 cm should be enough to resist the load according to Shields, but the same type of rocks as used in the bed protection in the tidal inlet will be placed (LMA 10-60, dn50 = 21 cm), in order not to hinder the growth of the vegetation, while keeping the mat in place. The layer thickness will consist of one rock layer (21 cm).

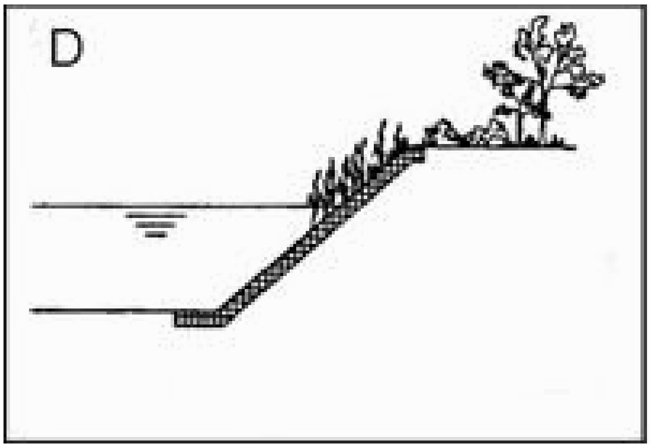

Figure 125 Vegetation mat as a bank protection (Schiereck, 2012).

Figure 126 Example of a bank protection (Schiereck, 2012) (above), schematic overview of the reinforced mat (Schiereck, 2012) (below).

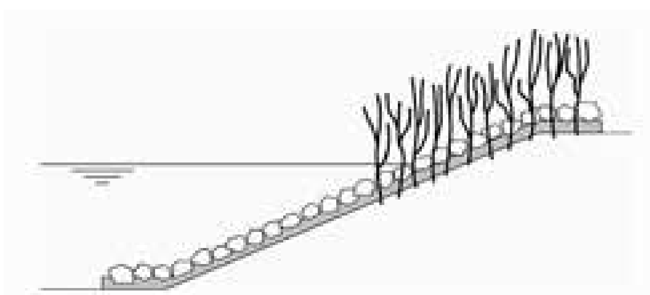

Figure 127 Natural Bank Protection

First, suitable vegetation is cropped in the area. Then, the mat is installed. Finally, one layer of rock is placed. The mat avoids the migration of sand particles from the bank and therefore reinforce the slope. When the vegetation is fully grown, the roots can serve to retain the soil, enhancing the resistance of the bank.

It might occur that the mat and the rocks are taken out by the local inhabitants. For this reason, vegetation without reinforcement can also be a viable option to protect the bank (Figure 128).

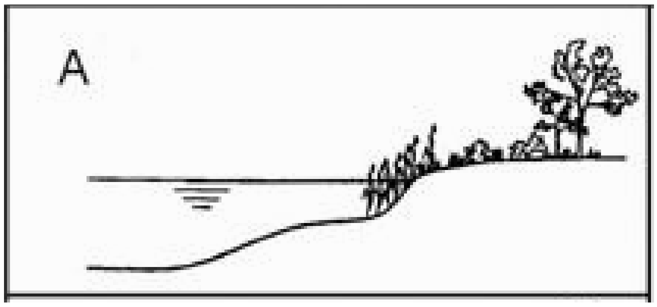

Figure 128 Vegetation without reinforcement as bank protection.

Lower bound for the resistance of the vegetation

In literature, extensive research has been carried out on the resistance of grass when used as a soft protection measure in banks. In this case, it is analysed if the grass would be suitable to resist the flow velocities in the bend. However, grass does not resist salty water conditions. Therefore, a vegetation type that might have a similar protective performance than grass is sought, but suitable for a salty environment.

For the vegetation of a grass cover, the resistance depends on the flow velocities, the duration of the event and the state of the grass (Figure 129).

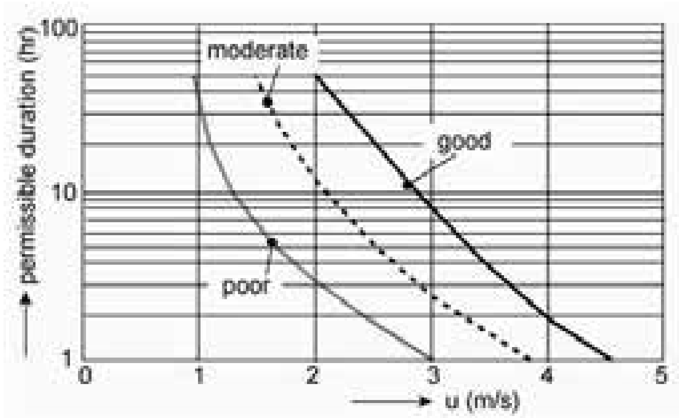

Figure 129 Permissible flow duration on grass cover (Schiereck, 2012).

As calculated before, the flow velocity in the bend is 1.2 m/s, what leads to a resistance of 20 hours given a poor state of the grass. The duration of the extreme event is assumed to be approximately 6 hours, and therefore, the use of grass would be sufficient to withstand the loads.

The vegetation of grass is an example which can be seen as a lower bound of the resistance. For the flow velocities in the bend, a grass cover could resist the loads. This means that if a denser and higher vegetation would be used, the protection against the flow would be higher.

Recommendations about the types of vegetation to use in the bank protection

As mentioned before, grass is not very suitable in the bank protection due to the salty conditions. Therefore, two species where found in Ghana (Mendoza-González, Martinez, & Lithgow, 2014) which could be used as vegetation for the banks of the bend (Figure 130 & 131):

- Sporobolus virginicus (Seashore dropseed)
- Canavalia Rosea (Beach bean)

Both species are populated at the upper beaches, cliffs and dunes in the tropical regions around the world. The plants are salty-tolerant which makes them suitable as vegetation.

Studies (Bell & O'Leary, 2003) have also shown that the growth of the Seashore dropseed is quite quick. In four weeks', the size increases from a few centimetres to already a few decimetres. This means that after planting the seeds on the bank, the vegetation and the rocks are protecting the bank already within a few weeks' time.

In a further stage of the project, the type of vegetation to apply on the banks should be determined, in consultation with the Ghana Wildlife Division (Forestry Commission). This depends on the local knowledge about the flora of the MPL, especially which species would suit best the lagoon environment and which seeds are available to be planted.

In the figure below (Figure 132), a cross-section of the bank protection in the bend section is shown.

Figure 130 Sporobolus virginicus (Environmental, 2019)

Figure 131 Canavalia Rosea (Ohsafaraway, 2019)

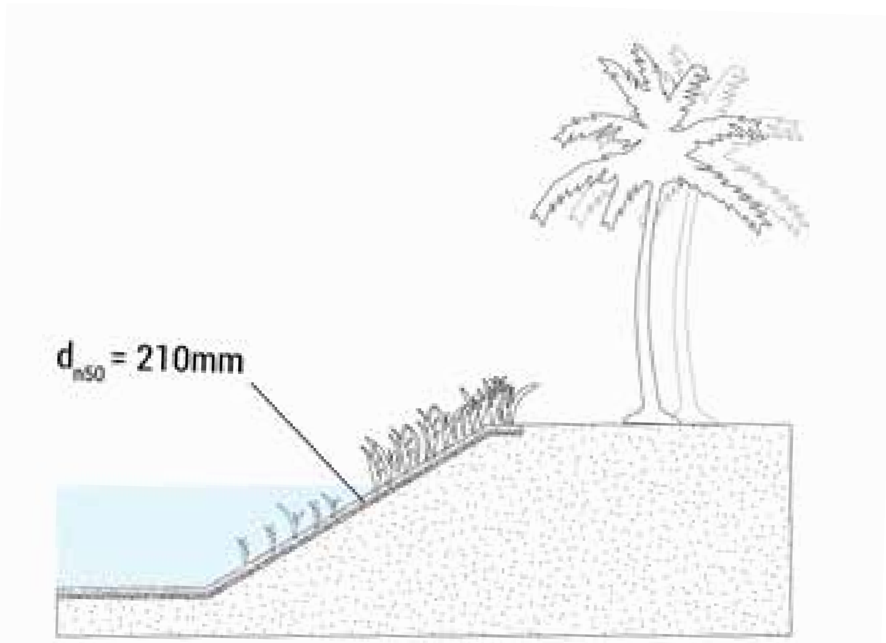

Figure 132 Cross-section of bank protection

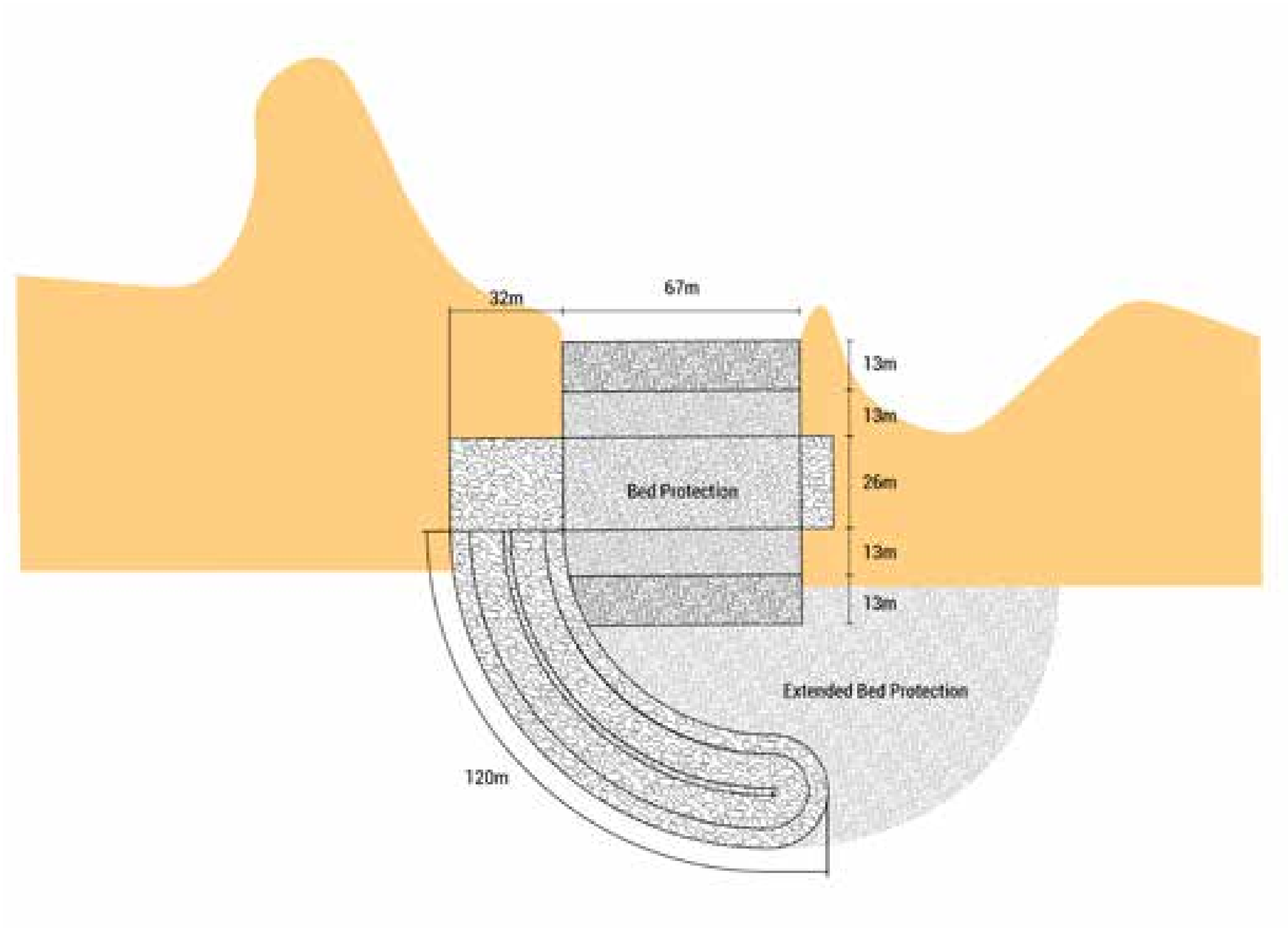

Figure 133 Conceptual model of the design of a stable tidal inlet in the Muni-Pomadze Lagoon.

Tidal Inlet

The proposal for a tidal inlet as discussed in section 6.7, consist of two steps. First the lagoon will be opened by light mechanic means, for instance an excavator. During the first years after the opening, the morphological changes of the coast will be monitored. Based on the effects observed in this initial period and a feasibility study, it will be evaluated if a breakwater is a viable alternative to create a permanent opening between the MPL and the ocean. A top view of the projected tidal inlet is shown in Figure 133.