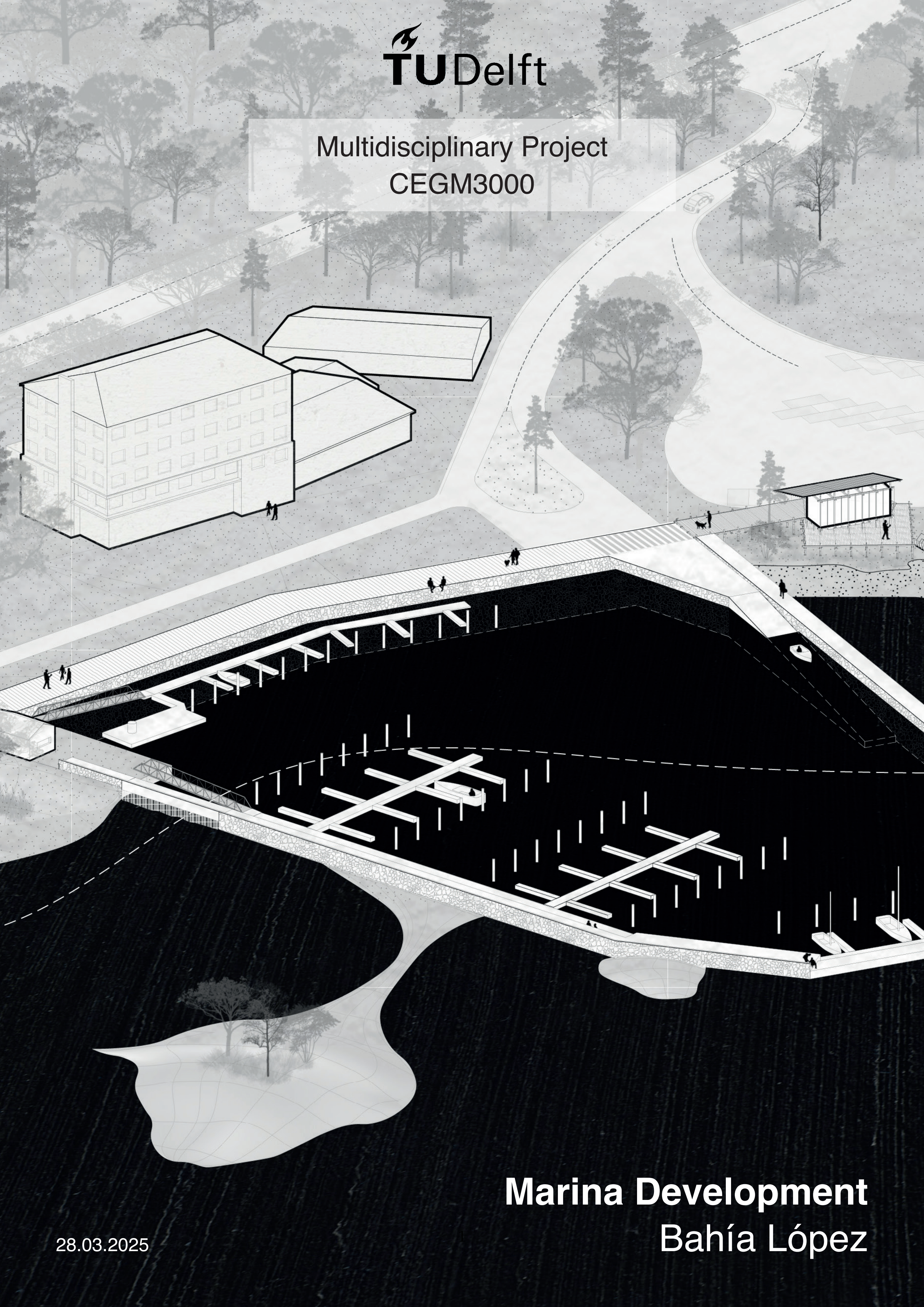

TU Delft

Multidisciplinary Project
CEGM3000

Marina Development

Bahía López

28.03.2025

Marina Development in Bahía López

Multidisciplinary Project - CEGM3000

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Preface

This report, titled *Marina Development in Bahía López*, is the result of a *Multidisciplinary Project* undertaken as part of the course CEGM3000, at the Technical University of Delft. In this course, students from various faculties collaborate to apply academic knowledge to a real-world challenge. The team acted as consultants for the concessionaire of the existing marina, offering expert advice on the design of the development of the marina in Bahía López, located in Río Negro, Argentina.

The team was composed of students with backgrounds in Architecture, Offshore & Dredging Engineering, and Biomechanical Design. This diverse composition allowed for a variety of perspectives, which led to innovative and integrated design solutions. The collaboration between these different disciplines was key to addressing the technical challenges, environmental considerations and ultimately shaping the final design solution.

Throughout the course, extensive background research was conducted, stakeholders were engaged, and a comprehensive design was developed for the marina's facilities and layout. This report was developed in close collaboration with Port Consultants Rotterdam, based in Buenos Aires, where the team was located for most of the projects duration.

The proposed marina location within the Nahuel Huapi National Park near Bariloche posed unique challenges, particularly with regard to environmental regulations and the parks conservation goals. A week-long site visit to Bariloche provided a deeper understanding of these constraints. During the visit, field research was carried out, local stakeholders were met, and insights were gathered that helped shape a design that aligns with both the natural environment and the needs of future users.

This report represents the bundling of these efforts, presenting a detailed design proposal for a sustainable and functional marina that will enhance the tourism infrastructure in the region while preserving the delicate ecosystem of Bahía López.

Acknowledgment

We hope that the preliminary design presented as the final result of this project is received with great enthusiasm and serves as a potential foundation for a future marina in Bahía López. This project would not have been possible without the guidance and support of several key individuals.

First, we would like to express our sincere gratitude to our supervisors from the TU Delft, Dr. José Antolínez and Ir. Jeroen Hoving, for their invaluable insights regarding sedimentation and the overall process. Additionally, we are thankful to Dr. Fransje Hooimeijer and Dr. Jovana Jovanova for their guidance and support throughout the project. Their feedback was helpful in refining our ideas and our approach.

A standout aspect of this project was the site visit to Bariloche, for which we are especially grateful to Miriam Bezic. She arranged all the stakeholder meetings and provided key insights that significantly helped us with our research. We would also like to extend our heartfelt thanks to the people of Bariloche for their warm hospitality and willingness to share their knowledge. Their openness and support made our visit not only beneficial for the project but also truly memorable.

Our sincere thanks go to the entire team at Port Consultants Rotterdam for offering us a welcoming workspace and for accommodating us throughout the project.
We are particularly thankful to Pablo Arecco for his invaluable insights and feedback during our meetings. Our discussions with him gave us a deeper understanding of the consultant's perspective and approach to problem-solving.

Finally, a special note of gratitude goes to Juan Bautista Saint Antonin, whose support was essential throughout the project. He not only accompanied us during the site visit as our translator and local guide, but also provided continuous assistance, helping with any questions or concerns we had. Without his help, the success of this project would not have been possible.

Buenos Aires, March 2025

Abstract

The Nahuel Huapi National Park, in the Lake District of Northern Patagonia, Argentina, is well known for its tourism industry all year round. After COVID-19, the area saw a significant increase in the number of tourists traveling to the area. This means that the lake located in the heart of the district, Lago Nahuel Huapi, is being used more and more to explore the environmental richness of the area by boat. Now, the capacity of mooring spaces is no longer sufficient in the region, resulting in the construction of illegal private docks along the shore. To reduce this impact on the environment the authorities granted in 2024 a concession to develop one of the last not yet commercialized marina's in the region: the marina in Bahía López.

This report provides a consult for the concessionaire of this development. The process begins with a research phase, consisting of an area study, and the mapping of environmental and hydrodynamic constraints. Subsequently, stakeholders are categorized, as the development of a marina in a national park entails complex regulations from multiple organizations. The outcomes of the research phase are translated into specific functional requirements for the marina. These functional requirements are the basis for the next phase, the design phase. This phase begins with the formulation of a design vision statement, formulating the project response to local conditions. Based on this, three different conceptual designs with various technical solutions are developed. Through a multi-criteria analysis, the concepts are tested on their robustness in order to chose a final concept. This concept is then elaborated into a preliminary design. Presenting an overview of the marina's facilities, including structural designs, operational needs, and capital costs. Finally, suggestions for future development are provided, outlining the next steps to advance the marina to a next phase.

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Nomenclature

Symbol	Description	Unit
H_s	Significant wave height	m
T_s	Significant wave period	s
F_e	Effective fetch length	m
$\bar{F}$	Dimensionless fetch length	-
R	Shoreline radius	m
R_0	Reference control line distance	m
$R(\theta)$	Distance of the fetch for each angle	m
θ_f	Angle between the fetches	degrees
β	Wave obliquity angle	degrees
θ	Control angle	degrees
C_0, C_1, C_2	Empirical coefficients	-
K_t	Transmission coefficient	-
h	Water depth	m
k_i	Wave number	1/m
d	Floating breakwater draft	m
$\bar{d}$	dimensionless water depth	-
B	Floating breakwater width	m
u	wind speed at the water surface	m/s
g	acceleration due to gravity	9.81 m/s^2
$\bar{H}$	dimensionless wave height	-
$\bar{T}$	dimensionless wave period	-

Abbreviation	Description
APN	Administración de Parques Nacionales
EsIA	Estudio de Impacto Ambiental (Environmental Impact Study)
EIA	Environmental Impact Assessment
IIA	Informe de Impacto Ambiental (Environmental Impact Report)
IMA	Informe Medio Ambiental (Environmental Report)
MCA	Multi Criteria Analysis
CAPEX	Capital Expenditure
PIANC	Permanent International Association of Navigation Congresses
DR	Dirección Regional (Regional Directorate)
DNC	Dirección Nacional de Conservación (National Directorate of Conservation)
IAC	Intendencia del AC (local park administration)

1 Introduction

Bahía López is located in the Nahuel Huapi National Park (Figure 1.1), Patagonias first national park, established in 1934. The beautiful nature and pristine lakes in this park attract many visitors as it provides a variety of recreational activities like hiking, boating and relaxing by the water. Bahía López is not only a stunning natural destination but also serves as a strategic stopover for travelers heading further south into Patagonia. Due to its location within the Nahuel Huapi National Park, near San Carlos de Bariloche, it provides an ideal resting point for visitors to enjoy nature before continuing their journey into more remote parts of Patagonia.

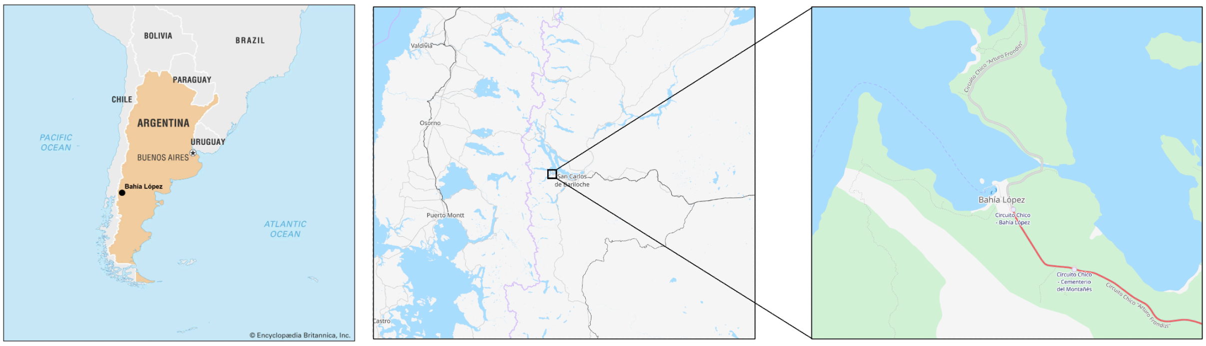

Figure 1.1: Map of Argentina and location of Bahía López [1].

Since the COVID-19 pandemic, tourism in Bahía López and the broader Patagonia region has seen a notable increase. In 2024, a national public tender has been approved to grant the concession for the development of a marina in this protected nature area. Figure 1.2 illustrates the current state of the marina.

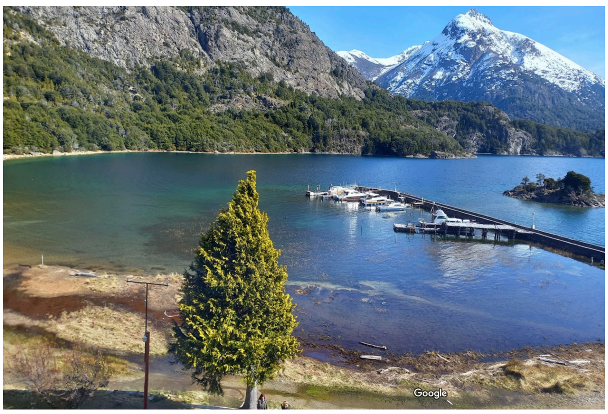

Figure 1.2: Current state of the marina (2025) [2]

The development of the marina area could potentially make the area even more appealing to both local and international visitors. This would not only boost the local economy but also enhance the regions accessibility, making it a more significant hub for adventurers and nature enthusiasts looking to explore the depths of Patagonia.

Multidisciplinary Approach

The project team consists of five master students from the Technical University of Delft, with diverse academic backgrounds. Three members specialize in Offshore and Dredging Engineering and focus on the coastal, civil and structural engineering aspects. Two members, with a background in Architecture, are responsible for the marinas design, landscape architecture and urban planning. Finally, one student has a background in Biomechanical Design and will focus on the integration of environmental engineering into the marina.

This combination of backgrounds resulted in a broad knowledge base from which the project was tackled. The multidisciplinary approach was beneficial for this project in requiring a deeper understanding in environmental conditions, alongside expertise in designing buildings and marina layouts.

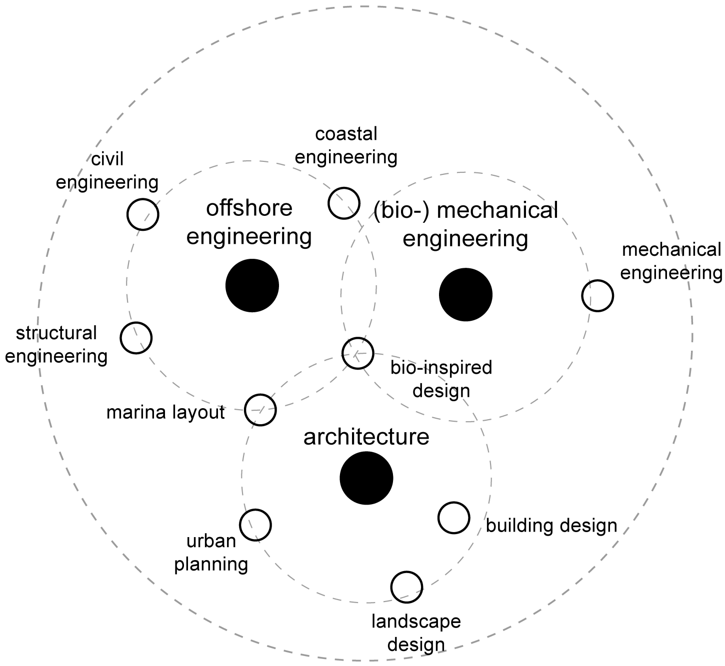

Figure 1.3: Multidisciplinary approach

Project Scope

The primary objective of this report is to develop a comprehensive preliminary design for a marina in Bahía López. The marina must serve multiple purposes, including providing improved mooring spaces for boat owners, incorporating a boat ramp for launching small motorboats, and accommodating a provision building. To establish a solid foundation for the design, an extensive area and market study will be conducted to determine the boundary conditions. Additionally, multiple stakeholders will be interviewed to map their interests and influence on the project. Based on these insights, the requirements for the new marina can be defined, guiding the development of a detailed design that includes the necessary facilities, infrastructure, and marina layout. The architectural design of the marina buildings is also presented.

Given that Bahía López is situated within a national park and adjacent to a recognized beach, the design must be environmentally conscious —working in harmony with nature rather than against it. Additionally, the project must comply with regulations set by national park authorities and the government, integrating sustainable solutions that align with these requirements.

2 Methodology

The design of a marina is a complex project. A successful outcome calls for a clear and systematic approach. In the following section the method of this marina development project will be explained step-by-step. It starts off with a research phase followed by a design phase. A schematic overview can be seen in Figure 2.1

2.1 Research Stage

The goal of the research phase is to gather all relevant literature and information about the marina area in order to define the functional requirements and boundary conditions. Based on this research, a design vision can then be developed.

Area study

The research phase begins with a comprehensive physical study of the area, as understanding its characteristics is important for making informed design decisions in the later stages of the project. This section includes a site analysis of Bahía López, along with topographic, bathymetric, geotechnical, hydrodynamic, and environmental studies, as well as a sedimentation analysis.

Stakeholder Analysis and Site Visit

The governmental structure in the region is complex, as the marina is located within a national park, with different authorities overseeing regulations. The stakeholder analysis identifies the key stakeholders involved in the Bahía López marina development and examines their relationship to the project. During a site visit to San Carlos de Bariloche, several interviews are held with key stakeholders. Their influences, interests and concerns are then evaluated to determine their significance and potential impact on the project.

Market Analysis

A market analysis is conducted to assess the need for the project by identifying current trends in the boating and tourism sectors. Also the existing marinas and beaches around San Carlos de Bariloche are examined. This highlights a clear market opportunity that the marina can address.

Functional Requirements

By combining the information from the area study, stakeholder interviews, and market analysis, a list of functional requirements is developed. Additionally, the regulations set by the national park and the government are outlined. This marks the end of the research phase, which will serve as the foundation for the development of design alternatives.

2.2 Design Stage

Based on the research conducted, various design options are investigated. First, using the functional requirements as a guideline, a design statement is formulated, which serves as the basis for the further development of the design.

Development of design alternatives

Based on the outlined vision, a design workshop is held in which a variety of different solutions to challenges deriving out of the program are drawn up. These solutions are then together documented in a morphological map, making it possible to compose three fundamentally different (but responding to the same program) concept designs. This stage ensures that all potential options are considered before narrowing down to the most suitable solution.

Multicriteria Analysis

In this section, the three concept designs for the masterplan are evaluated and scored, using the method of a multicriteria analysis (MCA). This provides a systematic approach to identifying the most promising features for inclusion in the final preliminary design. To check the robustness of the outcome of this analysis, scores of critical categories are changed, leading to a conclusion of an optimal design proposal.

Preliminary Design

In this section, the results from the MCA are used as a starting point to critically look at the design again, to form a single preliminary design. Following a general overview, each feature will be explained in detail, highlighting the key facilities of the marina.

Future Development Suggestions

This section outlines potential Phase 2 improvements for the marina, including redeveloping the vacant building, adding a dining venue, maintenance facility, and water sports rentals. It also suggests relocating parking, installing dry stacking berths, and expanding mooring points to meet demand.

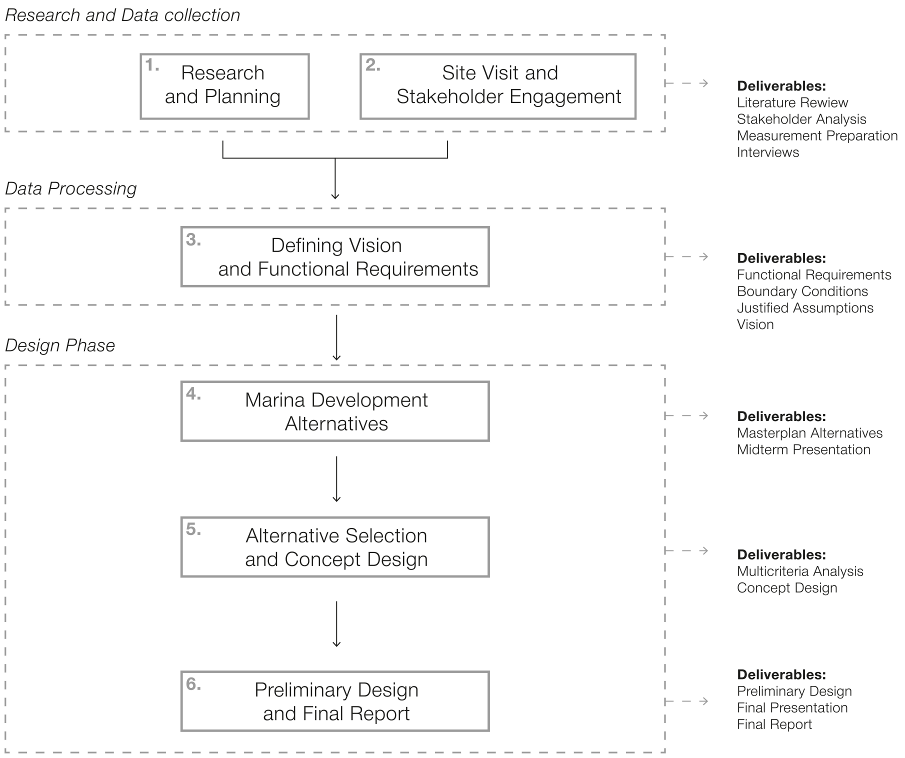

Figure 2.1: Process Scheme

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Area Study

In order to gain a good understanding of the conditions affecting the marinas location, an extensive area study is conducted. This involves assessing existing data from institutions and identifying additional data that must be obtained through surveys.
It contains: a broad location study, outlining the geographical context and existing infrastructure of the area; a topographic study, to examine land elevation and terrain conditions; a bathymetric analysis to assess water depths, underwater topography, and seabed characteristics; a geotechnical study to determine soil composition and stability. Additionally, a hydrodynamic analysis will evaluate wind-water currents, tidal fluctuations, wave conditions. The environmental study will focus on local flora and fauna, as well as ecological challenges to assess ecological impacts.

3.1 Site Analysis

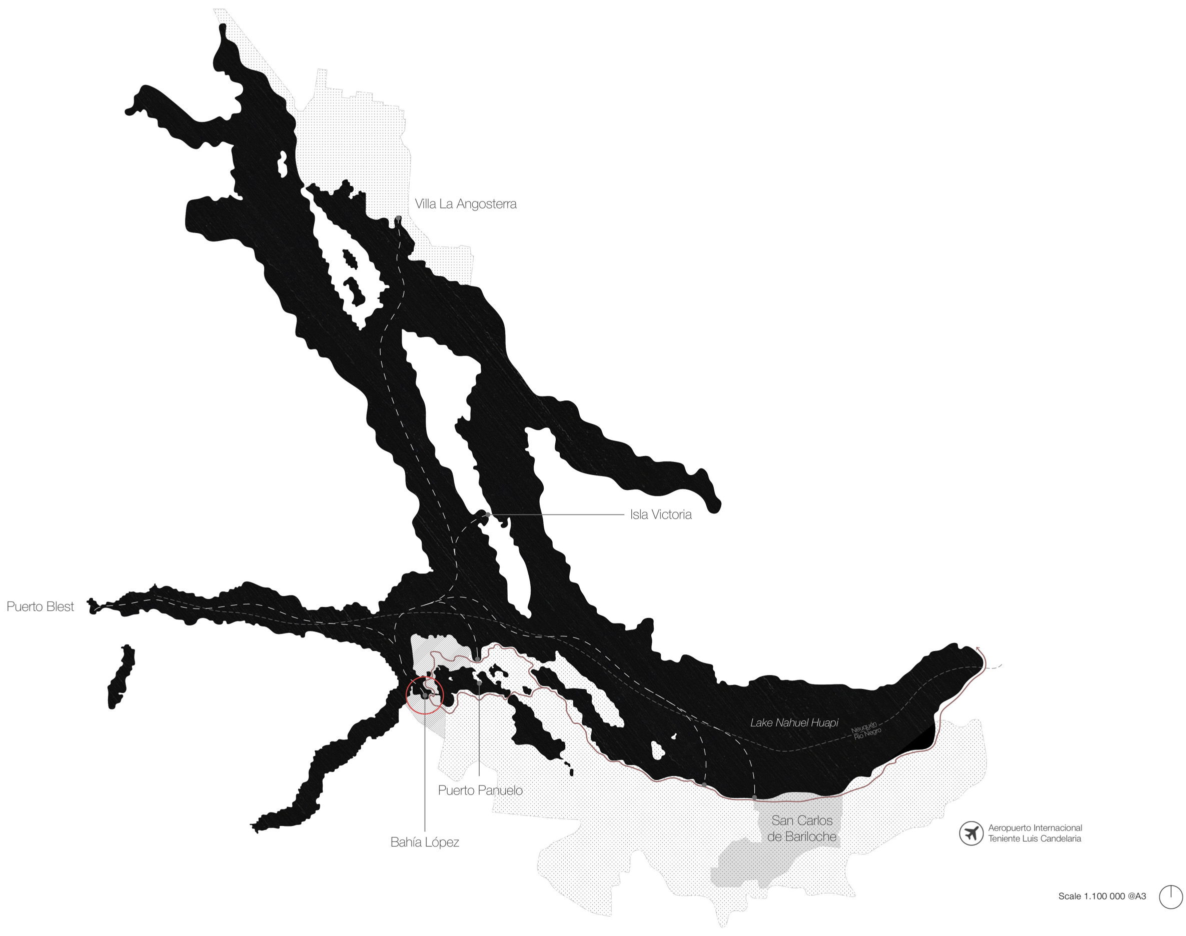

Figure 3.1: Map of Lago Nahuel Huapi

The Nahuel Huapi National Park is located in the northwestern region of Argentine Patagonia, with the largest lake in the park, Lago Nahuel Huapi (Figure 3.1), at its heart. On its southern shore lies the regional capital, San Carlos de Bariloche. Bariloche, with its nearby international airport, functions as an important gateway connecting the region with the rest of Argentina and international destinations.

Various branches of the lake (7 in total) provide boat access from Bariloche to key destinations within the park. The lake is primarily used for tourism and recreational boating, with popular spots including Villa la Angostura, Isla Victoria, Puerto Blest, and Puerto Pañuelo, the largest commercial port in the area. On land, the Circuito Chico, a scenic route, connects Bariloche to important locations south of the lake.

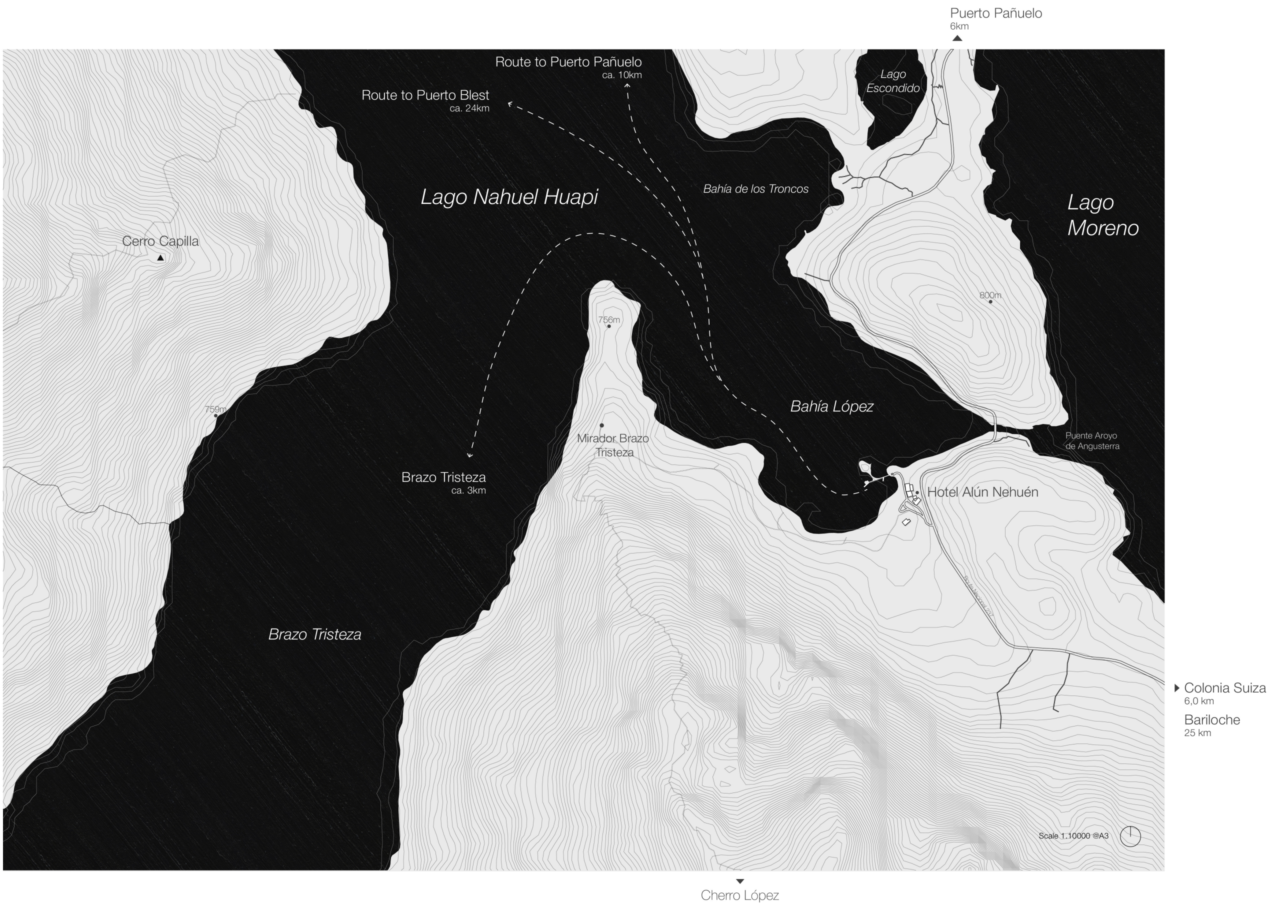

Figure 3.2: Situational Plan of Bahía López

When zooming in to the Bahía López itself (Figure 3.2), it becomes clear that the bay is strategically positioned between the Brazo Tristeza and Lago Moreno, offering easy water access to destinations in the western region of the lake. This strategic location led to the development of a small marina in the last century. Over time, locals began using the marina and the beach at Bahía López to launch their boats into the water. Today, it remains one of the last publicly accessible locations for local residents to launch their boats.

On land, the marina is accessible via the Circuito Chico, by both car and public bus. The circuit connects Villa Tacul and Villa Llao Llao to the north, and Colonia Suiza and Bariloche to the south. This area is part of Parque Llao Llao, a specific region within Nahuel Huapi National Park, which falls under the jurisdiction of the municipality of Bariloche. This creates a complex legal framework for the area, that will be further elaborated later in the report.

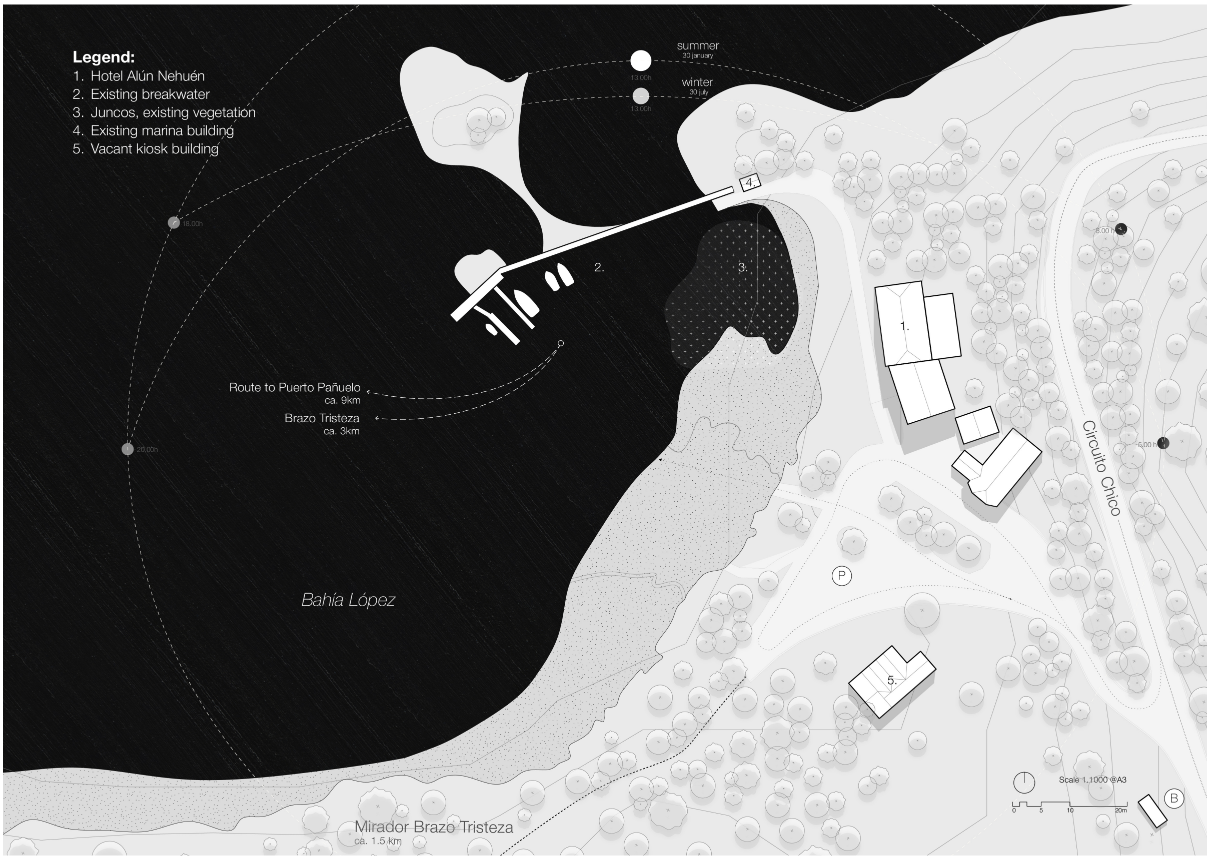

Figure 3.3: Current Situation, Bahía López

The drawing above (Figure 3.3) illustrates the current state of the marina. The breakwater, constructed in 1929, provides shelter from northwestern winds and their resulting waves. Adjacent to the marina, the Hotel Alún Nehuén has a prominent position along the shore. Its presence could influence the marina's design, the accessibility, and attract potential users, as it draws a significant number of visitors to the area.

Next to the hotel is a small parking lot, used by both hotel guests and beachgoers. From this parking area, visitors can either access the beach on foot or use it to launch their boats by car. The parking lot also marks the starting point for a hike to the panoramic point Mirador Tristeza, which offers views of the Tristeza branch and the lake. This entrance is marked by a vacant building, which was previously used as a kiosk.

Currently offering limited facilities, the marina's operational efficiency and user experience could greatly benefit from redevelopment. A key focus in this revitalization process will be maintaining the balance between private development and ensuring public access to the marina's facilities.

3.2 Topographic Analysis

The primary objective of the topographic study is to obtain an understanding of the physical landscape with the relief of the area surrounding the marina site. The area surrounding Bahía López is characterized by hilly terrain, with Mount López reaching a peak of 1,300 meters above lake level. The terrain rises steeply, which is why several hiking trails are found around the bay. In 2005, the Argentine Geological and Mining Service conducted a geological study mapping the regions major topographic lines [3]. It is important to note that the lake itself is already situated at 770 meters above sea level, and the referenced map uses sea level as its baseline, see Figure 3.4.

Observations from the site visit revealed that the beach and shoreline have a gentle slope. As a result, when water levels fluctuate, further analyzed in the bathymetric study section, the shoreline shifts significantly. This dynamic behavior contributes to the expansion and shrinking of the beach area.

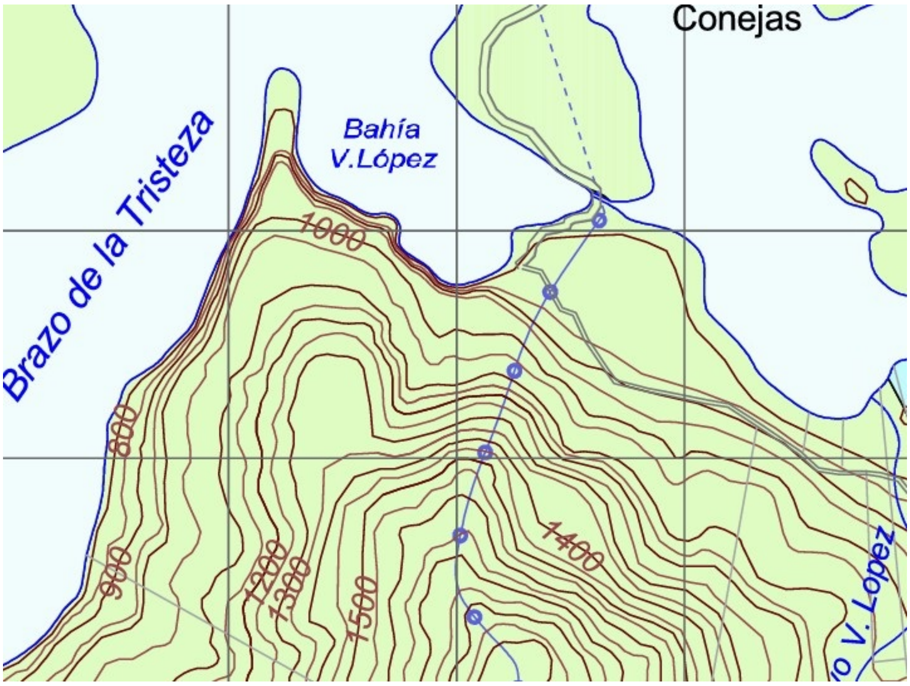

Figure 3.4: Topographic map Bahía López.

3.3 Bathymetric Analysis

The primary objective of the bathymetric study is to obtain a detailed understanding of the lakebed relief and identify any potential obstacles. The available bathymetric data for Bahía López and Lago Nahuel Huapi is limited and lacks the resolution required for the project. The existing data provides a general overview of Lago Nahuel Huapi, but does not provide the level of detail needed for the Bahía López area.

Bathymetric Data Overview

Since Nahuel Huapi is an inland lake with relatively low boating traffic, commonly used bathymetric applications such as Navionics and Garmin do not provide coverage for this area. As a result, alternative sources for bathymetric data had to be explored. Throughout interviews with various organizations, it became clear that reliable depth information was largely unavailable.

However, in 1971, Parques Nacionales conducted a bathymetric survey of the entire Nahuel Huapi Lake, including a mapping of Bahía López (Figure 3.5). While they provide valuable insight, there are concerns regarding their accuracy, particularly in the area around the breakwater. Visual observations during the site visit indicate that the water in this region may be shallower than the map suggests.

Despite these uncertainties, the bathymetric data confirm that further into the bay, the water depth is sufficient to accommodate larger vessels, such as sailboats and ferries, reinforcing Bahía López's potential as a promising location for marina development.

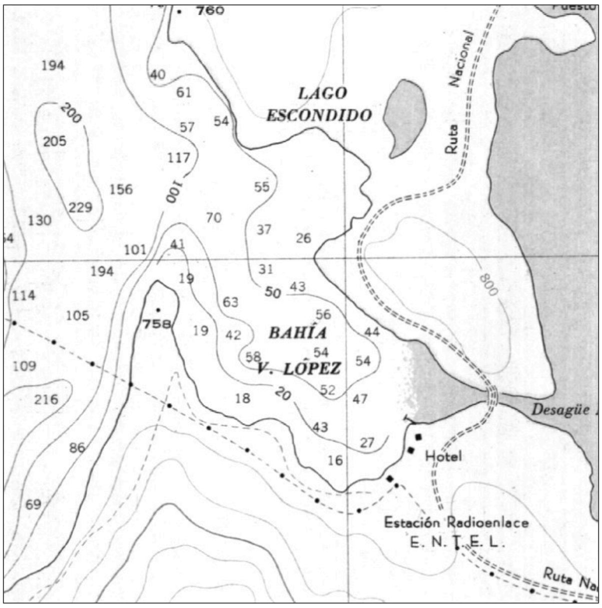

Figure 3.5: Bathymetric map of Bahía López, Servicio Nacional de Parques Nacionales (1971) [4]

During discussions with the Bahía López marina contractor, it was established that the marina should have a minimum depth of 1 meter throughout, with at least 1.5 meters of depth towards the end of the breakwater. These depth requirements will serve as the basis for the marinas design.

Water Level Fluctuations

In general, water levels in lakes naturally fluctuate due to seasonal variations in precipitation, glacial meltwater inputs and evaporation. Figure 3.6 presents a diagram of Lake Nahuel Huapi's water levels in 2014, compiled by the Provincial Department of Water. The highest water levels typically occur between June and October, primarily due to increased rainfall [5], while the lowest levels are observed between March and April, when precipitation is significantly lower.

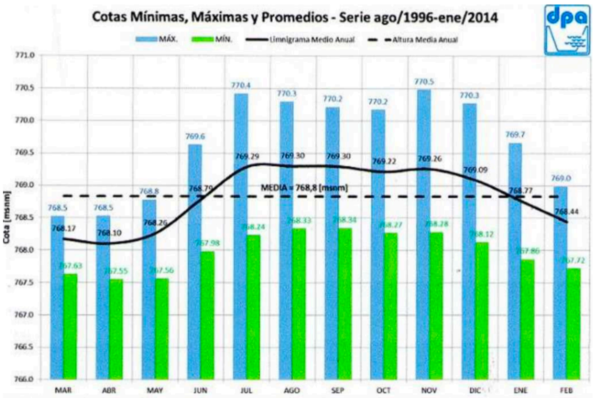

Figure 3.6: Water Level Variations in Nahuel Huapi Lake (1996 - January 2014) [6]

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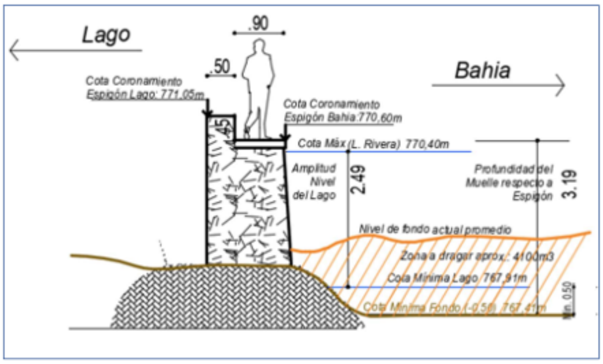

Figure 3.7: Cross-Section of the Breakwater [7]

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It is important to note that winter in the Southern Hemisphere occurs from around June to September, and summer from December to March. Although one might expect summer snowmelt from the surrounding mountains to raise water levels, the data indicates that rainfall is the dominant factor influencing lake fluctuations. This variation is a crucial consideration for the marina design, as regulations from Parques Nacionales state that both the highest and lowest recorded water levels must be taken into account [8]. Figure 3.7 illustrates a cross-section of the existing breakwater, showing the effects of fluctuating water levels, and Figure 3.8 visualizes shoreline changes in one year, from April to July.

Figure 3.8: Satellite images of April (left) and July (right) [9]

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Obsolete Structures

To the north of the existing breakwater lies a small island composed primarily of rocks, with several trees growing on it. During the low-water season, a tombolo forms, temporarily connecting the island to the breakwater, allowing it to be reached on foot. Additionally, a collection of deposited rocks is present at the end of the breakwater.

Adjacent to the breakwater, remains of an old wooden dock can still be seen. These structures are no longer functional and will need to be removed. See Figure 3.9 below for reference.

Figure 3.9: Remains of old dock.

3.4 Geotechnical Analysis

A geotechnical analysis was conducted to assess the soil composition at the beach and marina site, providing insight into the ground conditions relevant to construction and stability considerations.

Sandy Soils

The site visit revealed that the beach area consists of two distinct soil types. On the west side, the terrain is characterized by larger rocks, while the east side primarily consists of coarse sand with a high content of black grains, as can be seen in Figure 3.10. This distribution is closely related to sedimentation patterns, as discussed in the sedimentation analysis (subsection 3.6).

Figure 3.10: Coarse sand observed at the marina (left) and the dredging discharge pipe (right)

Volcanic Andisol Soils

The Nahuel Huapi National Park is predominantly composed of Andisols, specifically Hapludands, which are young volcanic soils derived from pumice (Lightweight, porous volcanic rock formed from rapidly cooled lava) and volcanic ash. These materials were transported and deposited through wind, erosion and water. Andisols have a high water retention capacity, contributing to moisture stability. Their bulk density is relatively low, typically below 0.90 g/cm^3, indicating a light and loosely compacted structure. The texture varies from medium to coarse, and the soils are moderately acidic [7]. Due to their low bulk density, Andisols are susceptible to erosion, particularly in areas exposed to water flow and heavy rainfall [10]. This factor should be considered in the design and implementation of erosion control measures at the site.

Geological Context

The area is part of the Principal Andean Cordillera in Argentina, shaped by subduction processes during the Jurassic period. It belongs to the Norpatagonian Cordillera, where the mountainous terrain in the west transitions into extra-Andean Patagonia in the east. The topography of Bahía López has been influenced by tectonic activity and glaciation, leading to varied rock formations and soil conditions (Figure 3.11).

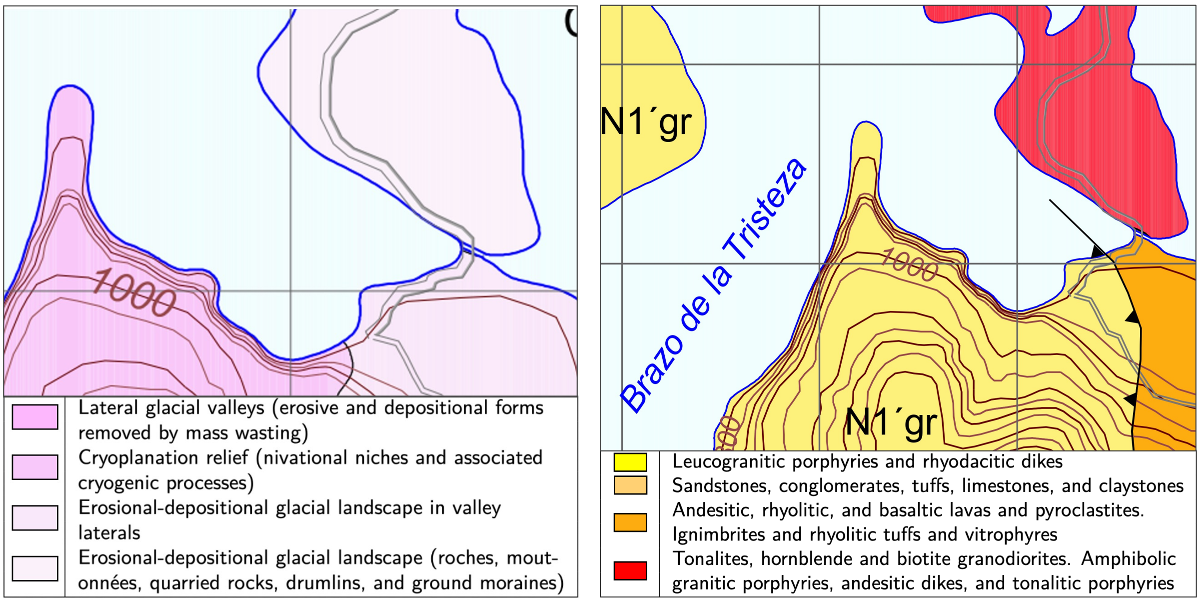

Figure 3.11: Geo-morphological features (left) and geological map (right) of the Bahía López area (2001) [11].

The geology of Bahía López is shaped by volcanic and plutonic rocks, along with deposits from rivers and glaciers. The marina site mainly consists of solid rock formations from the Miocene epoch, including leucogranitic porphyries and rhyodacitic dikes, which create steep and erosion-prone slopes. Across the inlet, older volcanic rocks from the Eocene-Oligocene period, such as andesites, rhyolites, and pyroclastic deposits, form softer, nutrient-rich soils that are less stable. A geological fault separates these formations, affecting erosion and sediment movement, though it does not directly impact the marinas foundation (left image of Figure 3.11).

Additionally, glacial and river deposits from the Quaternary period create loose, unstable sediments, particularly in areas exposed to strong water currents (right image of Figure 3.11). To prevent erosion and sediment displacement, shoreline stabilization and sediment control will be necessary. This may include reinforcing vulnerable areas and dredging where needed. Although the solid rock formations offer a stable foundation, the marina design must consider seasonal water level fluctuations and sediment accumulation to maintain long-term stability.

3.5 Hydrodynamic Analysis

The environmental conditions related to wind and wave dynamics are analyzed, as they impact the marina's layout and structural forces. This study also examines currents, which play a key role in sediment transport and accumulation.

Wind Analysis

Due to the location of the Bahia within the Nahuel Huapi lake's western sector and its orientation along Brazo Tristeza, Bahía López is partially sheltered from dominant westerly winds that prevail in Patagonia. However, wind channeling effects occur due to the narrow valley-like shape of Brazo Tristeza, which can accelerate wind speeds as air is trapped between the surrounding mountains. This effect can lead to strong localized gusts and turbulent wind patterns in certain conditions.

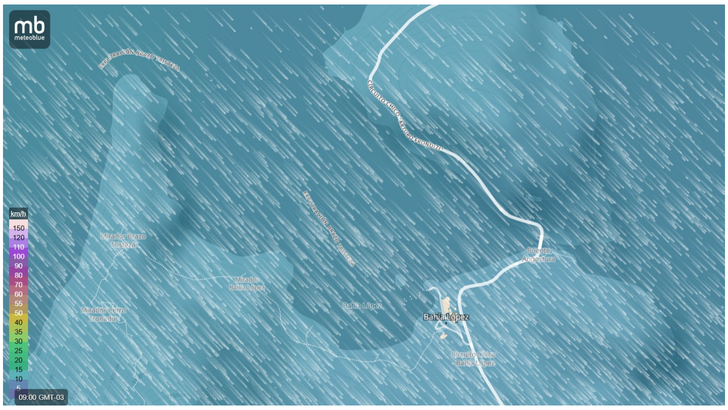

Figure 3.12: Wind direction at Bahía López [12]
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The wind direction typically follows the pattern of blowing from the lake into the bay, entering directly through the bay's entrance and impacting the marina, as can be seen in Figure 3.12. Due to the long fetch over the water, this wind can generate strong waves, currents, and contribute to shoreline erosion, influencing both navigational conditions and structural stability within the marina [12].

Since no direct wind speed data is available for Bahía López, the wind speed data from Bariloche is used as a reference. Bariloche is located in a more open area, allowing the wind to travel freely with fewer obstacles, which generally results in higher recorded wind speeds. In contrast, Bahía López is a more enclosed bay, surrounded by mountains that create a tunnel effect, channeling and sometimes accelerating the wind. This geographic setting can lead to localized variations in wind patterns, but since the predominant wind direction aligns with the bay entrance, we assume that the wind speeds in Bahía López are comparable to those in Bariloche, with potential variations in intensity.

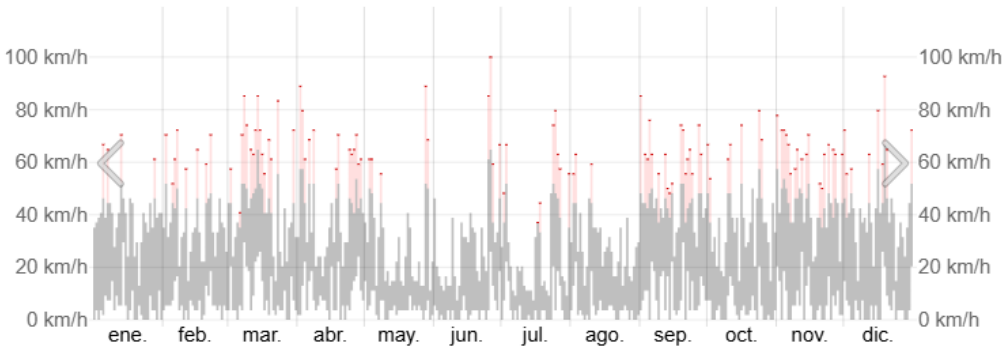

Figure 3.13: Wind speeds in Bariloche (2024) [13]
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Figure 3.13 shows that wind speeds change a lot throughout the year, with frequent strong gusts over 60 km/h, particularly in March, July, September and December. Wind levels stay high most of the year, with occasional very strong gusts surpassing 80 km/h. The monthly average wind speeds can be seen in Table 3.1.

Table 3.1: Monthly Average Wind Speeds [13]

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Wind speed (km/h)	13.7	12.8	12.4	12.2	12.2	12.6	12.7	13.2	12.8	13.2	13.9	14.3

Wave Analysis

As the marina is situated in a lake, wave generation is primarily driven by wind. While other factors such as seiches, tidal effects and boat traffic can influence wave behavior, their impact is considered so small that they can be neglected in this context. Therefore, wind remains the dominant force in generating waves in the lake. It is crucial to consider both significant wave heights and periods in the marinas design. The structural components must be designed to withstand the forces exerted by these waves, while the wave periods can influence design decisions, such as the selection of an appropriate breakwater type.

To calculate the wind-induced wave heights and periods a method by TAW (1985) is used [14]. This method calculates the wave height and period under conditions where wind blows steadily over a water surface for a sufficient duration to allow for maximum wave development. For a fetch of approximately 5 km, full wave formation typically takes between 45 to 60 minutes, depending on wind speed. This corresponds to the one-hour averaging period of wind data from Meteoblue [12]. Therefore, when using hourly wind speed averages, it can be assumed that the calculated wave heights are fully developed, as specified in the referenced method [15].
The significant wave height (H_s) and significant wave period (T_s) can be calculated using Equation 1 and Equation 2.

$$H_s = \bar{H}\frac{u^2}{g} \tag{1}$$

$$T_s = \bar{T}\frac{u}{g} \tag{2}$$

Where u is the wind speed at the water surface, g the acceleration due to gravity, $\bar{H}$ the dimensionless wave height, and $\bar{T}$ the dimensionless wave period. The dimensionless wave height $\bar{H}$ is calculated using Equation 3.

$$\bar{H} = 0.283 \tanh\left(0.35\bar{d}^{0.75}\right) \tanh\left(\frac{0.0125\bar{F}^{0.42}}{\tanh 0.35\bar{d}^{0.75}}\right) \tag{3}$$

Where:

- $\bar{d} = \frac{dg}{u^2}$ is the dimensionless water depth.
- $\bar{F} = \frac{Fg}{u^2}$ is the dimensionless fetch length.
- d is the water depth (m).
- F is the fetch length (m).

The dimensionless wave period $\bar{T}$ is given by Equation 4.

$$\bar{T} = 2.4\pi \tanh\left(0.833\bar{d}^{0.375}\right) \tanh\left(\frac{0.077\bar{F}^{0.25}}{\tanh 0.833\bar{d}^{0.375}}\right) \tag{4}$$

- **Water Depth (d)**: The water depth near the breakwater is the most relevant in this case, while the impact of local deep channels can generally be ignored. In our study, we used a water depth of 30 m based on the data provided in Appendix ....
- **Fetch Length (F)**: The fetch length refers to the distance over which the wind blows across the water. It is recommended to calculate the **effective fetch length** F_e, which accounts for the configuration of the water surface over the wind's travel path. The effective fetch length is calculated using Equation 5

$$F_e = \frac{\sum R(\theta)\cos^2\theta_f}{\sum \cos\theta_f} \tag{5}$$

Where $R(\theta)$ is the distance of the fetch for each angle θ, andθ_f is the angle between the fetches. The effective fetch length F_e is calculated for three different directions based on the predominant wind direction in Bahía López, as discussed in subsection 3.5. Given the complexity of determining the exact starting point of a fetch in mountainous regions, the reference point for the fetch is chosen as the side branch of Lago Nahuel Huapi, which leads into Bahía López. Using the formula for effective fetch length, this results in a value of $F_e = 3234$ meters, which was derived based on the configuration shown in Figure 3.14.

Figure 3.14: Fetch lengths Bahía López

Three wind speed values from Meteoblue (2024) [12] are considered: average wind speed (annual mean), moderate wind speed (above average but not extreme), and extreme wind speed (highest recorded values). An overview can be found in Table 3.2.

Table 3.2: Wind Speed, Significant Wave Height, and Wave Period Data

Wind Category	Wind Speed [km/h]	Wave Height [m]	Wave Period [s]
Average Winds	13.0	0.12	1.14
Moderate Winds	35.0	0.39	1.96
Strong Winds	60.0	0.72	2.57

3.6 Sedimentation Analysis

During the site visit to Bahía López and the interview with the concessionaire, an important challenge was identified: significant sediment accumulation at the marina and public beach, currently resulting in shallow water depths in the marina. The construction of the breakwater, shown in Figure 3.15, has significantly altered water circulations, creating a more complex hydrodynamic environment.

Figure 3.15: Breakwater build in 1929 and vegetation growth in marina

As a result, sediment accumulation has become a persistent issue, decreasing water depth and interfering with marina operations. This buildup of sediment has also facilitated the growth of vegetation, which further complicates dredging efforts. Not only does this vegetation make sediment removal more difficult, but it also creates a habitat for wildlife, introducing additional ecological concerns, as shown in Figure 3.15. Furthermore, this vegetation obstructs the natural water flow, causing the water to stagnate. If left unaddressed, the ongoing sediment accumulation could severely affect the long-term functionality of the marina.

As there is no available information or satellite images of the shoreline and marina area prior to 2007, it is difficult to determine the original geological form of Bahía López and what changes resulted from shoreline rotation and sedimentation after the construction of the breakwater.

Figure 3.16: West side of the beach at Bahía López

Figure 3.17: East side of the beach at Bahía López

In Figure 3.16 and Figure 3.17, it can be observed that the west side of the beach at Bahía López consists solely of small to medium-sized rocks, while the left side consists of sand. From this, it can be concluded that erosion is occurring on the west side, potentially transporting sediment towards the east side of Bahía López. The sediment accumulation on the east side of the beach and in the marina is analyzed in the following sections, based on two widely recognized theories.

Origin of Sand Deposits

Lake Nahuel Huapi is a glacial lake, meaning its basin was carved by glaciers and later filled with meltwater [16]. Glacial lake formation leaves behind sediment as glaciers erode rock surfaces and transport material. As the ice melts, these sediments are deposited, creating a lakebed rich in sand and rocks [17]. As shown in Figure 3.10, the dark sand observed suggests a composition influenced by volcanic and tectonic activity. This aligns with the geological context of the region, where volcanic rocks contribute to sediment deposits. Consequently, the sand found at Bahía López is likely a product of these combined geological and glacial processes.

When considering the available geological chart, it is difficult to pinpoint an exact location of where the sediments originate from. As shown in Figure 3.11, the geological chart ends further north, but the conclusion can be drawn that the sediments likely originate from upstream Bahía López and Lago Nahuel Huapi.

Littoral Drift

Littoral drift is the process by which waves and currents work together to move sediment along the shore. Unlike ocean shores, sediment transport in lakes is mainly driven by wind-generated waves and currents. Wind-induced waves diffract near the shore as water levels become shallow. Waves hit the shore at an angle (swash), while the backwash pulls sediment straight back, creating a zigzag sediment transport along the coast (Bosboom, 2023) [18], as explained in Figure 3.18.

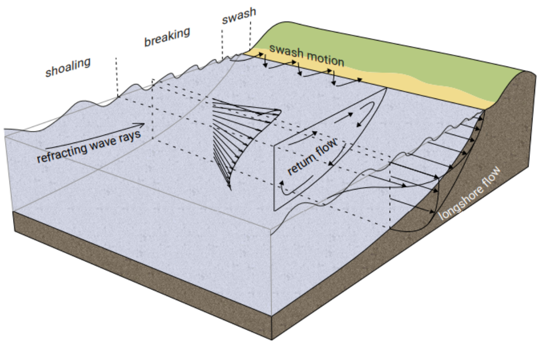


Figure 3.18: Explanation of littoral drift [18]

The zigzag transport, combined with wind-driven currents and waves in Bahía López, carries sediments along the coast toward the bays southern end, as shown in Figure 3.19. Figure 3.20 depicts erosion and sedimentation zones. The orange areas indicate erosion, where wave action and longshore currents transport sediment away, gradually wearing down the shoreline. In contrast, the green areas represent sedimentation zones, where material accumulates.

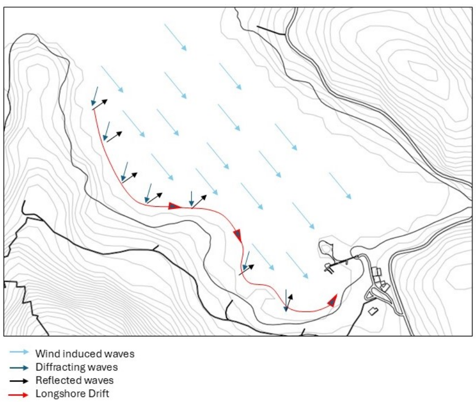


Figure 3.19: Littoral drift at Bahía López

Figure 3.20: Erosion and sedimentation zones Bahía López

Diffraction

When waves encounter an abrupt obstruction such as a breakwater or headland, their propagation is disrupted. Part of the wave front is blocked, while the remainder bends around the structure due to diffraction [18]. As illustrated in Figure 3.21, the undisturbed section of the wave train continues its regular motion, leading to predictable erosion patterns. Meanwhile, in the lee of the breakwater, the diffracted waves form a circular pattern, influencing sediment transport and resulting in a characteristic circular deposition zone. This phenomenon is particularly evident at Bahía López, where diffraction-induced sedimentation is clearly visible.

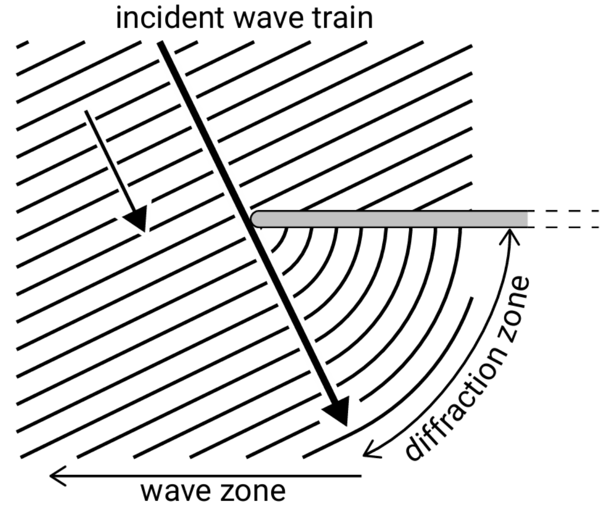


Figure 3.21: Wave diffraction around a breakwater, creating circular wave and sedimentation patterns [18]

The parabolic bay shape model developed by Hsu and Evans (1989) [19] provides an empirical method for describing the shoreline configuration in areas affected by wave diffraction and sediment transport. The model represents the equilibrium bay shape that develops in response to the presence of a breakwater or headland.

Derived from observed diffraction patterns and sediment dynamics, the model is expressed through an empirical formula (Equation 6). The coefficients in this equation are determined by the orientation of the incoming wave crest line, as shown in Figure 3.22.

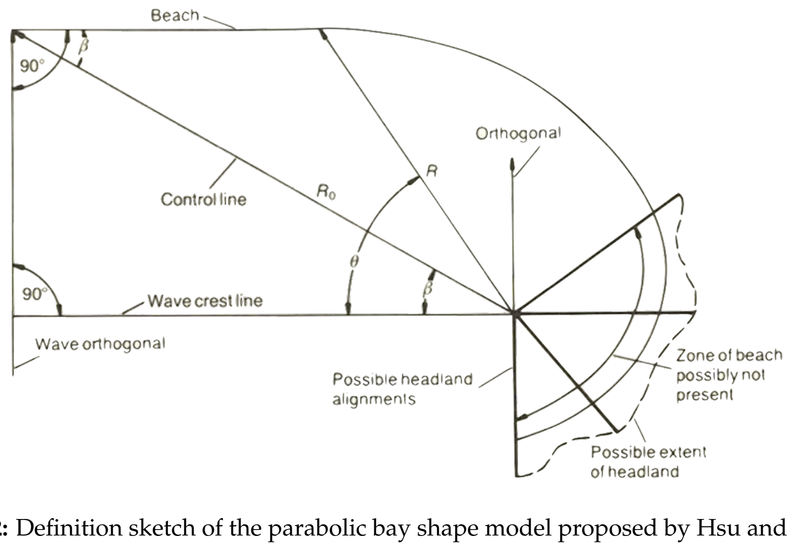


Figure 3.22: Definition sketch of the parabolic bay shape model proposed by Hsu and Evans [19].

The governing equation for the parabolic bay shape is given by Equation 6:

$$\frac{R}{R_0} = C_0 + C_1\left(\frac{\beta}{\theta}\right) + C_2\left(\frac{\beta}{\theta}\right)^2 \tag{6}$$

where:

- R is the shoreline radius,
- R_0 is the reference control line distance (e.g., from the breakwater head to the opposing shoreline),
- C_0, C_1, C_2 are empirical coefficients determined by HSU and Evans,
- β is the wave obliquity angle,
- θ is the control angle.

The empirical coefficients used in the model are listed in Table 3.3.

Table 3.3: Empirical coefficients for the parabolic bay equation.

Coefficient	Value
C_0	0.055
C_1	1.029
C_2	-0.088

This empirical model can be applied to Bahía López by incorporating local wave direction and geometric parameters. Using a design wind direction of 140° from the north and a control line distance of 260 meters from the breakwater head to the opposing shoreline, the resulting shoreline shape can be predicted. The coefficients from Table 3.3 are obtained from the study of Hsu and Evans [19].

The model was implemented in Python (see Appendix J), generating a modeled bay shape, which was then compared to the actual shoreline at Bahía López. The results demonstrate a strong correlation between the predicted and observed bay shape, confirming the models applicability. The comparison is shown in Figure 3.23.

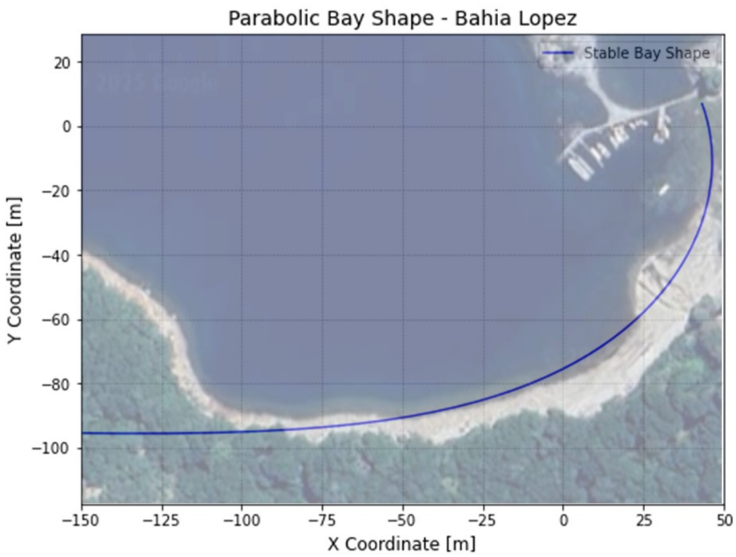


Figure 3.23: Comparison of actual bay shape with the modeled parabolic bay curve.

Tan and Chiew (1994) and later Elshinnawy et al. (2022) introduced modifications to the formula for plotting the beach line [20]. However, the revised equations did not provide a better fit than the original formula by Hsu and Evans. Therefore, they were not included in the analysis.

The bay shape plotting reveals a strong resemblance between the parabolic curve and the actual shape of the bay. While it is unclear whether the construction of the breakwater has completely reshaped the bay, the sediment accumulation behind the structure in a parabolic form suggests that the model offers a reasonable approximation of the bay's equilibrium shape. However, due to littoral drift and the original shoreline, the model does not provide a perfect fit.

A notable intersection point of the diffraction zone and the littoral drift can be identified, forming a deposition area. This suggests that while sediment is transported along the bay, it tends to settle in the sheltered region behind the breakwater, contributing to the observed buildup, highlighted green in Figure 3.24.

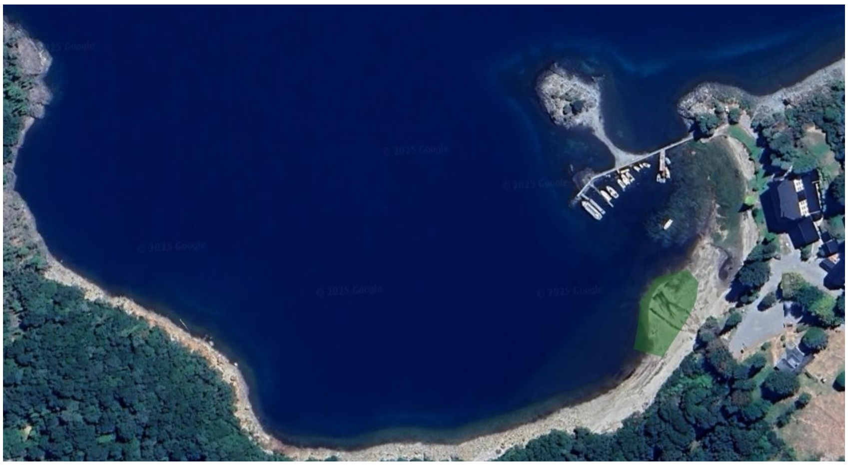


Figure 3.24: Interference point, diffraction point and longshore sediment transport

It remains uncertain whether the marinas current shape is entirely a result of sedimentation following the breakwaters construction in 1929. The concessionaire indicated that this is the first instance of dredging at the marina, implying that sediment accumulation occurs over an extended timescale. This suggests that while the breakwater influences sediment deposition, the rate of accumulation is relatively slow. Given that dredging has only become necessary after nearly a century, periodic sediment management, on a long term scale, appears to be a feasible approach to maintaining navigability in the marina.

3.7 Environmental Analysis

To ensure sustainable development of the marina, it is important to fully understand the biological properties and challenges in the area of Bahía López. By conducting an environmental analysis prior to the design process, the development of a harmful design can be prevented. This approach may also reveal win-win solutions that work in harmony with nature, rather than against it. The aim is ***"Maximizing opportunities, reducing frustrations"*** [21]. This approach is described and encouraged by the Permanent International Association of Navigation Congresses (PIANC) [21]. The following section will outline the current local flora and fauna, followed by a discussion of the ecological challenges. The section will conclude with an overview of the legal framework for nature conservation in project development.

Local Flora

The distribution of biomes in the area is shaped by environmental factors such as topography, hydrology and climate. From a phytogeographical perspective, the project area is located in the northern part of the Andean-Patagonian forest formation, specifically in the Subantarctic province.

The native plant communities in this region correspond to a temperate-cold forest, mainly dominated by Coihue forests (*Nothofagus dombeyi*). However, the specific area designated for the project has low vegetation coverage due to its proximity to the lake shoreline. Figure 3.25 provides an overview of the diverse vegetation types in the area of Bahía López.

This variation of vegetation types lead an even wider range species. The list is too long to include in this rapport, but the most characteristic native species are the Coihue, Arrayan, Fitzroya and the Tristerix. The biggest ecological challenge regarding the local fauna are invasive exotic species. Their invasive nature is a threat to more delicate native species and therefore a threat for the biodiversity of the area. The most invasive exotic spcecies are pine trees, scotch broom and wild rosehip [22].

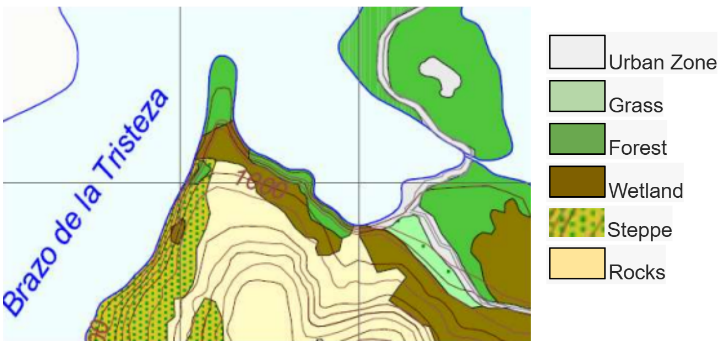


Figure 3.25: Map of vegetation types in Bahía López [22]

Figure 3.26: Vegetation in Bahía López [22]

Local Fauna

Nahuel Huapi National Park is home to over 1,100 native species, mostly birds, followed by mammals, amphibians, and reptiles. Additionally, there are 47 recorded exotic species. While this report cannot cover all of them, it focuses on the species most relevant to the Bahía López area.

The native species that live in this area are in the skies: the andean condor, chimanga caracara, magellanic woodpecker, buff-necked ibis, and upland goose. The ground is populated by the huillin, kodkod, culpeo fox, pudu deer, Patagonian lizard and various mouse species. The water is inhabited by small and large puyen fish, Patagonian perch and Patagonian silverside. These native animals face the same challenge as the native plants regarding competition of exotic species. The most invasive species include the American mink and various trout species.

The most critical species to pay attention to in this specific area are the huillin and the kodkod, as they are both threatened by extinction according to the International Union for Conservation of Nature [23].

They can be seen in Figure 3.27. Efforts must be made to avoid harming these species and their habitats.

Figure 3.27: Kodkod (left) and Huillin (right) [24],[25]

Legal Framework

To conserve the biologically diverse area, Nahuel Huapi was established as a national park on 9 October 1934 [26]. The population and tourism in the area has been growing ever since. A lot of infrastructure and buildings had to be constructed to accommodate this. Unfortunately, the increase in recreational activities and construction has compromised nature conservation efforts.

For this reason, Parques Nacionales Nahuel Huapi regulates and monitors not only wildlife, but also touristic activity and construction projects. Every ten years, an extensive plan for conservation strategies is conducted [27], with a midterm review after 5 years. This plan also includes a zonification where areas are assigned a specific function, specifically:

- Area Intangible (Untouchable Area): these areas have the highest level of protection. No human activity is allowed here, except scientific research with minimal impact, ecological maintenance actions and park ranger patrols.
- Area de Uso Publico Extensivo (Extensive Public Use Area): In these areas, low impact tourism activities like hiking are allowed. Infrastructure is limited to viewpoints, trails and small shelters.
- Area de Aprovecham de Recursos (Sustainable Resource Use Area): Human settlements and controlled resource extraction like grazing and forestry are allowed here.
- Area de Uso Publico Intensivo (Intensive Public Use Area): This area is designated for intensive public use. Visitor centres, camping grounds and parking areas can be build here.

The zonification map can be seen in Figure 3.28, which also shows the location of Bahía López. While it may appear that Bahía López falls under the jurisdiction of the municipality, Parques Nacionales confirmed that it is part of their jurisdiction and falls under the Area de Uso Público Extensivo.

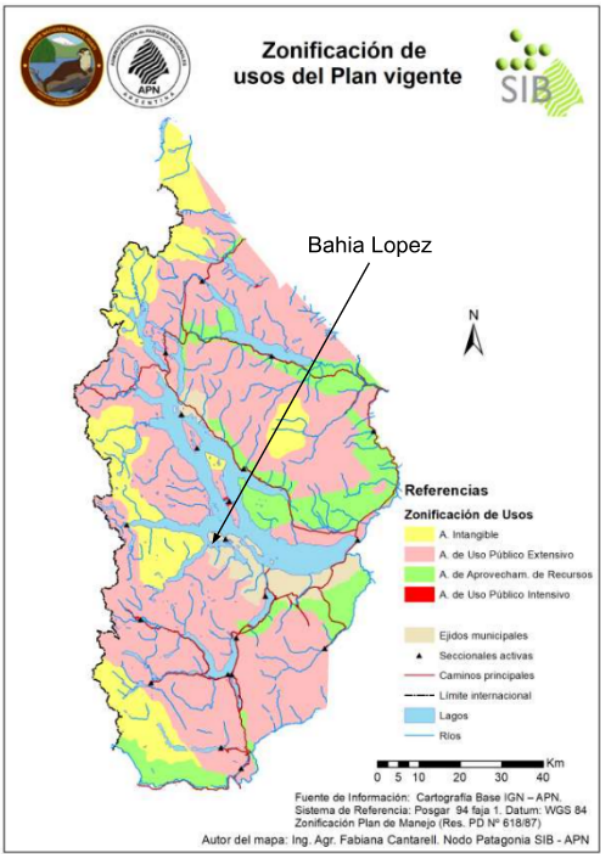


Figure 3.28: Zonification of Nahuel Huapi National Park [27]

From the stakeholder interviews that can be found in Appendix B, the main obstacle for a development project like this was identified to be the very complicated permit process of Parques Nacionales. Many stakeholders expressed frustration with the extensive duration and frequent rejections of projects.

Parques Nacionales maintains this rigorous permit process to ensure the highest level of conservation. However, due to the length and frequent rejections of this process, the supply of recreational activities and infrastructure has not kept pace with the growing demand. This has led to unregulated projects. Parques Nacionales has confirmed that controlled expansion of existing infrastructure is part of their conservation strategy to better concentrate recreational activities.

To make this process more transparent, a formal document was produced as a sideproduct of this project in collaboration with Parques Nacionales. A systematic overview can be seen in Figure 3.29. A description of what this process looks like for this project specifically, can be seen in subsection 6.3.

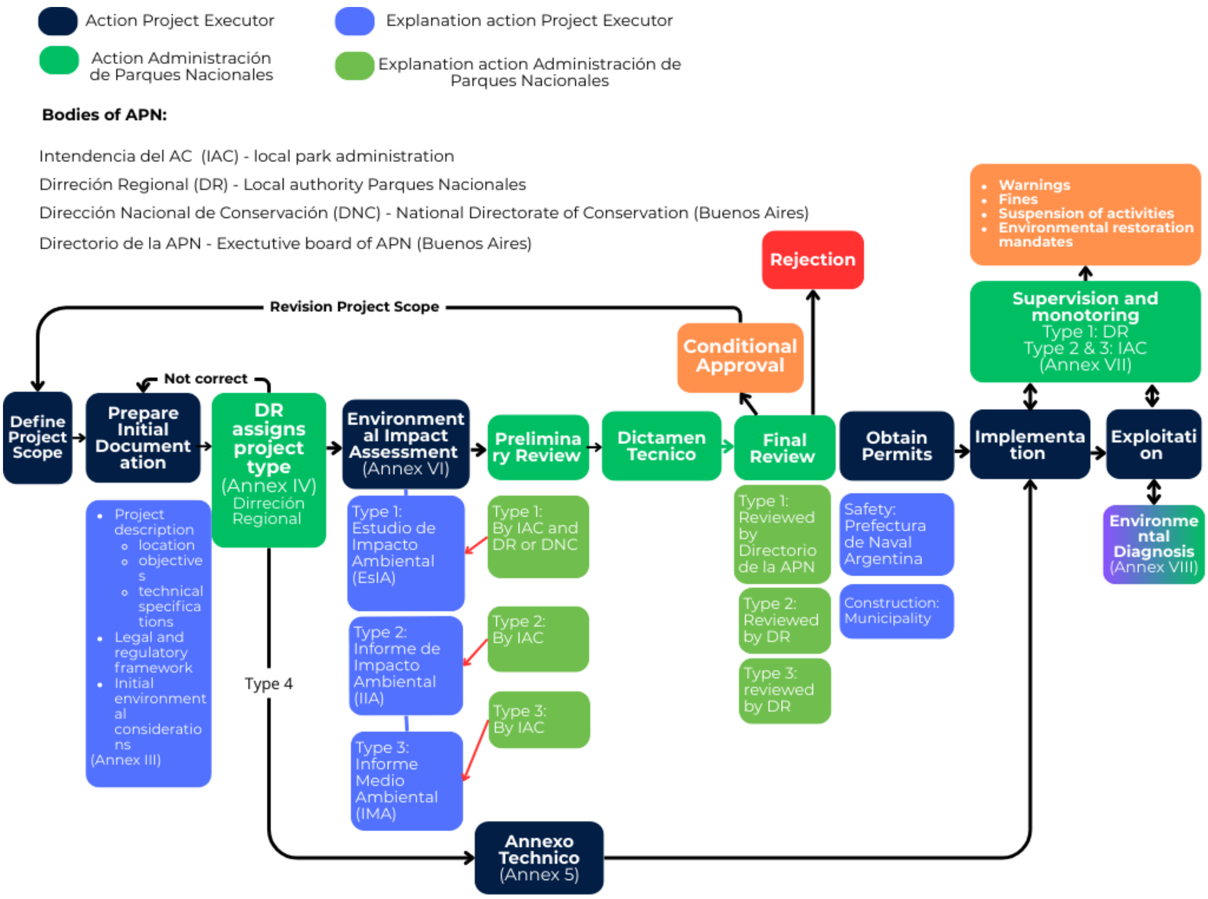


Figure 3.29: Permit Evaluation Process

3.8 Conclusion

The area study of Bahía López has provided critical insights into the various factors influencing the proposed marina development. Bahía López is strategically located within Nahuel Huapi National Park, offering easy access to key destinations within the park. The surrounding area is characterized by a mix of steep terrain, low vegetation coverage near the shoreline, and a historically significant breakwater structure. This locations accessibility, both by land (via the Circuito Chico) and water, makes it an ideal site for the marina, although the development must respect the complex legal and environmental framework governed by Parques Nacionales and the municipality of Bariloche.

The topographic study reveals that the site is characterized by steep terrain, with Mount López towering at 1,300 meters above lake level. This topography creates challenges for construction but also offers scenic views that could enhance the marinas appeal. The bathymetric analysis indicates limited available data on water depths, highlighting the need for further surveys to ensure the marinas viability. Existing data from 1971, while helpful, suggests that the water depth is sufficient for larger vessels, but ongoing monitoring and dredging will be required due to seasonal water level fluctuations.

The geotechnical analysis confirms that the soil composition is primarily sandy with some volcanic influences, which has implications for erosion control and construction stability. The sedimentation analysis reveals that sediment transport in the marina is driven by littoral drift and wave diffraction. Sediment is carried along the shoreline by littoral drift, leading to accumulation in and around the marina. Additionally, wave diffraction behind the breakwater generates a circular flow pattern that influences sediment deposition. Since the construction of the breakwater in 1929, sediment accumulation in the marina and beach area has been significant, though the rate of accumulation is relatively low. The marinas design and breakwater have created a stagnant zone where sediments naturally settle. This, along with vegetation growth, accelerates sedimentation, making the marina inoperable over time. Continuous sediment management and dredging will be required for long-term functionality.

Wind and wave conditions play a crucial role in shaping the marinas environment. The analysis shows that wind-driven waves, with significant gusts recorded throughout the year, contribute to strong currents and shoreline erosion. The empirical model for wave height prediction, based on wind data from Bariloche, suggests that the marinas design must account for these dynamic forces, particularly in terms of wave diffraction and sediment transport. The breakwater and marina structures must be designed to withstand these forces while ensuring navigability and safety.

The environmental study underscores the importance of preserving local biodiversity, particularly the threatened species such as the huillin and kodkod. Invasive species, such as pine trees and the American mink, pose a significant threat to the native flora and fauna. The marina development must mitigate these impacts by following the legal framework set by Parques Nacionales, which includes stringent conservation zones and a complex permitting process. The area falls under the Area de Uso Público Extensivo, where low-impact tourism activities are encouraged, and any infrastructure development must align with these regulations.

4 Stakeholder Analysis

Essential for this project is analyzing and identifying the involved stakeholders. By recognizing their roles and interests, informed decisions can be made for the development of the marina. Through meetings and interviews during the site visit with a total of eight stakeholders, a complete overview of their involvement and needs is created. A summary of these interviews is provided in Appendix B.

The stakeholders will be divided into governmental stakeholders and non-governmental stakeholders. The structure within the Argentine federal system will be further elaborated to understand the underlying hierarchy and influence structures. After that, a stakeholder map will be created that contains all stakeholders, both governmental and non-governmental.

4.1 Governmental Stakeholders

The governmental stakeholders involved in the project span three levels of authority, from the national government to the Province of Rio Negro and the Municipality of San Carlos de Bariloche. Each authority plays a different role in the regulation, approval, and oversight of the marina's development. This section provides an overview of the key governmental bodies, their responsibilities, and their influence on the project. Also, a clear overview of the government structure is given in Appendix A.

National Government

Argentina is organized as a federal republic, where power is divided between the national government and twenty-three provinces. Under the national government, there are three branches: executive, judicial and legislative. The executive branch consists of the president and ministries. Since October 2023, a government restructuring has taken place, reducing the number of ministries from eighteen to nine [28].

Administración de Parques Nacionales (APN)

The Administración de Parques Nacionales (APN) is responsible for the management and conservation of Argentinas national parks, including Nahuel Huapi National Park. Historically, APN was under the Ministry of Environment and Sustainable Development, but in December 2023, this ministry was dissolved. Since then, APN falls under the Ministry of the Interior [28].

The APN holds significant authority within Nahuel Huapi National Park, as all proposed development plans within the park require its approval. Additionally, the APN has the power to initiate projects and grant concessions. It is responsible for overseeing all activities within the park, including those on the water and most on land, with the exception of areas under municipal jurisdiction. Ensuring continuous engagement with the APN is therefore essential, both to keep them informed of project progress and to incorporate their feedback into the development process. See appendix B.1 for a detailed summery of the interview with APN.

Province of Río Negro

Argentine provinces are subdivided into departments and municipalities. Departments are administrative divisions within the province but do not have autonomous government structures. Municipalities on the other hand are self-governing local entities that manage public services, urban planning and local regulations. The provinces have a high degree of autonomy in matters such as education, health, infrastructure and tourism. Río Negro, where Bahía López is located, has its own provincial government, with executive, legislative and judicial powers.

Port Authority of Río Negro

The Port Authority of Río Negro is a recently created entity, it has legal status but is not fully operational yet. Its goal will be to manage maritime infrastructure and port operations within the province. While its primary focus will be the overseeing of commercial ports, its influence will extend to water navigation regulations and safety, which can impact tourism and transportation development in Bahía López. They influence the decision making on provincial level, but have less influence on the final approval regarding the development of the marina in Bahia Lopez.

Municipality of San Carlos de Bariloche

On a local level, the Municipality of San Carlos de Bariloche oversees urban planning, infrastructure, and environmental management within the city and its surrounding areas. Bahía López falls within a special jurisdiction zone where the municipality governs the land and the APN regulates activities on the water and along the shoreline. This division of responsibilities must be carefully considered in the planning and approval processes. The municipality is an important actor in approving or disapproving the proposed development plans for the marina of Bahia Lopez. As the governing authority, the municipality holds the final decision-making power regarding all aspects of the project that take place on land.

Tourism Secretary, Municipality of San Carlos de Bariloche

The Tourism Secretary is a department within the municipality, responsible for managing and promoting tourism, the region's primary economic driver. The national parks natural landscape, with its mountains and lakes, attracts visitors throughout the year, making year-round tourism a major focus for the municipality. Since COVID-19 an increased growth in tourist traveling to the municipality has been noticed, requiring the expansion of current infrastructure, such as marinas.

Another important consideration for the Municipality is ensuring public accessibility to the amenities at Bahía López. However, due to limited financial resources, the municipality lacks the capacity to independently maintain the public character of the marina. As a result, it relies on private investments and commercial parties to fund and maintain the infrastructure. See appendix B.4 for the detailed summery of the interview with the municipality.

Prefectura Naval Argentina, Bariloche Division

The Prefectura Naval Argentina (PNA) is the national maritime authority, responsible for enforcing navigation laws and ensuring safety on lakes and rivers. The Bariloche division of PNA oversees Lake Nahuel Huapi, working closely with APN and the provincial government to regulate recreational boating and tourism activities in Bahía López. Furthermore they have a decisive role in the approval of the plans for the new marina. After the APN approves the plan, the Prefectura will investigate the safety of the infrastructure, the final decision in the approval process.

4.2 Non Governmental Stakeholders

Beyond governmental authorities, non-governmental stakeholders such as local businesses, recreational users, and local organizations will be directly or indirectly affected by the marinas development. While they lack regulatory power, their support or concerns can influence the projects success. This paragraph outlines key actors in the private sector and community groups, highlighting their interests and potential impact.

Hotel Alún Nehuén

Hotel Alún Nehuén is the only tourist accommodation located in the Bahía López, situated directly adjacent to the marina. The hotel has a strong interest in the marinas development, as improved facilities are expected to attract more visitors to Bahía López, increasing the demand for accommodations. Furthermore, according to the Hotel manager, the hotel guests are currently the main users of the marina.

The hotel operates on a concession granted by the Municipality, giving it control over activities within its designated plot. However, its authority is limited to this area, as it holds no jurisdictional power over developments beyond its property boundaries, as became clear from the meeting with the municipality.

The hotel regards the marina development positively, since it increases the general quality of the services they can offer. They are aware that the road in front of the hotel will be used by vehicles towing boat trailers but believe that if traffic is well-organized, it will not pose a problem and may even benefit the hotel. Additionally, they have no objections to the potential addition of a kiosk or food trucks, considering them a valuable alternative to their existing restaurant.

Currently the only electricity and sewerage present in the bay is under the control of the hotel. They are open to a collaboration in which the marina's services are connected to these hotel systems. One concern raised by the hotel is the availability of parking, as they currently utilize a large portion of the parking spaces, especially during peak season. They recommend expanding the parking area alongside the marinas development to prevent capacity issues. Given the historically good relationship between the hotel and the existing marina, it is expected that this positive dynamic will continue even after the marinas expansion. See appendix B.8 for the detailed summery of the interview.

Club Náutico Bariloche

Club Náutico Bariloche is the largest boating club at Lake Nahuel Huapi, located at the edge of Bariloche. Founded in 1947, it operates as a non-commercial organization with over 400 active members. Currently, the club has reached full capacity and is unable to accept new members. Membership primarily consists of individuals who moor their boats at the club and children enrolled in sailing classes. The club offers approximately 100 mooring spaces in the water, along with dry berths for an additional 100 boats. In recent years, Club Náutico Bariloche explored expansion plans; however, due to regulatory constraints imposed by Parques Nacionales, Prefectura and the local municipality, these plans were halted and remain on hold. Additionally, the club features a restaurant which is open to non-members.

The marina development plans at Bahía López are closely connected to the existing facilities at Club Náutico Bariloche, making them potential competitors. However, interviews and market trend analyses indicate that demand for boat mooring continues to grow in popularity. Given this increasing demand and the fact that the new marina is located 30 kilometers away, its development is unlikely to negatively impact Club Náutico. Additionally, during the interview, Club Náutico did not express any doubts or complaints regarding the project. See appendix B.5 for the detailed summery of the interview.

Turisur

Turisur is the largest tourism company operating on Lago Nahuel Huapi, specializing in boat tours to scenic islands and remote areas of the lake. Currently, all Turisur trips depart from Puerto Pañuelo, which holds the exclusive concession for these operations until 2036. Due to this long-term agreement, Turisur has currently no interest in relocating or expanding its services to Bahía López, minimizing their influence on the project. Their business model and operations remain entirely separate from those planned for Bahía López. See appendix B.6 for the detailed summery of the interview.

Private boat owners

Private boat owners using the marina can be categorized into two groups based on their usage: those with permanent mooring places and those utilizing the boat ramp for temporary access. Each group has specific needs and expectations that influence marina operations and overall stakeholder satisfaction.

Recreational boat owners with permanent moorings
These users keep their sailing or motorized boats docked in the marina year-round or seasonally. They are located in the recreational part of the marina, where they rely on secure mooring, maintenance services, and convenient access to their vessels. Their primary concerns are mooring quality, safety, accessibility, and costs. Since they make up the largest share of mooring points, their satisfaction is crucial to the marinas success.

Boat owners who launch via the boat ramp
These users bring their boats to the marina only when they plan to go out on the lake. They are primarily located in the operational part of the marina, using the boat ramp for launching and retrieving their vessels. Their main priorities are efficient launching processes, parking availability, and minimal waiting times. While they do not require permanent moorings, their frequency of use can impact marina operations, particularly during peak boating seasons. Although neither group has direct decision-making power, they influence public perception and can shape overall community support for the marina.

Recreational Beach Visitors

These are individuals who primarily use the beach and shoreline for relaxation, swimming, and scenic enjoyment. Their experience may be negatively affected by the marina due to potential visual pollution, increased boat traffic, and reduced natural shoreline access. While they do not have a direct say in the marinas development, their perception can influence public opinion and community acceptance of the project.

Small Business owners

Several small businesses operate in and around the marina, with private boat tour operators being the most significant. Currently, around 30 different tour providers use Bahía López as their main entry point to the lake, making them highly interested in the marinas development.

Additionally, possible future kayak rental businesses rely on access to the waterfront and should be considered in the development plans. Other potential stakeholders include food truck vendors and a kiosk operator, whose presence could enhance visitor services. Engaging with these small business owners will ensure that the marinas development aligns with their operational needs.

4.3 Stakeholder Mapping

To visualize the role and significance of each stakeholder in the marina development at Bahía López, a stakeholder map is drawn up. This graph plots stakeholders based on their level of interest in the project against their degree of influence over its development. This method helps categorize stakeholders and determine how they should be engaged throughout the process.

1. Monitor (Low Interest, Low Influence) These stakeholders do not play a significant role in the decision-making process as they neither strongly benefit from nor are affected by the marinas development. In this case, Turisur and Club Náutico Bariloche fall into this category. Turisur, as a well-established tourism company, operates under a long-term concession at Puerto Pañuelo and has no incentive to expand into Bahía López. Club Náutico Bariloche, as an existing marina, may share similarities in use with the planned marina at Bahía López, but it remains largely unaffected and continues to function independently. Given this, Club Náutico holds slightly more interest than Turisur but still remains in the "monitor" category.

2. Keep Satisfied (High Influence, Low Interest) These stakeholders have authority over certain aspects of the project but are not deeply invested in its outcome. In this case, the Provincial Government of Río Negro fits into this category. While the province retains influence in some areas, many decisions are made at the municipal level, reducing the provinces direct involvement. However, its regulatory power means it must be kept satisfied throughout the project.

3. Keep Informed (High Interest, Low Influence) This category includes stakeholders who are significantly affected by the marinas development but lack the juridical authority to influence its definition. These stakeholders include private boat owners, recreational beach visitors, and small business owners such as private boat tour operators, kayak rental services, and food truck vendors. The marinas development will directly impact their activities, requiring them to be informed and engaged, but their ability to influence decisions is limited.
   Hotel Alún Nehuén also falls into this category. While the hotel has a vested interest in the marinas success, anticipating increased tourism and demand for accommodations, it has minimal decision-making power beyond its own property. However, it holds slightly more influence than individual recreational users due to its established presence and ongoing interactions with local authorities.

4. Manage Closely (High Interest, High Influence) These are the most critical stakeholders, as they hold both regulatory authority and a strong interest in the marinas development. The key stakeholders in this category are:

   - Administración des Parques Nacionales: As the governing body of Nahuel Huapi National Park, APN plays a decisive role in approving and regulating any developments within the protected area. Their main priority is conservation, making them a key - but potentially cautious - decision-maker.

   - Municipality of San Carlos de Bariloche: The municipality oversees land use and local infrastructure, making it a vital partner in the marinas development. Their support is crucial for project approval and integration with local tourism and economic policies.

   - Prefectura Naval Argentina: This authority regulates navigation, safety, and maritime infrastructure. Prefectura is particularly interested in the project, as it may use the service building and potentially secure a docking space within the marina.

   - Concessionaire (Highest Interest, Highest Influence): At the top-right of the mapping, the concessionaire holds the highest level of both influence and interest. As the primary developer and operator of the marina, they are directly responsible for its execution and long-term management. Their role in shaping the marinas services, infrastructure, and operations makes them the most actively involved stakeholder in the project.

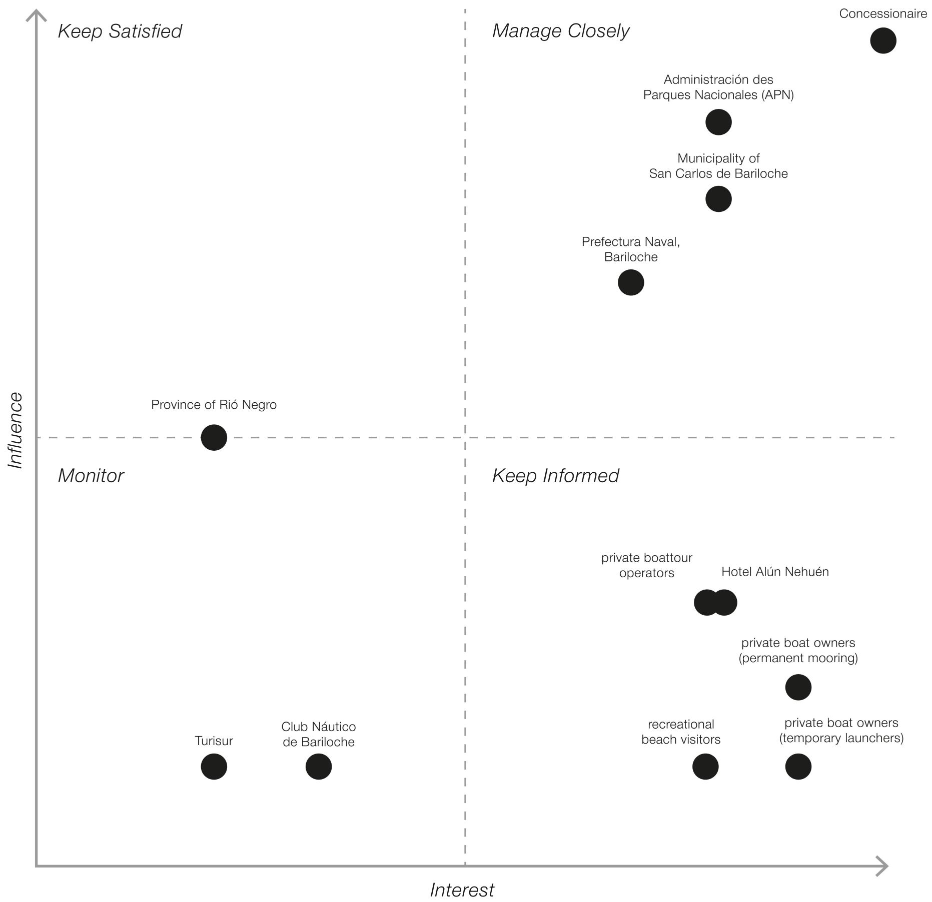


Figure 4.1: Stakeholder map

4.4 Conclusion

The governance of Bahía López is a complex structure of actors, as it is located at the juristical border between the Nahuel Huapi National Park and the municipality, that also declared the district separately as a protected area: Parque Llao Llao. While APN generally has jurisdiction over the water and land in national parks, the municipality retains control over land-based aspects inside their borders. In Bahía López these jurisdictions overlap, resulting in a situation where the APN has jurisdiction over the water and part of the shoreline, and the municipality over most of the land. Additionally, Prefectura Naval Argentina imposes further regulations, particularly concerning navigation, safety, and water use.

During interviews with stakeholders, it became evident that APN is the most influential stakeholder in this project. Their primary objective is to preserve the natural environment of the national park. This results in an extensive, complex regulatory framework. Getting the development plans approved by APN could be a difficult and time consuming process. Besides APN, the municipality stands out as one of the most affected stakeholders, given its role in managing local tourism and infrastructure.

Beyond APN most other stakeholders view the marina development positively, including the municipality, private boat owners, beach visitors, and local businesses such as Hotel Alún Nehuén. While there is broad support for the marina project, the regulatory complexities imposed by APN represent the most significant challenges. Navigating these regulations effectively while maintaining a strong collaborative base with local governmental bodies and tourism stakeholders will be essential for the project's success.

5
Market Analysis

The marina market study is conducted to establish key vessel design parameters, identify user demands, and determine the necessary services and infrastructure for the development of Puerto Bahía López. It provides data to support the commercial feasibility analysis and ensures that the marina meets the needs of its target market. The study takes into account different vessel types, occupancy rates, market trends, and competitive analysis to define an optimal slip mix and service offering. It is challenging to obtain statistically robust quantitative data for this area. As a result, the findings rely primarily on qualitative insights gathered through stakeholder interviews. A more extensive and in-depth market study could yield a more precise and data-driven outcome.

5.1 Market Overview

This section provides an overview of the current market for boating and recreational activities around Bariloche, including key trends and tourism data. It examines existing marinas and beaches, the growth of water-based tourism, and emerging patterns in recreational boating.

Tourism in and in the area of Bariloche

Bariloche is one of Argentinas most popular tourist destinations, attracting over one million visitors annually. Tourism plays a crucial role in the local economy, contributing approximately 30% of total revenue [29]. This revenue is primarily driven by two key seasonal industries: winter tourism, which includes skiing and snow-related activities, and summer tourism, including hiking, sailing, swimming, and other outdoor recreation. As shown in Figure 5.1 (left), about half of the total number of tourists visit Bariloche during the summer, resulting in approximately 2 million visitors during this season.
As shown at the right in Figure 5.1, tourism in Bariloche has been steadily increasing. This trend is evident from the rising number of hotel visitors, though the actual figures are likely even higher when considering stays in Airbnbs and hostels. A notable development in the later stages of the pandemic was the sharp rise in domestic tourism, a trend confirmed by all stakeholders during interviews. With international travel restrictions limiting outbound travel, many Argentinians chose to vacation within the country, leading to a newfound appreciation for Bariloches natural beauty. This shift has continued post-pandemic. This reinforces the feasibility of a marina, as a growing number of visitors may drive demand for boating-related activities.

The total number of occupied tourist accommodations fluctuates significantly throughout the year, with peaks around the summer months (December to March) and another rise in winter season (July to November), see figure 5.1. This suggests that a marina should be designed to accommodate high seasonal demand and possibly offer flexible services that cater to both summer and winter tourism.

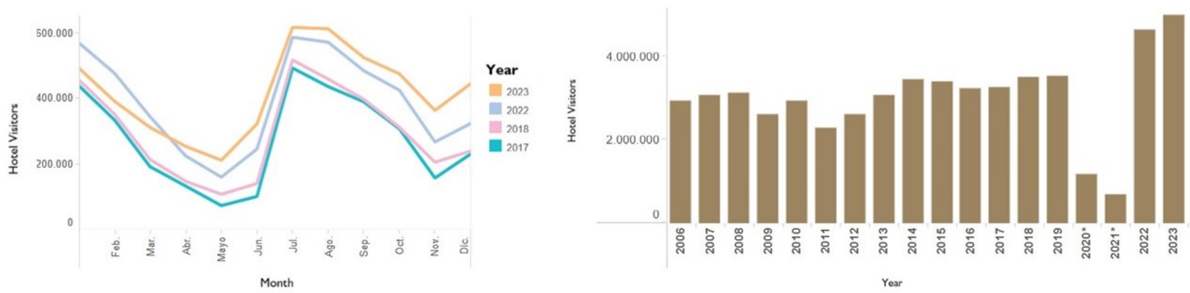
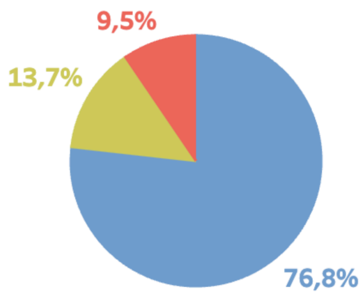


Figure 5.1: Number of hotel visitors in Bariloche (left: seasonal trend, right: annual trend) [29]

As can be seen in Figure 5.2, the majority of tourists in Bariloche are of domestic origin, with 76.8% coming from within Argentina [29]. Another 13.7% arrive from neighboring countries such as Brazil, Chile, and Uruguay, while only 9.5% come from the rest of the world. This suggests that the local tourism sector is primarily geared toward Argentine visitors.



Isla Victoria / Bosque de Arrayanes	25,7%
Montañismo	2,0%
Ninguna actividad	18,9%
Ninguna excursión	11,1%
Otras actividades	14,8%
Otras excursiones	10,4%
Pesca / Caza	1,3%
Playa	23,8%
Puerto Blest / Lago Frías	6,3%
Rafting	1,7%
San Martín de los Andes / Siete Lagos	23,7%

Figure 5.2: Origins of tourists (left) and excursions & activities (right) [29].

Tourists in Bariloche participate in a variety of water-based recreational activities, reinforcing the demand for marina-related services. With 23.8% of visitors spending time at the beach, there is a clear market for leisure-focused marina facilities, including boat rentals and waterfront services. Boat excursions are also a key attraction, as 25.7% of tourists visit Isla Victoria and Bosque de Arrayanes, while 6.3% travel to Puerto Blest and Lago Frías. These figures highlight a steady demand for boat rentals, docking facilities, and dedicated entry points for recreational boaters. While fishing and hunting (1.3%) and rafting (1.7%) make up smaller portions of the tourism market, they still present opportunities for specialized marina services, such as guided fishing trips, equipment rentals, and adventure-based water sports activities [29].

Existing Marinas and Beaches

Bariloche and the surrounding Nahuel Huapi Lake are home to several existing marinas and ports (Figure 5.4), though they are not abundant. While some marinas offer high-quality mooring facilities, the limited number of large-scale docking areas poses a challenge. Currently, there are six marinas / ports in the area, with only three marinas providing mooring places. Due to the lack of expansion and the growing demand for docking space, many local residents have opted to construct private docks (Figure 5.3). However, this is not always legally permitted by Parques Nacionales and requires extensive documentation and permits, making it a complex process for boat owners.

Figure 5.3: Satellite view of private docks near Bahía López from Google Maps [30].

In addition to functioning as a marina, Bahía López also serves as a popular recreational beach, attracting swimmers and other visitors. Given this dual role, it is essential to assess the availability of beaches in the surrounding area. The graphical overview in Figure 5.4 highlights the existing popular beaches and marinas, showing that there are several accessible waterfront areas. However, what stands out is that Bahía López is the most remote beach along Circuito Chico, the main scenic route that runs along the lake from Bariloche. Additionally, Bahía López is currently the only location around Nahuel Huapi Lake where vehicles can directly launch boats into the water by driving off the beach (Figure 5.5). No other beach in the area offers this natural boat launching facility to the public, making it a unique and strategic site for boating enthusiasts. This means that Bahia Lopez could serve as a leaving point to do for instance to excursions to Brazo Tristeza and Puerto Blest.

Figure 5.4: Marinas and Public Beaches in the area

Figure 5.5: Cars launching their boat into the water at Bahía López. Photo taken by the author.

While overall tourist satisfaction with beach and lake access is high, relatively few visitors report being very satisfied, suggesting room for improvement. Enhancing water access could be a key opportunity for Bahía López, particularly through better docking points, waterfront boardwalks, and improved facilities that cater to both boaters and recreational visitors. A well-integrated marina could help bridge this gap by offering convenient lake access while preserving the natural appeal of the area [29].

Vessel Type Distribution

According to the Municipality of Bariloche, approximately 4,000 boats are registered on Lake Nahuel Huapi, primarily consisting of motorboats and sailboats. PIANC categorizes these two main vessel types, with additional subcategories based on their specific use. An overview of vessel types and their characteristics according to PIANC is provided in Figure 5.6.

Vessel type	Typical characteristics [1]		
	Length Overall	Draft	Beam
Day boat (motor)	< 10 m	< 1 m	< 4 m
Day boat (sail)		< 2 m	< 4 m
Small cruising (motor)	10-15 m	< 1.5 m	< 5 m
Small cruising (sail)		< 3 m	< 5 m
Large cruising (motor)	15-20 m	< 2 m	< 6.5 m
Large cruising (sail)		< 3.5 m	< 6 m
Luxury (motor)	20-25 m	< 2 m	< 7 m
Luxury (sail)		< 4 m	< 7 m
Super-yacht [2]	> 25 m	See note 2	

[1] Typical characteristics apply to mono-hull vessels only.
[2] For specific guidance relating to superyacht, megayacht and gigayacht vessel characteristics the designer should refer to PIANC RecCom Report No. 134 – 'Design and Operational Guidelines for Superyacht Facilities' (2013).

Figure 5.6: Typical vessel types and design dimensions according to PIANC [31].

Observations and interviews with stakeholders confirm that most boats on Lake Nahuel Huapi are *day boats*, with fewer *small cruising boats*. The marina should be designed with this in mind, ensuring that the layout and facilities accommodate the types of boats most commonly used on the lake. Given the growing demand for mooring space, fuel stations, and maintenance services, the marina must optimize the use of its available space while catering to different boat sizes.

Since sailboats require deeper water and more room to maneuver, careful planning of berth placement and access routes is necessary to avoid congestion and ensure safe navigation. The findings gained from this analysis will inform decisions on berth sizes, marina layout, and operational planning to meet the needs of both local boat owners and visitors.
Based on this information and the concession agreement, the following boat size distribution has been determined. According to the concession, 20% of boats are large type, 60% are medium type, and 20% are small type [32].

Table 5.1: Design Boat Sizes

Boat Type	Length [m]	Width [m]	Draft [m]
Large	10	3.5	1.5
Medium	10	2.5	0.75
Small	8	2.5	0.75

5.2 Market Growth

The rising demand for mooring space in Lake Nahuel Huapi underscores the need for expanded marina facilities. According to Club Náutico, mooring requests have increased significantly, and the club is currently operating at full capacity with a growing waiting list. This trend highlights the necessity for additional infrastructure, such as the proposed marina at Bahía López, to accommodate the expanding sailing and boating community.

Recognized as Argentinas sailing capital, Lake Nahuel Huapi hosts numerous regattas and sailing events, further driving the demand for motor boating equipment [33]. The lakes strong reputation as a premier motor boating destination reinforces the case for investing in marina infrastructure to support this growing market.

Beyond sailing and boating, Argentinas broader water sports industry is also on an upward trajectory. The Argentina Water Sports Gear Market Research Report, 2028, published by Actual Market Research, valued the sector at over USD 280 million in 2022 [34].

Additionally, discussions with the municipality of Bariloche revealed an expected increase in tourism in the coming years. The Tourism Secretary is actively investing in promotional efforts to attract more visitors, further highlighting the potential for growth in the regions boating and water sports sector.

5.3 Market Opportunity

Building on the current state of marinas, beaches, and tourism in Bariloche, along with expected growth trends, this section evaluates the potential gaps in the market and assesses the suitability of Bahía López for marina development. By considering demand, local conditions, and market trends, it highlights the opportunities that position Bahía López as a valuable enhancement to the regions marine infrastructure.

With limited expansion in mooring facilities and a growing demand for boating tourism, the potential for marina development at Bahía López is significant. Existing marinas in the region are already at full capacity and unable to expand, leaving boaters with few docking options. At the same time, tourism in Bariloche is expected to increase in the coming years, as a large percentage of Argentinians choose to vacation within their own country. This trend, combined with the municipalitys vision to accommodate more visitors, creates a strong case for the development of new marina infrastructure.

Starting with mooring spaces, it is evident that the current availability does not keep pace with the growing number of boating enthusiasts. As demand continues to rise, the need for additional marina capacity with private moorings becomes increasingly clear. Establishing a new marina at Bahía López would help address this shortage, providing much-needed docking space for both local and visiting boaters.

Beyond mooring space, several key facilities and services are currently lacking, presenting opportunities for Bahía López to fill these gaps. One major issue is the lack of proper boat launching infrastructure. At present, launching a boat into the lake is difficult, as there are no designated ramps. Many boat owners resort to submerging their cars partially in the water, which is neither convenient nor accessible for all users, currently only owners of a big 4x4 pickup truck dare to launch their boats there.

Due to the lack of an alternative, boat owners have no choice but to use the public beach as a launch site. This creates safety risks for beachgoers and reduces the recreational experience. The development of a dedicated boat ramp would make launching safer, easier and more accessible. This encourages more boating activity on the lake while ensuring a clear separation between recreational beach areas and boat operations.

Another missing facility is passenger mooring. Recreational boaters looking to sail across the lake, dock for a few hours and enjoy local amenities currently have limited options. While Puerto Pañuelo does offer mooring services, they discourage short-term stays by charging prohibitively high fees of around $150 USD. This highlights an opportunity to develop affordable short-term docking facilities at Bahía López, making it an attractive destination for boaters seeking a stopover for dining, relaxation, or sightseeing.

In addition to mooring and launching infrastructure, visitor amenities are another key area for improvement. Dining and beverage options at Bahía López are currently minimal, with only the hotel offering restaurant services. Beachgoers and boaters have very few food and drink options, creating an untapped business opportunity. Establishing a small food kiosk, beach bar, or food trucks could greatly enhance the visitor experience, offering essentials such as water, soft drinks, alcoholic beverages, snacks and casual meals. A comparison to Playa Sin Viento, where a small beach bar operates successfully, shows that similar services at Bahía López could attract more visitors and increase the area's appeal.

Another key opportunity lies in the introduction of small sailboat rentals, a service currently unavailable in the Bariloche area. Offering rentals for boats such as Optimists, Lasers, or larger sailboats designed for multiple passengers would create a new recreational attraction at Bahía López. This would not only cater to experienced sailors but also encourage beginners and tourists to explore the lake in an accessible and enjoyable way. By providing this option, Bahía López could further differentiate itself as a destination for water-based activities and attracting more visitors.

Overall, the combination of rising tourism, insufficient marina infrastructure, and unmet visitor needs presents a strong case for investment in Bahía López. By addressing the gaps in boat launching, passenger mooring, and visitor services, the marina could position itself as a key boating hub in the region, attracting both local boaters and visiting tourists.

6

Requirements and Regulations

This chapter outlines the design requirements and constraints for the Bahía López Marina development. These are based on the official concession, insights from stakeholder meetings, and findings from the market study. Additionally, relevant marina regulations have been reviewed and incorporated into the constraints.

6.1 List of Requirements

Based on the official concession specifications for the marina, along with additional proposed functionalities, a comprehensive set of requirements has been established. The marina area is divided into a wet surface area and a dry surface area. The wet surface area encompasses all elements located in the water, such as docking facilities and mooring spaces, while the dry surface area includes land-based infrastructure and amenities, such as access roads, parking and service facilities. Table 6.1 and Table 6.2 give an overview of the requirements.

Table 6.1: Functional requirements for the wet surface area.

Category	Requirement
Private Mooring	Minimum of 31 paid private mooring points.
Large Boat Mooring	6 mooring points (10 m x 3.5 m).
Medium Boat Mooring	18 mooring points (10 m x 2.5 m).
Small Boat Mooring	7 mooring points (7.5 m x 2.5 m).
Passenger Docking	Docking berths for passengers.
Authorities Docking	1 docking berth for Prefectura Naval Bariloche, 1 docking berth for A.P.N.
Maneuvering Area	Area(s) for coupled vehicle and boat maneuvering.
Water Depth	At least 1 m water depth in areas designated for boats.
Sedimentation Control	Sedimentation control mechanism.
Infrastructure	Removal of obsolete structures, repair of breakwaters, optional expansion of breakwaters.
Boat Launching	Installation of a boat ramp (possible rollable mobile pathway)
Boat Maintenance Services	Bilge water disposal.
Public Accessibility	Access to the existing recreational beach.
Zoning	Clear definition of operational and recreational areas.
Swimming Safety	Designated swimming zone to separate swimmers and boats.

Table 6.2: Functional requirements for the marina, categorized into wet and dry surface area.

Category	Requirement
Mooring Access	Access to private mooring points via gangway.
Berth Access	Access to berths for local authorities.
Boat Maintenance Services	Fueling service and waste water disposal.
Building Area	See Table 6.1.
Parking Expansion	Increase parking capacity.
Facilitate trailer spaces	At least 4 boat trailer parking spots.
Parking expansion	From 40 to 60 cars.
Disabled parking space	2 disabled parking spots.
Informational Signs	Signs informing visitors about local flora and fauna, as well as signs warning about forest fire risks.

Building Area

The building area encompasses all facilities that are fully or partially housed within a structure. These facilities may be located in a single building or spread across multiple structures. An existing small office building at the start of the breakwater will accommodate some of these functions. Additionally, a new building, referred to as the pavilion, will be designed to house further facilities. The various spaces and their respective sizes are detailed in Table 6.3.

Table 6.3: Building Area Breakdown

Facility	Area [m^2]
Reception and Administrative Center	6
Kiosk + Outdoor Terrace	20 + 30
A.P.N. Office	10
Prefectura Naval Office	10
4 Toilets	8
1 Disabled Toilet	3
Marina Storage Space	36
Semi-Covered Area	30

6.2 Future Development Suggestions

The functional requirements outlined above focus on enhancing the current marina while ensuring environmental and economic feasibility. However, there remains potential around the marina that could be explored in the future. The following list highlights ideas that were considered but not implemented at this stage due to feasibility constraints:

- Expansion of mooring points.
- Rental of boats, kayaks, SUP (stand-up paddleboard), windsurf and kite surf material.
- Redevelopment of the vacant building next to the parking area into a new dining venue or bar.
- Sailing school.
- Maintenance facility.
- Dry stack berthing.
- Boat crane

6.3 APN Project Requirements

To obtain approval for a project like this from APN, an extensive permit process must be followed. As previously mentioned, a document on this process was made as a side product of this project. The following subsection will outline the specific steps for our project. A simplified version of the process scheme that excluded everything that is irrelevant for this project, is shown in Figure 6.1. All steps are further explained in the text below.

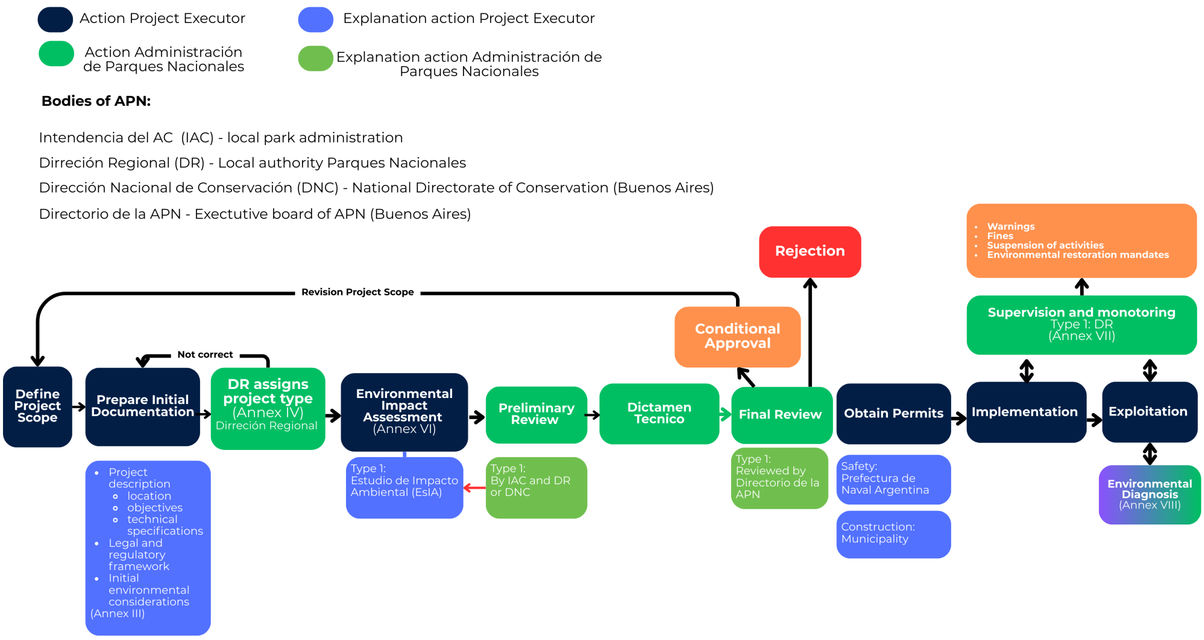


Figure 6.1: Permit Process for Development of Bahía López Marina

Define Project Scope & Prepare Initial Documentation

The first step is the definition of the project scope and the preparation of the initial documentation. A preliminary project report called the *Ficha de Projecto* (Project Form) should be conducted and delivered to the Dirección Regional (DR) of APN. This report has to include:

- **Project Identification:** This section should state the title of the project, the name of the proponent, the responsible environmental professional (if there is one) and contact information.
- **Location:** A description of The Area Protegida (AP) and the specific site within it. This section should ideally include maps and sketches to provide context on the projects geographic location.
- **Project Description:** This section provides a detailed explanation of the project, including its goals, justification, and a general overview of the activities to be carried out, along with an expected timeline.
- **Environmental Context:** Brief information on the natural and socio-cultural environment. Any notable environmental sensitivities, if present, should also be highlighted in this section.
- **Documentation:** This section should include complementary technical documents if they are available. Most importantly, if the project is framed within a contract with another public entity, documentation of this contractual relationship should be provided as proof.
- **Classification Request:**The proponent states which classification the project falls under (type 1 to 4), as this will determine the type of environmental impact assessment (EIA) that needs to be conducted in the next step.

After submission of this Ficha de Projecto, it is reviewed by the DR. If it is not extensive enough, the DR will ask for additional information. If they think it is sufficient, they will assign the project type, which will decide what EIA will have to be conducted.

Environmental Impact Assessment

In the case of the development of the Bahia Lopez Marina, project type 1 would be assigned [35]. This is the type for large scale projects. Therefore, the most extensive EIA will be required; the Estudio de Impacto Ambiental (EsIA). The required contents of this document can be seen in Table 6.4.

Table 6.4: Required Contents of EsIA

Section	Description
Project Description	Detailed explanation of the proposed project, including: • Geographic location with maps and georeferencing • Objectives and justification of the project • Intended users and direct/indirect beneficiaries • Estimated cost and investment schedule • Timeline of activities • Descriptions of each project phase • Affected area (direct and indirect) • Infrastructure and design elements • Machinery, technology, and resources used • Waste generation by type and quantity • Human resources involved • Closure and restoration plan
Legal and Regulatory Framework	Analysis of the project's compliance with applicable regulations: • National legislation (e.g., Law Nž 22.351) • Local (provincial/municipal) regulations • APN internal regulations and zoning • Legal responsibilities and required authorizations
Environmental Baseline Study	Characterization of the current state of the environment: • **Physical:** climate, geology, soils, hydrology • **Biological:** ecosystems, species, habitats • **Socio-cultural:** communities, traditions, infrastructure • **Landscape:** visual and spatial features • **Management context:** zoning, plans, liabilities
Environmental Impact Assessment	Evaluation of potential project impacts: • Positive and negative, direct and indirect • Temporary, permanent, reversible, or cumulative • By project phase (construction, operation, closure) • Use of matrices, maps, and indicators • Uncertainty and limitations

Section	Description
Mitigation Measures	Strategies to reduce or offset negative impacts: • Design or technology adjustments • Restoration or rehabilitation actions • Compensation (if mitigation is unfeasible) • Enhancement of positive impacts • Justification of each proposed measure
Environmental Management Plan (PGA)	Operational plan for environmental performance: • Mitigation and restoration programs • Contingency and monitoring systems • Waste and resource management • Stakeholder engagement and training • Timeline, responsibilities, and budget
Public Consultation and Stakeholder Engagement	Public involvement and consultation process: • Public access and publication of the EsIA • 15-day period for public feedback • Integration of feedback into decision-making • Indigenous consultation (if applicable)

Review Process by APN

The EsIA is submitted by the proponent to the DR or the Dirección Nacional de Conservación (DNC), which is part of the national body of APN. Either one of those performs a preliminary review and requests additional information if needed. When they are satisfied, the DNC will form an evaluation committee of interdisciplinary experts. This committee will then review the EsIA and can also ask for clarifications, corrections or additional information. They may also suggest modifications to reduce environmental impact.

Simultaneously or afterwards, the document will be made publicly available via local newspapers and the APN website. Any member of the public can make comments or objections that will be considered. The evaluation will then combine the public input with their own to produce the Dictamen Técnico. In this document they formulate their recommendation for approval or rejection of the project. The Dictamen Técnico is then delivered to the Directorio de la APN, which is the highest governing body of APN, who will take the final decision of approval or rejection.

Obtain Permits

This stage focuses on securing the necessary permits to begin the projects implementation. For this specific project, the primary permits will be issued by the municipality, as the dry area of the marina falls under its jurisdiction. The municipality will approve the construction of infrastructure and buildings, among other related activities. In addition to municipal permits, safety permits will also be required. These include water safety permits, issued by the Prefectura Naval, and fire safety permits, issued by the local fire prevention authorities. A formal document outlining the agreements resulting from the public consultation process should also be submitted. This may cover aspects such as co-management arrangements, benefit-sharing, and activity restrictions. Given that there are no permanent residents near the site, this document is expected to be relatively brief.

Implementation & Exploitation

The implementation phase marks the start of actual construction. It must be carried out in strict adherence to the approved EsIA. During this phase, the DR will oversee the supervision process on behalf of APN and issue periodic reports to the DNC. If any instances of non-compliance are detected, APN will take immediate corrective action. Measures may include requiring the proponent to implement restoration or mitigation actions, or suspending the project until the issue is properly addressed. Once the project is completed, the proponent must submit a final environmental compliance report.

During the operation phase, the project must function exactly as outlined in the EsIA. The monitoring plan included in the EsIA should be rigorously followed, including the submission of periodic reports to APN. Additionally, the DR will conduct routine inspections to ensure compliance.

7

Design Development

Now that the research phase is concluded with the translation to a set of functional requirements, the next phase in the process can begin, the design development. This phase is structured to explore various design possibilities while allowing for objective evaluation. The process started with the identification of a wide range of solutions to the challenges identified during the research phase, which were documented in a morphological map.
Subsequently, in team discussions - where all disciplines were present - three different solution combinations were determined based on this map, resulting in three alternative concept masterplans. By evaluating these through a multi-criteria analysis, it became possible to select one concept masterplan for further development.
This chapter discusses the process of refining a list of requirements into a single design concept.

7.1 Design statement

Before the functional requirements are translated into a design, a design statement is formulated that describes the project's intent and essence. It sharpens the formulation of the problem and defines challenges against which the design must always be tested throughout the design process:

"It is precisely the untouched and pristine condition of this paradisiacal environment that allows visitors to wander endlessly through the mountains and on the lakes. For this reason, in 1934, the Lake District of northern Patagonia was declared the first national park in Argentina: Parque Nacional Nahuel Huapi.

Catalyzed by Covid-19, the national park saw a spectacular incline in visitors, resulting in an even busier tourism industry. At the heart of this district lies its capital, San Carlos de Bariloche, where throughout the seasons, international and domestic tourists gather to explore the mountains and the lakes. Under the pressure of these growing tourism numbers, the area is becoming more and more commercialized, resulting in a bustling sequence of construction sites. A paradox has emerged: the act of building for these visitors - essentially humanising the landscape - is altering the very condition that attracts them.

The climax of these activities can be found in the form of Cirquito Chico, a route that connects the cocktail of different ventures and views. At the farthest point of this route lies a quiet marina, around the corner of the large commercial Puerto Pañuelo, offering an escape from the hustle and bustle of the road...

Bahía López is the last bay that has not undergone the process of commercialization. This is the place where local residents have the opportunity, at one of the last remaining public spots in the region, to launch their boats into the mother of all lakes, Lago Nahuel Huapi. The result is a constant coming and going of vehicles with trailers and boats, navigating across the beach, through puddles of water, past old tree trunks, eventually finding their way into the lake. Here again, it is the closeness to an immaculate intact nature that has been widely embraced by the residents, who are concerned that the development of the marina will take away their free access to the lake.

Less concerned with these thoughts, but more successful in its influence, the Parques Nacionales is doing everything possible to protect and preserve the nature of the surrounding area. In this rare occasion these two interests - ultimately - align...

One could think that the logical thing to do would be doing nothing at all, to leave it as it is. To simply accept the marina's disorderliness and the chaos that comes with the order of the day. However, the area is presented with an even larger problem: the decentralization of docks, built illegally by anyone who can get their hands on a piece of land along the lake. The total lack of control over the activities that take place from these docks, combined with the sheer area that they occupy, will turn out to pose a bigger threat to the environment. Not expanding the capacity of the marina will inevitably lead to the construction of more docks along the lake's shoreline.

This means that intervention is inevitable, to organize, regulate and expand, but without making it (principally) profit-oriented. Here, sustainability equals equality; an inclusivity driven by its accessibility to everyone.

But this presents us with a challenge, of ***intervening without interfering****; controlling without dominating; resulting in the apparent paradox of saving by making...*

It calls for an introverted design, avoiding the loudness that a marina can be. This means responding to the autonomy of the urban and landscape fabric in a dynamic way, being able to accommodate the ever-growing demand from the tourism industry in the future."

As a conclusion to this design statement, a list of design objectives was formulated:

- **Minimizing environmental impact:**
  - Minimizing resource-use.
  - Reusing existing (infra)structures.
  - Minimizing footprint.
- **Taking inclusivity in account:**
  - Maintaining a *publicly accessible* beach area.
  - Making the design *physically accessible* and comfortable for all.
- **Organizing program components:**
  - Clearly defining a *separation* between an operational area (marina) and a recreational area (beach).
  - Facilitating the *regulation* of marina guests, passengers, and the launching of boats.
  - Clearly defining the program components spatially and making them easily *identifiable* on the site.
- **Enhancing general experience:**
  - Improving the *entrance experience* by using elements of surprise.
  - Offering *optimal views* over the Bahía.
  - Encouraging the natural tendency of visitors to *explore* the area.
- **Ensuring flexibility:**
  - Ensuring that the design principles remain *technically functional* and reliable for (at least) the next hundred years.
  - Taking into account, from the outset, the *possibility of expanding* various program components.
  - Ensuring that the program components can remain *functionally relevant* in the future by their capability to adapt to changing demands.

7.2 Concepts

With the design statement and objectives in mind, three concept designs have been developed. This process is guided by a morphological chart, as presented in Appendix G and Table G.1, where each element offers multiple possible solutions. Through internal discussions, three distinct concepts emerged. The selection of the optimal concept is not a linear process; rather, it will be iterative, with continuous refinement of the designs to ensure the best solution is achieved.

7.2.1 Concept I

Concept I proposes relative to the others some significant interventions. The defining feature is the addition of a breakwater, which provides several benefits; It prevents sediment from accumulating in the marina, instead creating a minor expansion to the beach. Also, it creates a clear separation between the marina and the beach, transforming the marina into a distinct and well-defined space, creating a separate bay within Bahía López. Adjacent to the breakwater, a boat ramp is installed, with a roundabout allowing enough maneuvering space.

Within the marina's building zone, offices for APN and Prefectura will be established, along with toilets and storage facilities. The coastline next to the marina will be paved to accommodate dry stacking areas, while floating docks will form the marinas docking system, to handle the fluctuations in water level. Between the beach and the parking area, space will be designated for a kiosk or food trucks, offering refreshments for both beach visitors and marina users. See Figure 7.1.

The dredging work is extensive, as the entire marina will be deepened to 1 meter to accommodate numerous mooring spaces. With the addition of the new breakwater however, a significant reduction in sedimentation is expected, minimizing the need for frequent maintenance dredging.

A key strength of this concept is the clear separation between two zones, an operational and a recreational area, that is defined upon entering the complex. Beachgoers, who are not concerned with marina activities, can turn left to the beach and parking area (the recreational area), while boat launchers can go right to access the marina (the operational area) without having to cross the beach. However, both groups come together at the kiosk area, where they can enjoy a drink.

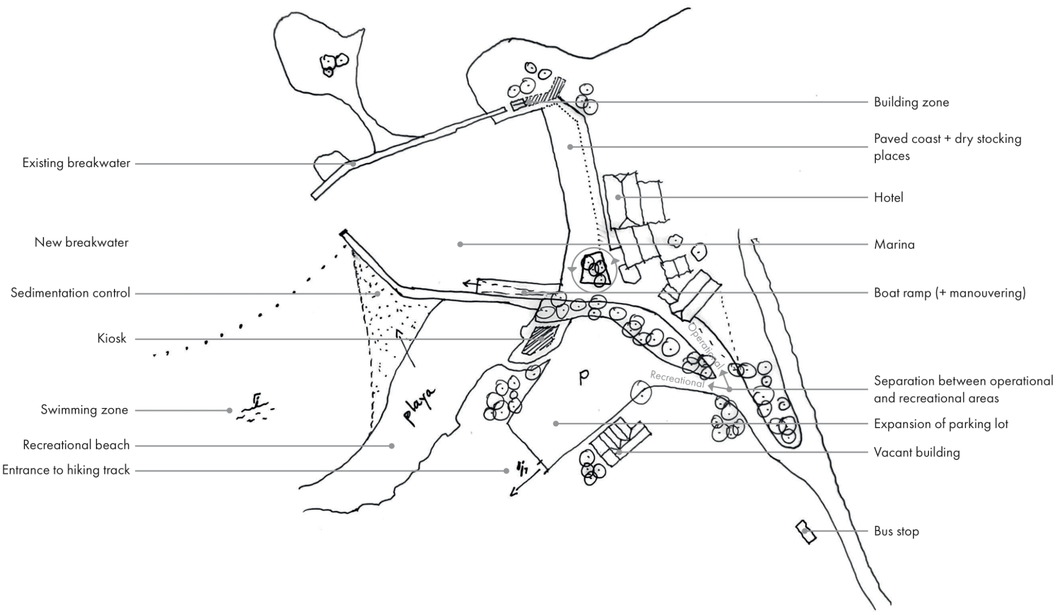


Figure 7.1: Sketch of Concept I

7.2.2 Concept II

Concept II has a lower impact on the existing environment in the short term. The current breakwater remains unchanged, and the beach area is left unaffected. All interventions are focused on the northern side of the marina. The boat ramp is positioned just behind the breakwater, with sufficient clearance for maneuvering. However, due to the absence of a new breakwater, some sediment accumulation is expected, requiring periodic maintenance dredging.

Boats will be moored using piled mooring and buoyed mooring points, which, while less space-efficient than floating docks, significantly reduce the impact on the natural environment. Additional parking spaces will be created within the marina area to ensure that marina users have designated parking, even on busy beach days.

The main achievement of this concept is its minimal impact on the environment, preserving the area almost as it is today. Given the importance of conserving the national park, this low-impact approach is a significant advantage.

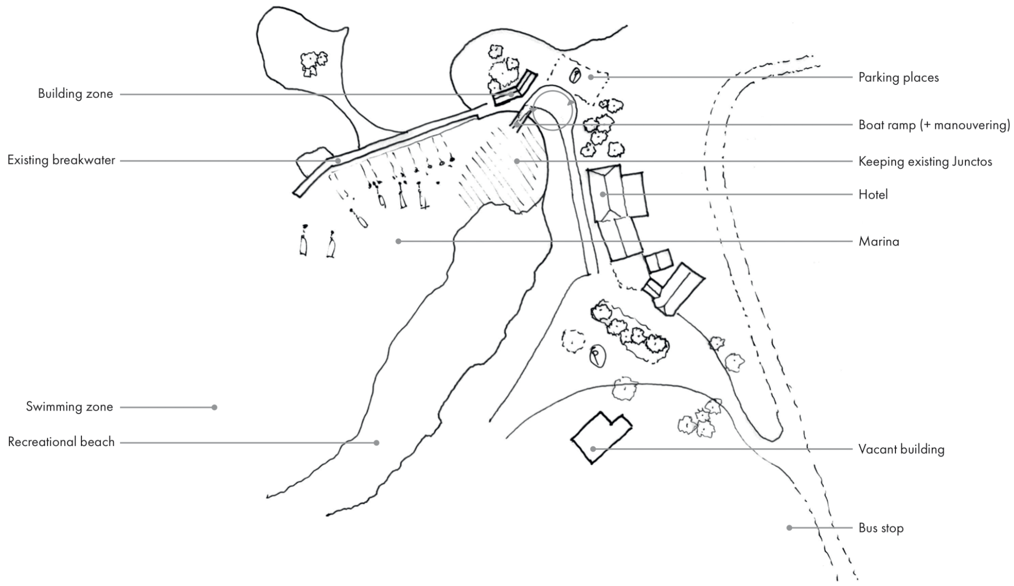


Figure 7.2: Sketch of Concept II

7.2.3 Concept III

Concept III seeks a balanced approach. To separate the marina from the rest of the bay, the existing breakwater will be extended using a floating breakwater, connected by a gangway. The boat ramp will be positioned at the beach, serving as a division between the beach and the marina area. Floating pontoons will be installed for docking.

This concept requires less dredging, and the coastline remains largely intact. A key change is the relocation of parking to the area behind the vacant building, which is currently an underutilized open space. The vacant building itself will be repurposed, potentially as a nautical shop or marina storage. At the location of the old parking lot, dry stack berthing spaces will be introduced, providing more storage for boat owners. Those wishing to use their boats for daily trips can conveniently access their boat and use the boat ramp.

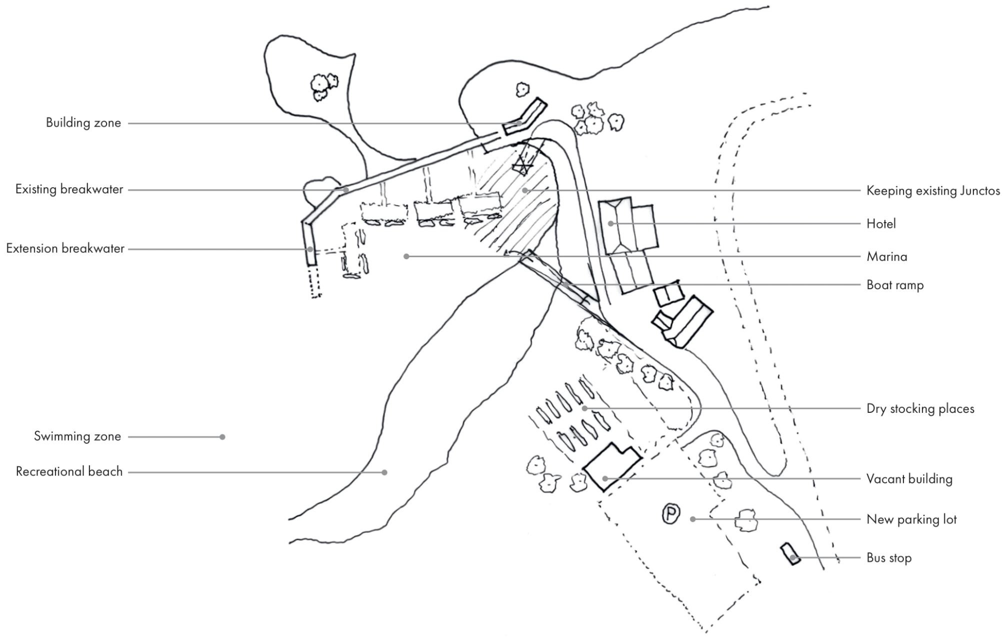


Figure 7.3: Sketch of Concept III

7.3 Multi-criteria Analysis for Concept Selection

To evaluate the pros and cons of the different design concepts, a multi-criteria analysis (MCA) was conducted. Each criterion is broken down into sub-criteria. This allows for a more detailed assessment of specific design aspects, contributing to the best selection of aspects for our final design.

Each concept was assigned a score for every sub-criterion. The scores were then averaged within each main criterion and summed to obtain a total score, where the highest score indicates the most balanced design choice. To ensure a reliable evaluation, it was essential that all team members shared a clear understanding of each criterion and scoring scale. This approach minimizes subjective bias and enhances consistency in the scoring process.

The following sections provide a breakdown of each criterion and the rationale behind the assigned scores.

Environmental Impact

The environmental impact is a critical factor in the development of the marina, especially in obtaining building permits. However, it has proved to be challenging to quantify this. To make this (approximately) measurable, a combination of the following sub-criteria were used in the evaluation:

- **Reuse of existing infrastructure:** Reusing the infrastructure that is already present prevents unnecessary use of materials and pollution caused by construction and demolition. Examples are the breakwater, the small office at the end of the breakwater, the vacant building and the parking lot.
- **Minimal use of resources:** When constructing program components, the design still has to be built with the goal of minimizing the use of materials. Minimal use of resources reduces environmental impact by reducing transportation emissions and possibly production emissions of the products in question.
- **Minimal ecological disturbance:** This criterion emphasizes the importance of minimal ecological disturbance. Think of things like landscape alteration. This is an important criterion since there are animals living in the area that are threatened with extinction, like the Gato Huiña and the Huillìn, who's habitats should not be compromised.

Technical Feasibility

The technical feasibility of a concept is best explained in two ways. Firstly, the short span technical feasibility, represented by the sub-criterion 'ease of construction', is regarding the properties of different program components, for example their dimensions and materials, and the time and effort it would take to build it. And secondly, the technical durability of different program components, meaning the technical performance of the constructed parts, represented by the sub-criteria 'resilience to environmental conditions' and 'sedimentation control'.

Operability

This criterion focuses on the performance of the program components, individually and as a whole, not necessarily in a technical way, but from a functional point of view. The sub-criteria that contribute to this are:

- **Layout efficiency:** focuses on the relationships between the different program components with regard to the ease of their operability.
- **Marina layout efficiency:** rates the efficiency of the wet part of the marina.
- **Accessibility:** rates the ease of accessing the marina, both on the dry and wet part.
- **Expansion potential:** considers the potential of expanding relevant different program components and the marina as a whole.

Service Quality & User Experience

This criterion is all about the customer. It provides an insight how user friendly the concepts are based on the following sub-criteria:

- **Clear distinction between area's:** the area's that are referred to are an operational and recreational area. In the current state of the marina, people launch their boats from the beach. While they do this, they have to maneuver between the beach goers. A clear distinction between the operational area, where people can launch there boats, and the recreational area, where people can lay on the beach, reduces frustrations for both parties.
- **Parking & maneuvering:** rates the parking facilities, qualitative and quantitative, and the ability to maneuver at the launching area.
- **Aesthetic appeal:** considers the fact that the eye wants something as well.
- **Public and private facilities present:** the Bahía is well-known for its public boat launching facility. Other examples include the beach, possible lavatories and options for food and drinks. Examples of private facilities are the mooring spaces and private parking spaces.

Economical Feasibility

The development of a marina is a costly undertaking, and the design costs must align with the specific context of Bahía López. This criterion assesses the initial capital investment, ongoing maintenance for long-term viability, and overall feasibility.

Concept Selection

With all three concepts clearly defined, a multi-criteria scoring table was developed. For simplicity, each main criterion was initially given an equal weight of 1. By adjusting the weights later of critical criteria, the concept's robustness can be evaluated. This way, it can be validated whether the same concept continues to score the highest when the importance of different factors is altered. Within each criterion, sub-criteria were scored on a scale from 0 to 3, using the following grading system:

- 0 = non-compliant
- 1 = partly compliant
- 2 = compliant
- 3 = exceeds compliance

Once the scores were assigned, the average score per criterion was calculated. The concept with the highest total score is considered the most balanced option. However, to ensure robustness, sensitivity checks were performed by adjusting the weight of individual criteria (e.g., increasing the weight of a single criterion to 1.5) to determine whether another concept overtakes the highest-scoring one. If the ranking remains unchanged across multiple tests, the selected concept is considered robust. If another concept surpasses it under different weightings, further evaluation is necessary. In Table 7.1, an overview is given of the concept selection process.

Table 7.1: Multi-criteria Concept Selection Table

Criteria / Subcriteria	Weight	Concept 1 Score	Concept 1 Avg.	Concept 2 Score	Concept 2 Avg.	Concept 3 Score	Concept 3 Avg.
Environmental Impact	1		1		2.7		2
Reuse of existing infrastructure		2		3		2	
Minimal use of resources		1		3		2	
Minimal ecological disturbance		0		3		2	
Technical Feasibility	1		2		1.7		1.7
Resilience to environmental conditions		3		1		2	
Ease of construction		1		3		2	
Sedimentation control present		2		1		1	
Operability	1		2.5		1.5		1.5
Layout efficiency		3		2		1	
Accessibility		3		1		2	
Expansion potential		2		2		2	
Service Quality & User Experience	1		2.5		1.3		1.8
Clear distinction between area's		3		1		2	
Aestetic appeal		3		2		1	
Public and private facilities present		2		1		2	
Economical Feasibility	1		1.5		2		2
Construction costs		1		3		2	
Maintenance costs		2		1		2	
Total	5		**9.8**		**9.3**		**9.0**

Results

After evaluating the three different concepts based on measurable criteria and sub-criteria in the MCA, Concept 1 emerged with the hightest score. However, after testing the concepts for robustness, it was found that a shift in importance towards Environmental Impact would change the outcome. An increase of 30% in the importance of this criterion would cause Concept 1 to no longer be the top choice. This is due to Concept 1 scoring lower on Environmental Impact compared to the other concepts. This result can be found in Table 7.2 and more detailed in Appendix H.

Table 7.2: MCA outcome with shifted weights

Criteria	Weight	Concept I Score	Concept II Score	Concept III Score
Environmental Impact	1.3	1.3	3.5	2.6
Total Score		10.1	10.1	9.6
Economic Feasibility	2	3	4	4
Total Score		11.3	11.3	11

Given the critical importance of environmental impact, particularly due to our location within the National Park, a 30% shift in importance is considered a small margin. As such, the outcome of the MCA cannot be deemed fully robust in these circumstances. As a result, the decision was made to revisit the concept and improve its environmental performance. This will be addressed in the Preliminary Design section, section 8. It is important to note that the MCA serves as a decision-support tool rather than a definitive selection method. It offers a structured approach to objectively compare design concepts, minimizing subjectivity in the decision-making process. In this case, the MCA was particularly valuable as it enabled a detailed comparison of the concepts across multiple factors, including environmental impact, technical feasibility, operability, service quality, and economic feasibility.

8
Preliminary Design

The three concept designs were evaluated using a multi-criteria analysis, revealing that Concept 1 is not yet sufficiently robust. The highest-scoring concept overall has shortcomings in terms of environmental impact, highlighting the need for further refinement. Through an iterative process involving internal discussions and additional research, the design was improved to achieve the best balance across all criteria, resulting in a robust final concept. This chapter presents the final concept, visualised in a masterplan.

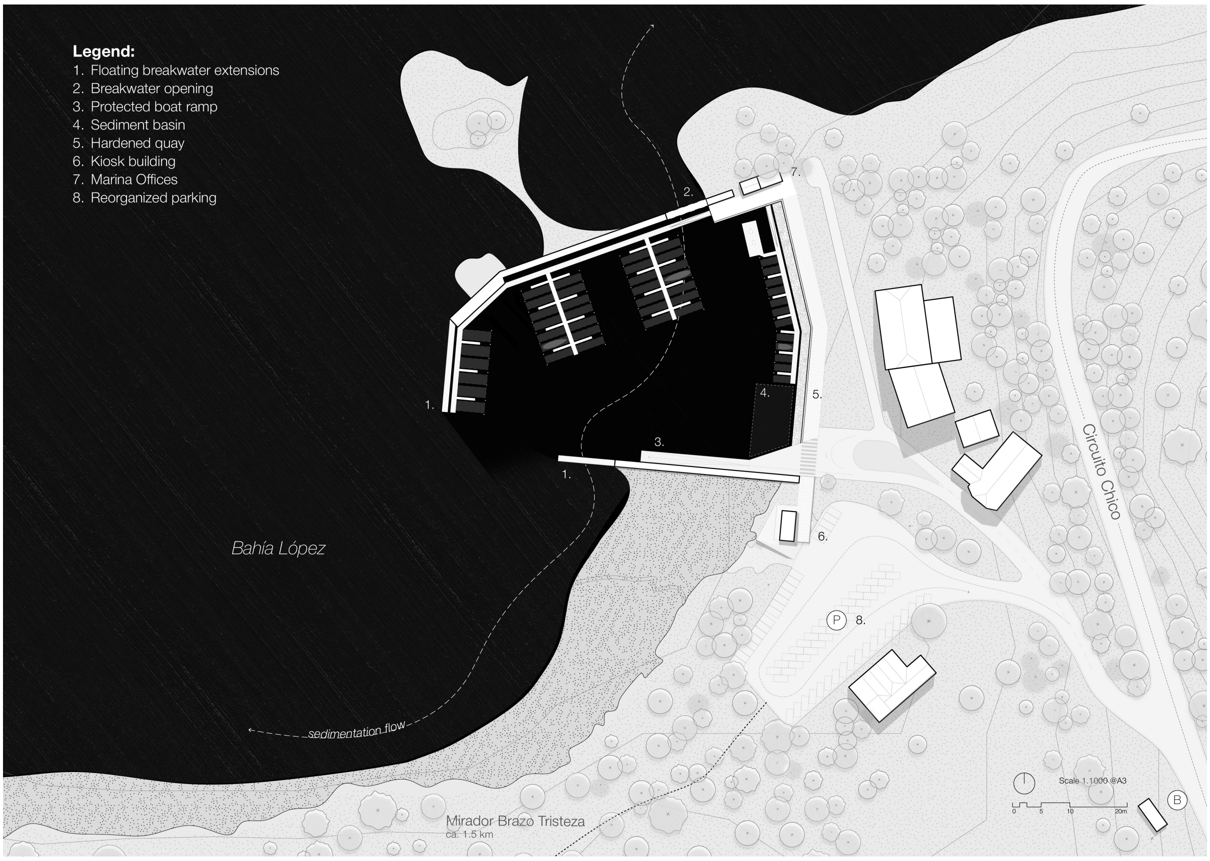


Figure 8.1: Proposed Masterplan Phase 1

8.1 The Masterplan

The proposed masterplan for Phase 1 is shown in Figure 8.1, highlighting eight key developments in and around the marina. The design clearly creates a division between the operational and recreational side of the bay. This is achieved by introducing a walkable pier with floatable extension.
This layout improves the marina's protection from sediments and currents, with an extended breakwater creating a more defined entrance. The new configuration allows for more efficient use of the space, providing 46 mooring spots for vessels of various sizes, which is 15 more than initially planned.

An opening has been incorporated at the start of the existing breakwater to restore the natural water flow. The currents flowing through the opening pass over a sediment basin, allowing sediment to settle naturally.

Along the new pier, which also acts as a protective barrier, a boat launch ramp has been integrated. This provides boat owners with a safe and convenient way to launch their boats. The design also ensures enough space for maneuvering trailers with vehicles.

On the marinas hotel-side edge, a reinforced quay with revetments has been designed, which includes at the top a walking path for safe access to the docks. This quay is also built to withstand fluctuating water levels, providing greater durability.

At the center of the bay, between the pier, parking area, marina, and beach, a kiosk building is positioned. It features a terrace with a scenic viewpoint over the bay. The kiosk will offer food and beverages, allowing visitors to enjoy them at the terrace tables.

On the northern side of the marina, the Marina Offices will be expanded. This space will provide offices for Parques Nacionales and Prefectura, as well as a small storage area for nautical equipment.

Finally, the parking area will be expanded, offering more spaces in total, including dedicated spots for cars with trailers and additional spaces for disabled parking.

The following sections will provide further details on the various aspects of the marina, including layout plans, design decisions, calculations, and structural designs.

8.2 Breakwater Design

The current fixed breakwater causes wave diffraction at its end, allowing oblique waves and currents to enter the marina. This results in lateral loads on moored boats, reducing stability and safety. Additionally, the marina lacks a clearly defined entrance, making navigation more difficult, especially under adverse conditions. Currently, the rock-concrete breakwater extends 80 meters into the bay, with a 16-meter extending nod. Originally, this nod was 24 meters long, but eight meters have been lost due to neglect and lack of maintenance (see Figure 8.2).

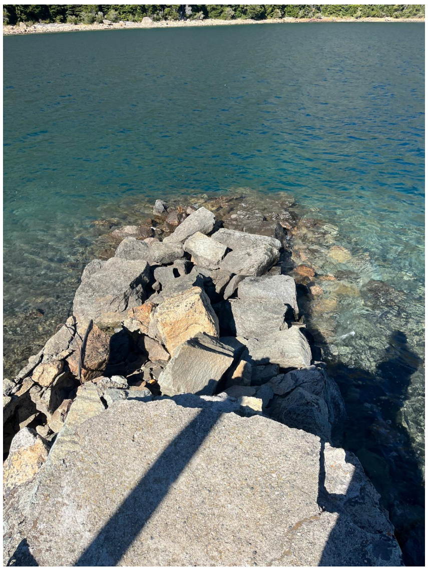


Figure 8.2: Current condition of breakwater end

It can be observed from the picture above that the water depth rapidly increases after this extension, which is also confirmed by the bathymetric study by Parques Nacionales in 1971 (see Figure 3.5), which shows a water depth between 16 and 27 meters in the marina area. While this data may not be perfectly accurate for the current state around the breakwater, it can be agreed that there is a significant drop in water depth between the breakwater and the beach coast.

To minimize intervention while maximizing effectiveness, an extension should be approached. First, the lost eight-meter section should be reconstructed to restore the original functionality of the breakwater. Once this is completed, an alternative could be to extend the breakwater under an angle and complement it with a floating attenuator. Floating breakwaters are an effective solution in environments with significant water level fluctuations. Their low visual impact makes them a favorable choice for maintaining the natural aesthetics of the marina, while their environmentally friendly design ensures minimal ecological disturbance. Additionally, floating attenuators are relatively easy to construct at a lower cost compared to fixed breakwaters. This design also creates a clearer separation between the marina and the bay, improving wave protection for both the marina and the launch area.

Design Procedure Floating Breakwater

PIANC offers a scheme for designing floating breakwaters (as referenced in Figure 8.3).

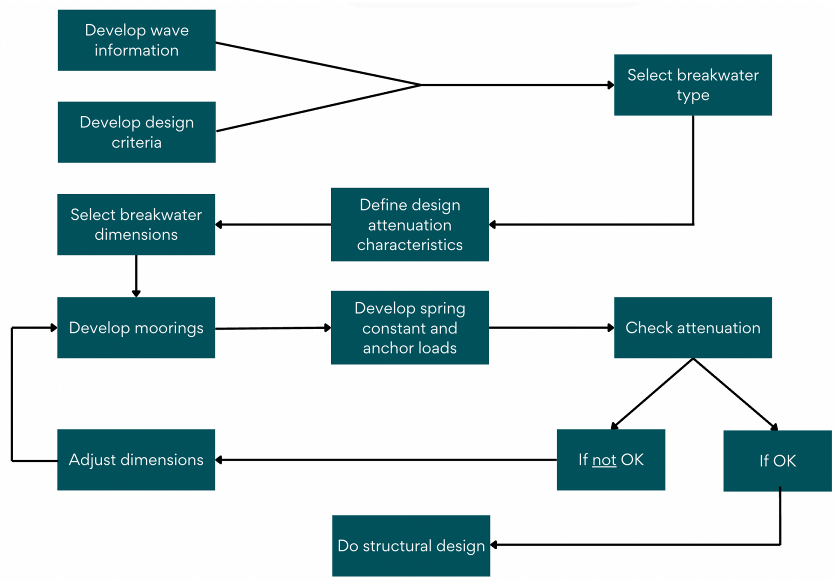


Figure 8.3: Process scheme of designing a floating breakwater (by PIANC, 1994) [36]

Below is a breakdown of the steps needed for the design:

Develop Wave Information

The average significant wave height (H_s) and wave period T are 0.12 m and 1.14 seconds, respectively. For the design, the predicted wave height for strong winds is 0.72 m, and the corresponding wave period is 2.57 s. The corresponding wavelength L and wave number k_i can be calculated combining Equation 7 and Equation 8. This results in the values listed in Table 8.1.

$$L = \frac{T^2 \cdot g}{2\pi} \tag{7}$$

$$k_i = \frac{2\pi}{L} \tag{8}$$

Table 8.1: Wind Speed, Significant Wave Height, and Wave Period Data

Wind Category	Significant Wave Height H_s [m]	Wave Period T [s]	Wavelength L [m]	Wavenumber k_i [m^{-1}]
Average Winds	0.12	1.14	2.03	3.10
Moderate Winds	0.39	1.96	6.00	1.05
Strong Winds	0.72	2.57	10.3	0.61

Develop Design Criteria

For the marina at Bahía López, the floating breakwater must meet several important criteria to ensure it is effective and practical. It should be easy to install, with modular components that can be quickly assembled, minimizing disruptions to marina operations. The design should also allow for easy replacement or upgrades of individual sections when needed, especially in areas where water levels or environmental conditions might cause wear and tear. This modular approach ensures that the system can be maintained with minimal disruption.

In addition, cost-effectiveness is key. Floating breakwaters are generally more affordable than fixed alternatives because they require less construction and no heavy foundations. By using durable and lightweight materials, both initial and ongoing maintenance costs can be reduced. The environmental impact must also be considered; the breakwater should allow for natural water flow and require little dredging or land alteration. The materials used should be durable and prevent the release of harmful substances into the water.

Aesthetics are also important, particularly in a location like Bahía López, where the natural beauty is a priority. The floating breakwaters low profile ensures that it doesnt obstruct views, blending seamlessly with the environment. Finally, according to PIANC [36], for small craft marinas, the recommended maximum significant wave height is $H_s < 0.30$m.

Select Breakwater Type

Based on the research and literature on floating breakwaters in subsection D.2, the box-type breakwater emerges as the most suitable option for the Bahía López marina. This type has been extensively studied and is recognized for its effectiveness in dissipating wave energy, primarily by reflecting incoming waves. Its simple geometric design makes it cost-effective to construct and install, which aligns with the projects goal of keeping costs low while providing reliable protection.

Moreover, the box-type floating breakwater is known for its proven performance in various marine environments, making it a preferred choice for many coastal projects. The design also minimizes environmental impact, ensuring minimal disruption to the surrounding ecosystem, which is particularly important for maintaining the natural setting of the marina.

Define Design Attenuation Characteristics

The floating breakwater must be designed to protect the marina from the harshest environmental conditions, specifically the strongest winds in the bay.

A key parameter in floating breakwater design is the transmission coefficient K_t. Equation 9 is obtained by Macagno, 1953 [37] and represents the ratio of transmitted wave height to incident wave height, based on linear wave theory, with the assumption of no motion of the breakwater, no green water on the top deck, and constant water depth conditions .

$$K_t = \frac{1}{\sqrt{1 + \left[\frac{k_i B \sinh(k_i h)}{2\cosh(k_i h - k_i d)}\right]^2}} \tag{9}$$

Here, B represents the breakwater width, h is the water depth, d is the draft, and k_i is the incident wave number. The transmission ratio should be interpreted as the proportion of wave energy transmitted through the breakwater. For instance, a transmission ratio of $K_t = 0.70$ means that 30% of the wave energy is reflected, while the remaining 70% is transmitted through the breakwater.

The chosen design parameters for wavelength L and corresponding wavenumber k_i are based on the strong wind conditions outlined in Table 3.2. Given significant water level fluctuations, the breakwater draft is limited to a maximum of 1 meter to prevent grounding at either end. Since the exact water depth is uncertain, we plotted the breakwater width against the water depth for various transmission coefficients using Python Appendix J. This results in the graph shown in Figure 8.4.

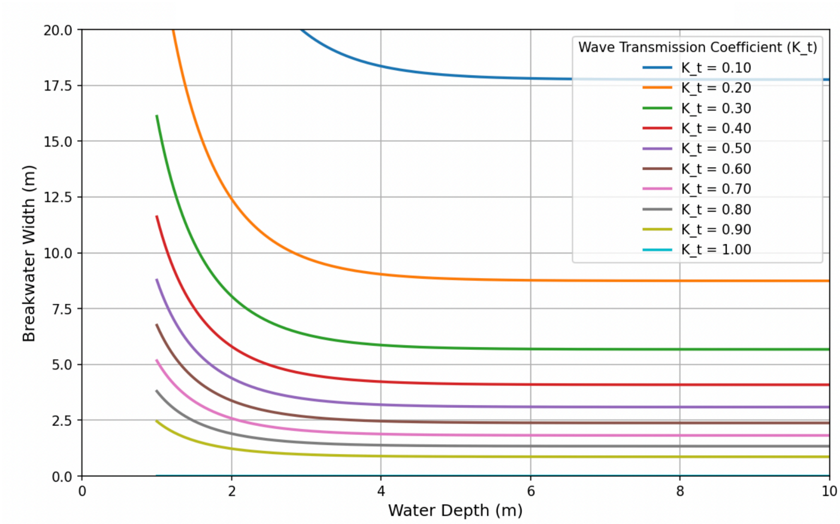


Figure 8.4: Mooring line slope at design load

It can be observed that the transmission coefficient stabilizes as the water depth increases. The physical explanation for this is that, as the water depth grows, waves transition from shallow-water waves, influenced by the seafloor, to deep-water waves, which are unaffected by the seafloor. In deep water, wave behavior becomes less dependent on the water depth and more reliant on the breakwaters design. Therefore, once a certain depth is reached, further increases in water depth do not significantly affect the transmission coefficient, as the wave attenuation capacity of the breakwater is primarily determined by wave characteristics and structure, not water depth.

To determine the optimal transmission coefficient, the situation must be carefully monitored. Based on the wave statistics in Figure 3.13, strong winds occur regularly throughout the year. Consequently, the transmission coefficient must be high enough to withstand waves generated by these winds. However, the fixed breakwater already partially blocks incoming head waves, with the remaining waves diffracting or entering obliquely, reducing their energy. Thus, the chosen transmission coefficient is $K_t = 0.6$, which corresponds to a breakwater width of $B = 2.38$ m in the graph.

Select Breakwater Dimensions

Most of the breakwater dimensions have been established, including the width $B = 2.38$ m and the draft $d = 1.0$ m. The remaining dimension to be determined is the length. This decision is important for several reasons. Firstly, the length of the breakwater directly influences the location of the diffraction point, which affects how incoming waves interact with the marina. A properly positioned diffraction point can minimize the amount of wave energy entering the marina, improving stability for boats moored within.

Secondly, the length also affects the number of boats that can moor along the inner side of the breakwater. A longer breakwater provides more docking space, which is important for supporting future growth and maintaining efficient marina operations.
Finally, the breakwater length should be designed to ensure that the marina layout is logical and coherent. The breakwater should define a clear entrance and outline the marina, ensuring safe navigation into and out of the facility. Therefore, its length should be carefully considered in conjunction with the overall marina design.

External Force Calculation

The external forces acting on the floating breakwater include both the wind force and the wave force. Although the wind and waves generally approach the breakwater at an angle, uncertainties in their directions must be accounted for.

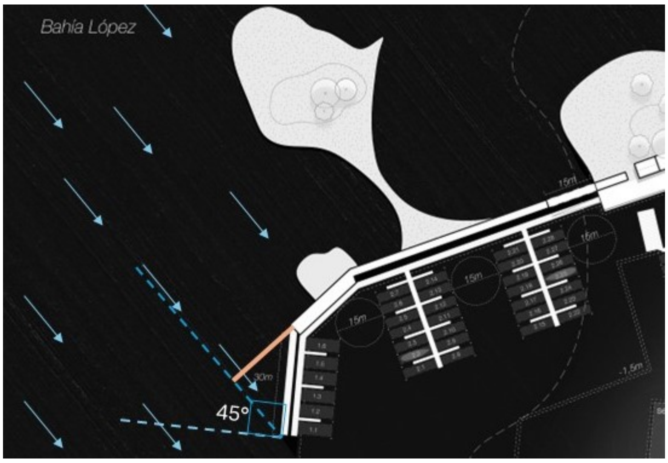


Figure 8.5: Effective area breakwater exposed to environmental loading

Since the mooring lines will align with the direction of the forces acting on the structure, the forces are assumed to act directly on the frontal area accounted for an incoming angle of 45° of the breakwater. The wind force is calculated using the following equation:

$$F_w = C_D \frac{\rho V^2}{2} A \tag{10}$$

where:

- F_w : Wind force (N, Newtons)
- C_D : Drag coefficient (2.0 for a Rectangular box [36]).
- ρ : Air density (1.225kg/m)
- V : Wind speed (m/s)
- A : Projected area (mš) object exposed to the fluid.

The resulting wind forces for different wind speeds are shown in Table 8.2.

Table 8.2: Wind Force at Different Speeds

Wind Speed [m/s]	Wind Force [N]
3.61	670.91
9.72	4863.14
16.67	14291.67

The wave force follows from the Morison equation for a box, following from Morison (1950) [38] and PIANC (1994) [36].

$$F(t) = F_{\text{inertia}}(t) + F_{\text{drag}}(t) \tag{11}$$

The detailed expression for the total force $F(t)$ is:

$$F(t) = \rho C_M V \cdot \dot{u} + \frac{1}{2}\rho C_D A \cdot u \cdot |u| \tag{12}$$

where:

- $F(t)$: Total force on the structure due to wave action (N, Newtons)
- ρ : Fluid density (kg/m^3)
- C_M : Added mass coefficient of 2 (dimensionless) [39]
- V : Volume of the displaced fluid (m^3)
- $\dot{u}$: Acceleration (m/s^2)
- C_D : Drag coefficient (dimensionless)
- A : Projected area of the structure (m^2)
- u : Velocity of the structure relative to the fluid (m/s)
- $|u|$: Magnitude of the velocity vector, representing the relative speed between the structure and the fluid (m/s)

The velocity and acceleration of the wave particles are given by:

$$u(z) = \frac{\omega H \cosh k(z+h)}{2 \sinh kh} \tag{13}$$

$$\dot{u}(z) = -\frac{\omega^2 H \cosh k(z+h)}{2 \sinh kh} = -\omega u(z) \tag{14}$$

The parameters used in these equations are:

- ω : Angular wave frequency (rad/s)
- H : Wave height (m)
- k : Wave number (rad/m)
- z : Vertical position (m)
- h : Water depth (m)

The calculated wave velocities and accelerations for different wind conditions are presented in Table 8.3.

Table 8.3: Wind Speed, Angular Velocity, Wave Velocity, and Wave Acceleration for Different Wind Conditions

Wind Speed [m/s]	Angular Velocity [rad/s]	Wave Velocity [m/s]	Wave Acceleration [m/s^2]
3.61	5.53	0.330	1.82
9.72	3.22	0.619	2.00
16.7	2.45	0.872	2.14

These calculations for the three different conditions result in the wave force components listed in Table 8.4. Adding the wave and wind forces for the different conditions results in the values listed in Table 8.5.

Table 8.4: Wave Forces for Different Wind Conditions

Wind Speed [m/s]	Wave Force [N]	Inertial Force [N]	Drag Force [N]
3.61	1.88×10^5	1.85×10^5	2.31×10^3
9.72	2.11×10^5	2.03×10^5	8.11×10^3
16.67	2.33×10^5	2.17×10^5	16.1×10^4

Table 8.5: Wind and Wave Forces for Different Wind Conditions

Wind Speed [m/s]	Wind Force [N]	Wave Force [N]	Total Force [N]
3.61	6.71×10^2	1.88×10^5	1.89×10^5
9.72	4.86×10^3	2.11×10^5	2.16×10^5
16.7	1.43×10^4	2.33×10^5	2.48×10^5

For the design of the mooring system we take the biggest load of 248 KN, this load is divided over two ends of floating breakwater. To account for the mass-acceleration forces a safety factor of 1.4 is applied, which results in a design load of 175 kN.

Develop moorings

The mooring system for the breakwater must function effectively across different water depths and with water level fluctuations. Given the maximum water level variation of 2.5 meters, it is important to ensure operability within this range. Furthermore, the system must perform adequately under different weather conditions, as outlined in Table 3.2.

To account for these varying conditions, the external loads on the mooring system are determined by considering both wind and wave loads, with the latter calculated using the Morison equation. As there the mooring system will also be subjected to a load due to mass-acceleration of the breakwater, a factor is included to account for the uncertainty in the systems response.

At the point where the floating breakwater and the breakwater meet piles can be used to moor the floating breakwater. As the floating breakwater moves into bigger water depths this is not possible for the other end. A different solution needs to be applied there. Catenary mooring lines are ideal for floating breakwaters because they can adapt to varying water levels. The flexible nature of the lines allows them to adjust to changes in depth, ensuring the breakwater remains securely moored while distributing forces evenly, even as water levels fluctuate. This adaptability provides stability under different conditions.

With a design load of 175 kN for the mooring line (total design load of 350 kN) following form Figure 8.2 we applied the model described in Appendix E to determine horizontal position changes (x_{tot}), mooring line length (S_{tot}), submerged weight of the mooring line (w) and the tension in the mooring line (F_t).

For the water depth of the mooring we assume a depth of 25 m and 27.5 m to take into account the maximum water level fluctuations following from Figure 3.5. In Figure 8.6 the mooring profile is modeled for the design load configurations.

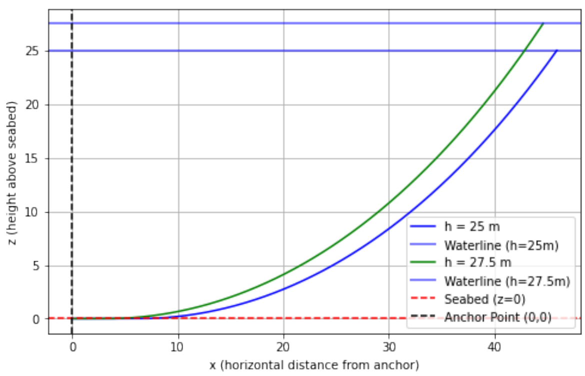


Figure 8.6: Mooring line slope at design load

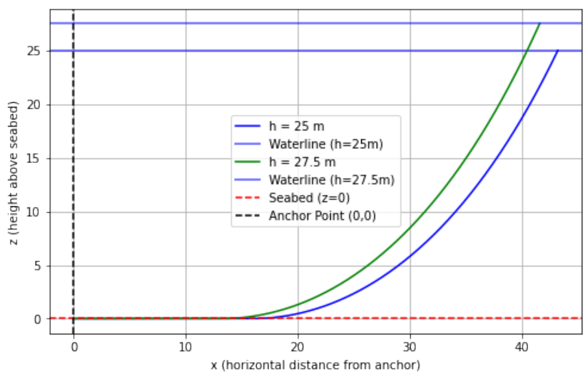


Figure 8.7: Mooring line profile at average load

In the figure can be seen that the configuration will suffice for the design load of 175 kN on the mooring. This is in the case of an submerged weight of the mooring line of 5 kN/m, which can be achieved by placing clamped weights on the mooring line.

Table 8.6: Mooring Line Characteristics at 16,7 m/s Wind Speed

Height [m]	Suspended Length S [m]	Horizontal Distance x_{tot} [m]	Line Tension F_t [kN]
25.0	48.7	45.9	300
27.5	51.9	44.6	312

The same configurations are also modeled for the loading at an average wind speed of 3.61 m/s. Resulting into the following distance parameters in Table 8.7.

Table 8.7: Mooring Line Characteristics at 3,61 m/s Wind Speed

Height [m]	Suspended Length S [m]	Horizontal Distance x_{tot} [m]	Line Tension F_t [kN]
25.0	39.1	43.3	215
27.5	41.8	41.6	228

The difference in the position of the end of the floating breakwater between extreme and average weather conditions is approximately 2.5 to 3.5 meters, which is within a reasonable fluctuation range. The submerged weight of the mooring line, set at 5 kN/m, is considered substantial but achievable through the use of clamped weights. This model is used to determine variations in the horizontal position of the breakwater and assess the effects of water level fluctuations and external loading on the mooring line tension. The calculations indicate that a mooring line length of 55 meters, with a suspended weight of 5 kN/m, is sufficient to moor the floating breakwater without inducing vertical forces on the mooring anchor. Alternatively, it is possible to reduce the mooring line length by placing a large weight at the end of the line instead of using a mooring anchor, which would allow vertical forces at the mooring point. The model provides a good understanding of the feasibility of mooring a floating breakwater in this environment, and it can be applied accordingly. However, it can be further optimized for the specific situation in Bahía López.

Material

Figure 8.8 on the right shows a floating breakwater design by *Poralu Marine*. The floating breakwater consists of concrete units that meet the C50/60 standard and are filled with blocks of polystyrene for buoyancy. These concrete pontoons are reinforced with a layer of galvanized steel, ensuring protection against corrosion and environmental wear. The galvanized steel adheres to BS4449 and BS IN ISO 1461 standards. The top surface of the breakwater is finished with a non-slip concrete coating, providing safety for both boats and pedestrians.

Figure 8.8 on the left illustrates a similar breakwater being installed at Muelle de Piedra in Nahuel Huapi Lake. This installation is carried out by *Las Marinas Muelles*, a company based in Tigre, Buenos Aires [40]. As shown, the box-type sections are connected in parts, making it easy to extend during future phases. Given that this floating breakwater system has already been successfully implemented at a nearby location in Nahuel Huapi Lake, it offers promising prospects for a potential solution at Bahía López as well.

Figure 8.8: Installation of a floating breakwater (left) [41]. Concrete floating breakwater (right) [42]

8.3 Dredging Work

To ensure that the marina maintains sufficient depth for the design vessels, dredging operations are necessary. Additionally, current vegetation must be removed from the where the ramp will be installed. The desired water depths across the marina are illustrated in **??**. Closer to the entrance, the depth will be greater to accommodate larger vessels. Since this area extends further into the lake, the natural depth is already deeper, minimizing the required dredging effort.

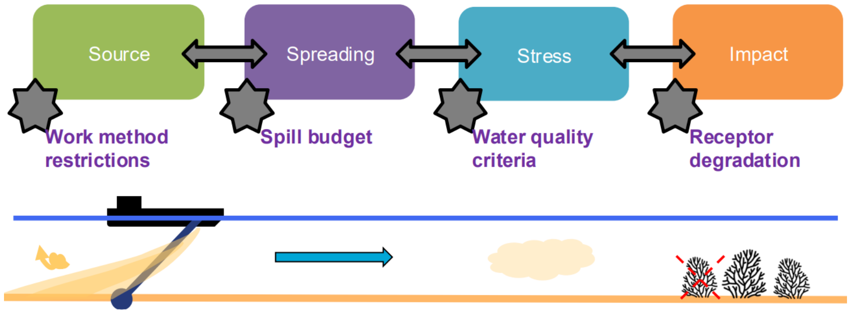


Figure 8.9: Dredging Considerations [43]

Figure 8.9 outlines the process of assessing the environmental impact of a disturbance, such as dredging operations. During dredging, large amounts of fines can be suspended in the water, which can affect water quality and harm the ecosystem. In Parque Nahuel Huapi, it is important to prevent the suspension and spreading of these fines, as they can harm aquatic life and spread contaminants. Therefore, controlling sediment resuspension is essential to protect the parks biodiversity and water quality.
To prevent the suspension of fines, the use of floating curtains is recommended. Floating curtains, made from geotextiles and equipped with floats, can form a vertical barrier that blocks the penetration of fines onto the lake, PIANC Dredging of Marinas (2004) [44].

The marina will generally be maintained at a depth of 1.5 meters to accommodate the largest design vessels, with a designated fairway leading to the fuel dock. Adjacent to the quay, the depth will be at least 1 meter, making it only suitable for smaller vessels. Due to the potential sediment movement in this area, it will not be suitable for large sailboats with deep keels. To address this sediment flow, a sediment basin with a depth of 2.5 meters will be installed nearby, as will be explained in the next section, 'Sediment Control'. The total area corresponding to the three different depth levels is provided in Table 8.8. See Figure 8.11 for the different areas.

Table 8.8: Area corresponding to different depth levels

Depth [m]	Area [m^2]
1.00	3000
1.50	5000
2.50	500

The concession plans includes the dredging of 800 cubic meters of material. In comparison to this preliminary design, which requires a larger area and greater depth at most points, an estimate has been made to calculate the necessary dredging volume. A total of 3,000 cubic meters of material needs to be dredged to achieve the desired depth. This is, of course, not a precise number, as bathymetric data is lacking, but it serves as a first estimate.

Figure 8.10: Cutter suction dredger at Bahia Lopez

To carry out the dredging, an excavating machine is necessary. This will be done using a cutter suction dredger equipped with a disposal pipe, as such a vessel is available in the Bariloche area. According to the information provided by the concessionaire, the dredging vessel has a power output of 140 HP, as shown in Figure 8.10. This is sufficient for the required dredging work. Alternatively, for excavating vegetation and sediment near the shore, an excavator and backhoe from land could be used.

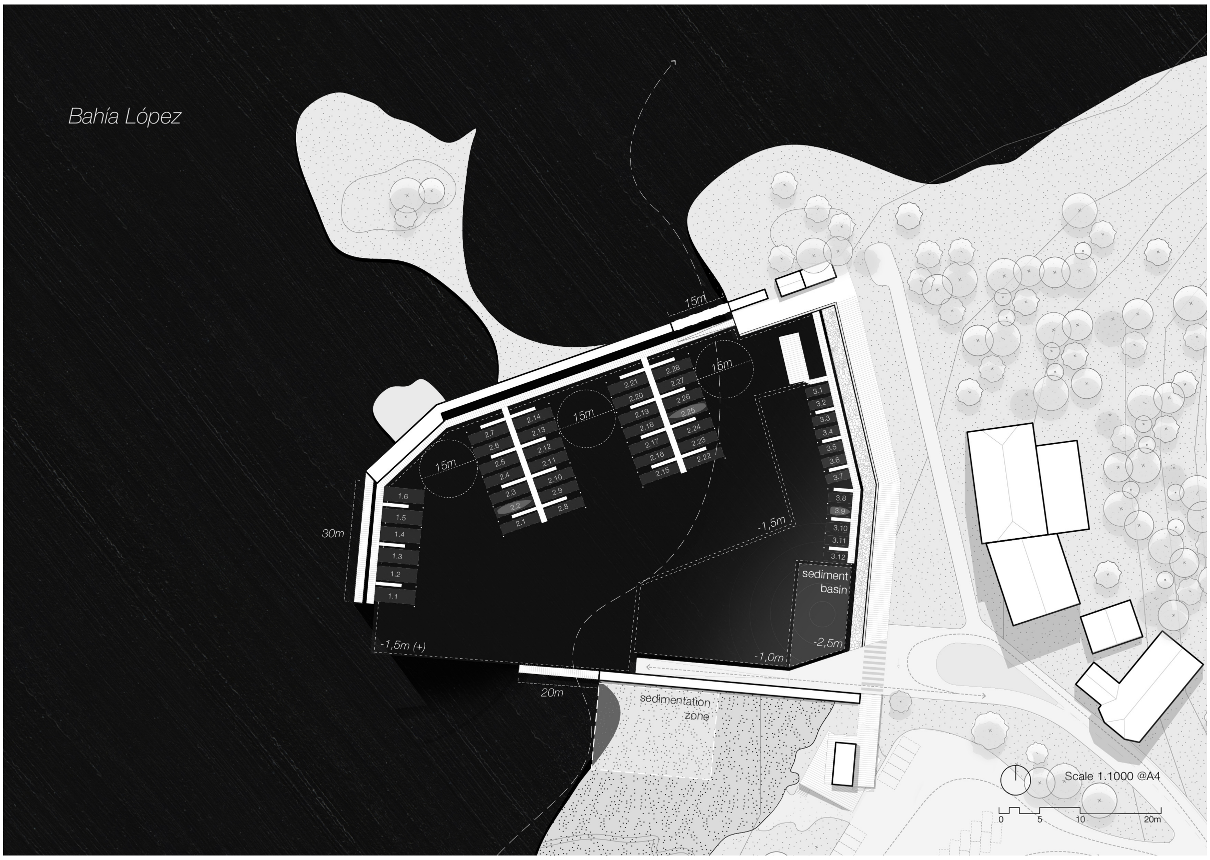


Figure 8.11: Technical drawing of the Marina.

This creates a considerable amount of sand that will need to be disposed. The majority of this sand will be used to fill the 90-meter-long quay, as will be described in the 'Marina Wall' section. The quays core will be built from the sand extracted from the marina. Additionally, a half-meter increase in sand height will be needed to level the pavement. As a result, most of the dredged material will be repurposed for the quay construction. The remaining sand will be deposited on the beach, as it matches the natural sediment type. This will not change the appearance of the area, simply expanding the beach, giving it back to nature.

8.4 Sediment and Vegetation Growth Control

As discussed in subsection 3.6, the primary cause of sediment accumulation and vegetation growth in the marina is the trapping of sediments and stagnant water pocket within the marina. This occurs because the breakwater built in 1929 disrupts the natural water flow, preventing water circulation within the marina and preventing the sediments from escaping the marina and causing them to accumulate.

The most effective solution against sediment accumulation within the marina would be to construct a breakwater extending from the shore towards the existing breakwater, as shown in Figure 7.1. In this design, the marina entrance would need to be narrow and aligned with the direction of the main current, Van Rijn (2012) [45]. In this design the breakwater will stop the sediments due to longshore drift and the diffraction of the breakwater from entering the marina. This will be again be of influence to the water circulation in the Bahia. To optimize this operation the required length of the breakwater will have to be calculated based on the rotation state of the beach at Bahía López.

As this project is based on Working With Nature philosophy, we propose addressing this issue by restoring natural flow within the marina. This would mean reintroducing water circulation and preventing a stagnant water pocket causing sediment build-up and vegetation growth.

To restore and maintain natural water circulation within the marina, a proposed solution is to modify the existing breakwater by replacing it partially with a wave screen. A wave screen is basically a porous wall that dissipates wave energy while still allowing water flow. The location of the wave screen and the resulting natural flow can be seen in Figure 8.12. This flow encourages sediment suspension and allows for the natural prevention of vegetation growth in the marina area.

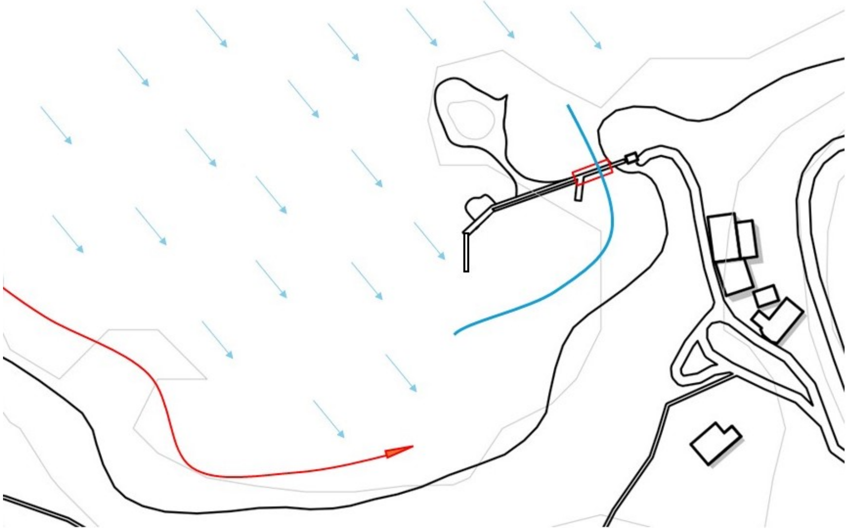


Figure 8.12: Restoring natural flow in marina

The waves approaching the location of the proposed opening, are partially sheltered by the island and are approaching in shallower waterdepths. Assumed is a water depth of 4.5 meters at high waterlevels. Because of this the wave conditions are assumend to be moderate; a wave height of 0.39 meter and a wave period of 1.96 seconds, following from Table 8.3. The total wave transmission will be higher if the water is deeper, therefore the depth at high water level is used, which is 4.5 meters.
Based on extensive experimental data from Thomson (2000) [46], the following wave screen setup was selected. A 15 meter long double-screen configuration featuring horizontal slats and a porosity of 30% (defined as the ratio of open gaps to the area blocked by the slats). The screens will be 59.5 centimeters apart. This setup has the highest porosity while maintaining a wave transmission coefficient of below 0.7, which is more than sufficient to attenuate the waves to the maximum height of 0.3 meters in the marina. This design with the highest possible porosity was chosen to maximize the natural flow while maintaining a sufficient wave transmission coefficient. An example of a double screen wave screen can be seen in Figure 8.13.

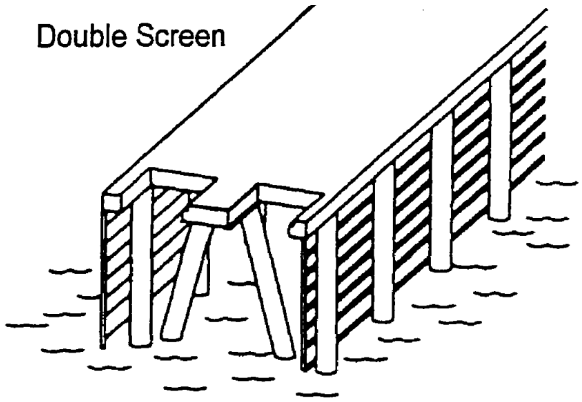


Figure 8.13: Double Wave Screen

This solution will not fully stop sedimentation inside the marina because the design does not prevent sediments from entering. In the bottom right corner of the marina, an over-depth zone has been designed to act as a sedimentation area, where sediment will naturally accumulate Figure 8.1. This area, effectively a sand pit or sediment trap, takes advantage of the reduced flow velocity upon entry into the marina. As the water slows down, sediment carried by the current is deposited in this stagnant water area, PIANC (2015) [47]. By concentrating sediment in this zone, it becomes easier to manage the buildup with minimal disruption to the marina's operations. This design strategy allows for more targeted dredging when needed, as the sediments are already concentrated in one area, reducing the need for widespread and costly dredging efforts. This approach not only helps maintain the cleanliness of the marina's berths but also minimizes the environmental impact by reducing the need for extensive dredging across the entire marina. Since the sediments are expected to primarily accumulate in the overdepth sedimentation zone, maintenance dredging can be efficiently carried out using a standard excavator from the land, which will reduce the costs of maintenance. As the exact sedimentation rates in the marina area are not determined it is difficult to predict the period after wich maintenance dredging is necessary.

In addition to sediment control and vegetation growth prevention, this approach would improve water quality by ensuring proper water exchange between the marina and the open water body.
With this solution, we embrace the Working with Nature principle within Parque Nahuel Huapi, aligning with the parks preservation strategies. By partially recreating the original configuration of Bahía López, we aim to restore and improve the natural dynamics of the area, promoting sustainability and minimizing human impact in Bahía López. This approach ensures that the breakwater system integrates with the surrounding ecosystem, supporting both environmental protection and long-term stability.

8.5 Boat Ramp

To accommodate the large number of recreational users launching boats at Bahía López, a dedicated boat ramp will be constructed. As mentioned before, currently boats are launched directly from the beach, sharing space with beachgoers, which can create congestion and safety concerns. The new ramp will provide a structured and safe launching area, improving efficiency and minimizing conflicts between different users.

Boat ramps are primarily designed for launching trailer-mounted vessels using a vehicle, but they should also accommodate smaller, non-motorized boats, such as kayaks, canoes, and inflatables, which can be launched by hand. To ensure safe and efficient operation, the ramp design includes sufficient maneuvering space, appropriate slope and dimensions, and necessary facilities for users (Figure 8.14).

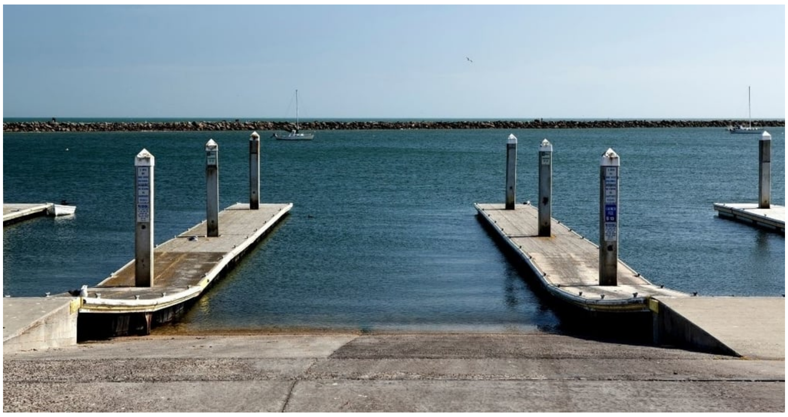


Figure 8.14: Boat launching ramp with side berths [48].

Ramp Dimensions

The length of the boat ramp is determined by several key factors, including design water levels, head and toe elevations, slope, and local topography. A proper design ensures that the ramp remains functional across varying water levels throughout the year.

To establish the appropriate ramp length, the design is based on historical water level data. Seasonal fluctuations in the area, as shown in Figure 3.6, indicate a minimum water level of 767.5 m above MSL and a maximum of 770.5 m above MSL. The ramp must be designed to accommodate these variations, ensuring year-round usability.

The head level of the ramp should be at least 0.6 meters above the design high water level, while the toe level must extend at least 1 meter below the design low water level and continue a minimum of 1 meter underwater at this depth [49].

A uniform slope is essential for safe and efficient boat launching. The recommended slope ranges between 12% and 15%, with a preferred slope of (12%). Additionally, each ramp lane must be at least 4 meters wide to provide adequate maneuverability for vehicles and trailers, at Bahia Lopez 1 lane will suffice [50]. The transition between the launchin apron and the ramp, can not be too abrupt, a vertical curve makes the transition smoother. See the figure below for the cross section of the ramp.

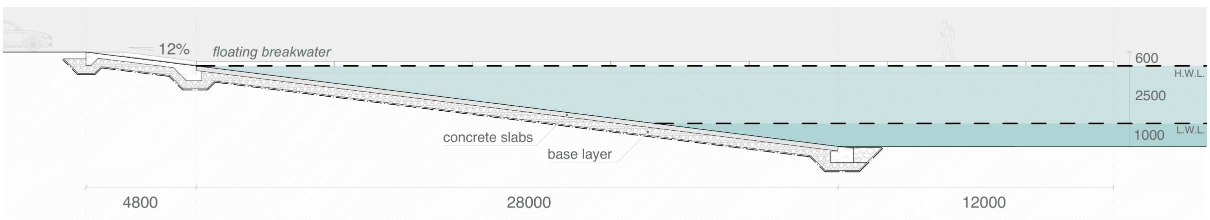


Figure 8.15: Cross section boat ramp.

Launching Apron

The launching apron serves as a transition area between the driveway and the ramp, providing space for vehicles with trailers to maneuver and turn. To optimize visibility and ease of reversing, counter-clockwise turning should be prioritized, as it allows drivers to maintain a clear view of their trailer, see Figure 8.16.

Additionally, the apron must provide sufficient space for vehicles backing up with trailers and accommodate waiting vehicles without obstructing the ramp or access roads.

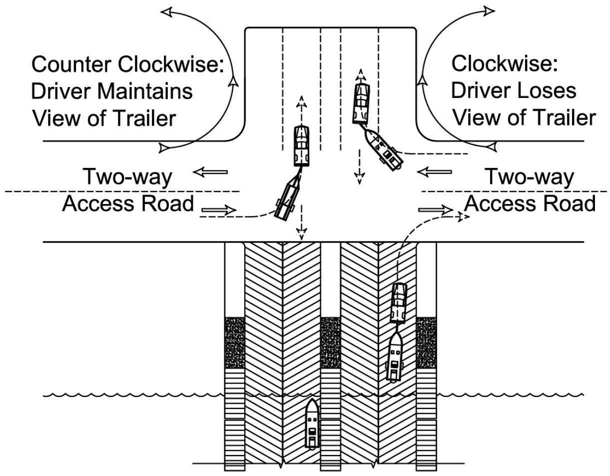


Figure 8.16: Benefits of counter-clockwise turning [50].

Grooves

The surface finish of the boat ramp is important for providing traction for vehicles and pedestrians while also aiding in sediment control. To achieve this, the concrete deck should incorporate deep, molded grooves. They facilitate self-cleaning by allowing water and debris to drain efficiently [51].

The recommended groove dimensions are 25 mm deep and 25 mm wide, placed at an angle between 30° and 45° relative to the ramp slope. This design enhances grip when wet, prevents excessive marine growth, and helps channel sediment and debris off the ramp surface [50]. Proper alignment is critical, as poorly placed grooves may trap sediment and create slip hazards.

To maintain long-term functionality, regular inspections and cleaning of the grooves are necessary to remove accumulated sediment and marine growth, which could otherwise reduce their effectiveness over time.

Material

The construction of the boat ramp requires durable materials that can withstand continuous exposure to water, sediment, and vehicular loads. The ramp should be built on a stable sub-base to prevent settlement and structural failure. A layer of $50 - 100$ mm sized gravel should be placed with a minimum thickness of 150 200 mm to create a well-compacted base. The use of filter fabric over the base material is recommended to prevent erosion and migration of fine particles [49]. The concrete mix must be designed for long-term durability, particularly in wet and submerged conditions. It should meet the AS 1315-1973 standard, using Type D or Type C concrete with a tricalcium aluminate content of no more than 5% to enhance resistance against sulfate attack [49].

For both above-water and underwater sections, a Class 40 (40 MPa) concrete mix is recommended to ensure structural integrity and resistance to environmental exposure [49]. Precast panels are the preferred choice for construction as they can be efficiently installed using a crane, with or without the use of cofferdams. To ensure long-term durability and proper alignment, the panels should incorporate a male-female connection system, allowing for a secure fit and minimizing displacement over time.

Sediment protection

To ensure toe stability, measures must be taken to prevent scour and erosion. This can be achieved by placing medium-sized rocks (10 - 20 cm in diameter) at the toe of the ramp, forming a protective layer that reduces the impact of water flow and minimizes material displacement.

Effective sedimentation control is crucial for maintaining the required minimum water depth at the ramp. Excessive sediment buildup can obstruct boat launching and retrieval, reducing overall functionality. To minimize sediment accumulation, constructing a breakwater in open waters is not recommended, as it may interfere with natural sediment transport and cause unintended deposition at the ramp entrance.

However, situating the ramp behind a breakwater or similar protective structure can help mitigate sedimentation by shielding the area from strong currents and wave action. Despite these measures, regular maintenance will always be necessary to prevent sediment accumulation and ensure long-term usability (Figure 8.17).

Figure 8.17: Boat ramp affected by sedimentation [51].

Safety and Facilities

To ensure the safe and efficient use of the ramp, several facilities will be installed. A floating dock will be positioned alongside the ramp, either on one or both sides, allowing boats to be temporarily moored while the car and trailer are parked. A floating dock is essential due to the significant seasonal water level variations in Bahia Lopez, ensuring accessibility throughout the year.

For improved visibility during early mornings and evenings, a street lantern will be installed near the ramp. Proper lighting enhances safety, making launching and retrieving boats easier in low-light conditions.

Additionally, clear signage will be placed to indicate ramp usage rules, and designated pedestrian pathways will be incorporated to minimize conflicts between pedestrians and vehicles, ensuring a safe environment for all users.

8.6 Pier

A clear separation between the beach and the marina is crucial, as the marina will be dredged to a depth of 1 meter, while the beach remains at its natural level. To prevent excessive sediment movement and potential collapse, this boundary must be structurally stable. The transition occurs at the ramp, necessitating the installation of a ramp wall for reinforcement.

Positioned at the edge of the ramp, the pier will protect against side currents while maintaining the division between the two areas. It will extend 64 meters in length and have a width of 2.4 meters, reaching slightly beyond the low-water level. A schematic overview of the pier and how it relates to the beach and boat ramp, including dimensions, is shown in Figure 8.18

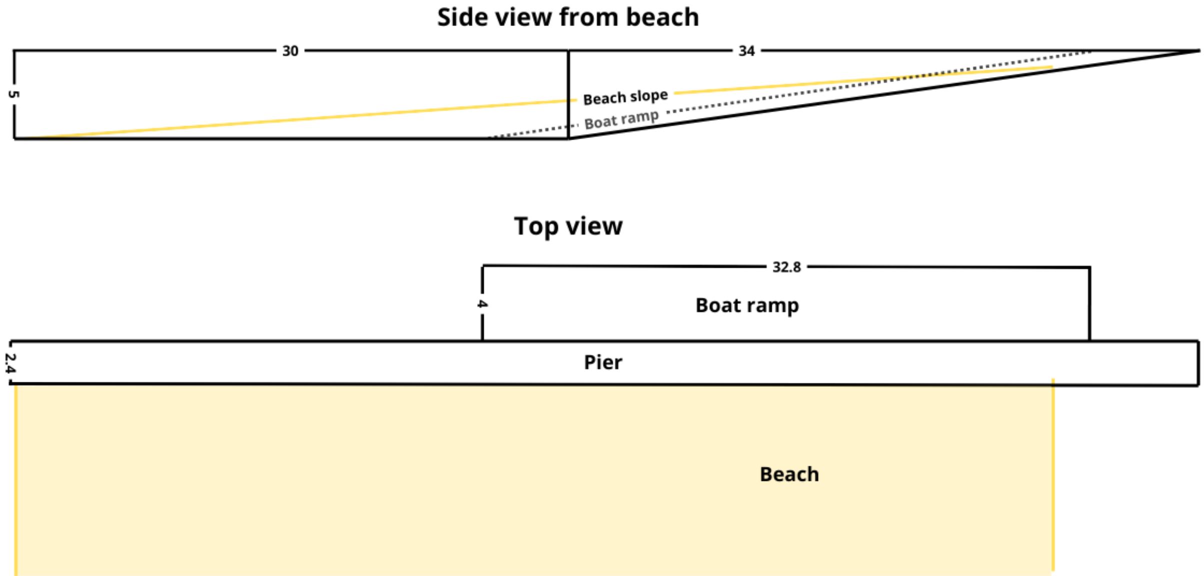


Figure 8.18: Schematic overview of pier dimensions (own figure)

Despite its size, the landward section of the wall will start at ground level, serving as a walking path and pier. This design enables visitors to stroll toward the water, providing an elevated vantage point overlooking the marina and the entire From the pier, they will also have an unobstructed view of the existing breakwater, the lake, and the marina.

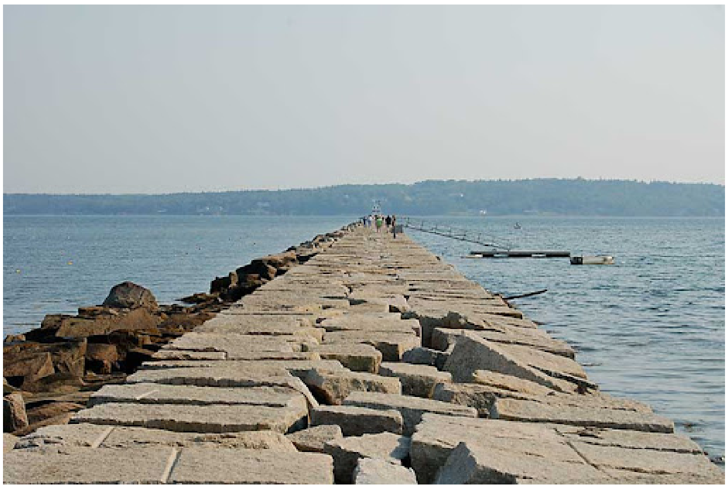


Figure 8.19: Walkable pier [52]

8.7 Marina Layout

The design and layout of a marina must adhere to specific guidelines and frameworks to ensure safe boat maneuvering and navigable waterways. Various institutions have established their own set of guidelines, which is why PIANC is developing a unified set of standards to streamline these regulations.

Mooring Dimensions

The design of the inner waterways and berth spaces must accommodate a variety of boat sizes, as specified in the functional requirements and the concession agreement [32]. The concession identifies three distinct boat sizes, as illustrated in Figure 5.1.
The largest vessels expected to use the marina will have a length of 10.0 meters. This dimension serves as the basis for the marinas design, influencing the layout of fairways and entry points. Mooring spaces will be designed to fit the three boat sizes identified in the market study, with additional space provided to ensure safe maneuvering. The maximum size of the mooring spaces, based on the design boats from the market study, will be as follows:

- Large moorings: 10 x 3.5 meters
- Medium moorings: 10 x 2.5 meters
- Small moorings: 8 x 2.5 meters

To prevent collisions between boats due to slight wave movements, a clearance of 1 meter will be maintained between mooring spaces [53]. Alternatively, a finger dock can be installed between two moorings, as detailed later in this chapter.

Internal Channel and Fairway

The width of the internal channel and main fairways can be estimated by multiplying 1.5 times the length of the longest vessel in the marina [53]. For the Bahía López Marina, the design boat is 8.0 meters long, the required channel width becomes 15 meters. An efficient design approach involves positioning larger vessels near the entrance, where there is more space for maneuvering, while placing smaller boats further inside the marina. This arrangement allows for easier navigation of smaller boats and results in more efficient use of space. It also enables the design of narrower fairways farther from the entrance, increasing the number of available mooring points. Additionally, the marina will feature an overall design depth of 1 meter, with a deeper area near the entrance to accommodate larger and deeper vessels, as sailboats. For smaller boats, with a design length of 8 meters, the fairways will be 12 meters wide.

According to the concession requirements, the marina must maintain a minimum depth of 1 meter throughout. This depth is adequate for small to medium-sized design boats. However, to accommodate larger vessels, a designated area near the marinas exit will be reserved. This internal channel will be dredged to a depth of 1.5 meters, ensuring that the largest design boat can safely moor in this section.

Berthing

The criteria for dimensioning berthing options depend on several design factors. The first decision is whether to use a fixed or floating berth. Given the significant seasonal water fluctuations at Bahía López, a floating berth is the most appropriate choice and has been selected.
The floating docks will be held in place by piles. To ensure stability, these piles will be driven 2 metres into the ground and have a diameter of 20 cm [54]. In order to remain usable in high water they have to extend 5 metres above ground level. This results in piles of 7 metres. The material of the piles will be wood. This material offers great stability, is relatively cheap and it causes no contamination of the water.
The floating docks themselves will be made primarily out of aluminum. This material offers the best balance between durability, costs and possible contamination. A comparison of different materials for floating docks can be found in subsubsection D.3.5.
The next consideration is choosing between a piled or fingered berthing system, both of which are viable options. A fingered system offers a better user experience by allowing easier access, but it is more expensive and less efficient in terms of optimizing berthing spaces. On the other hand, a piled

system requires boats to enter via the bow, making it less user-friendly. Additionally, the piled system necessitates driving piles into the ground, which has a higher environmental impact.
Finally, there is the option to choose between single or double berthing configurations (see figure Figure 8.20).

For the final marina design, the double berth fingered system was chosen. This system is efficient, and ensures good accessibility.

The berth width is calculated using the following formulas:

- Single Berth: $W_b = \text{max vessel beam} + 1[m]$
- Double Berth: $W_{db} = 2 \times \text{max vessel beam} + 1[m]$

For alongside berths where boats are positioned bow to stern, the space between the vessels should not be less than 0.2 times the design length, 1.6 meters [53].

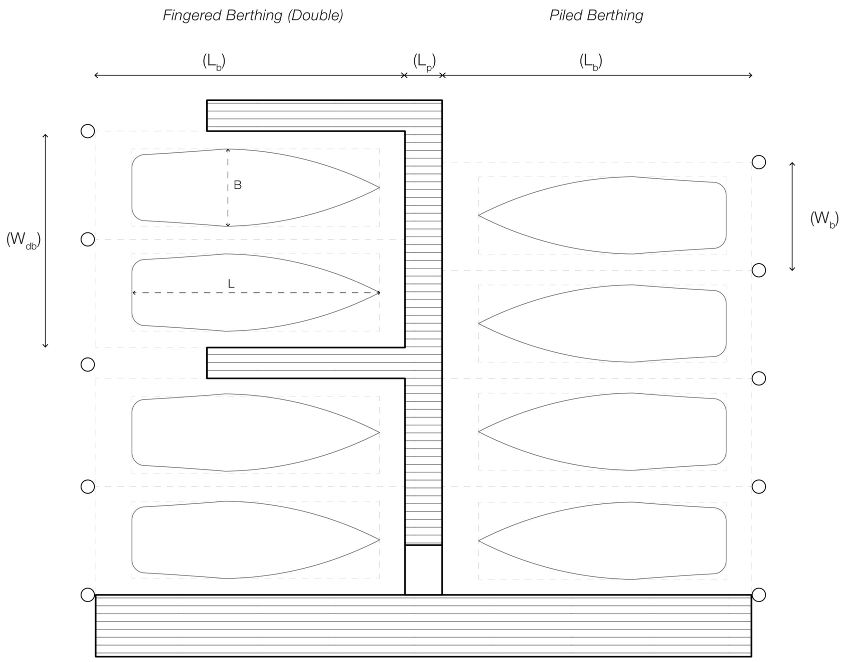


Figure 8.20: Dimensioning of floating dock

Walkways and Fingers

Finger docks should be at least 0.8 times the design boat length. For vessels up to 24 meters, the minimum width should be 10% of the berth length, which in this case amounts to 80 cm . When designing walkways shorter than 200 meters, a width of 1.5 meters is sufficient [55]. See Figure 8.20 for the dimensioning of the berthings. And see Figure 8.11 for the implemented spaces in the marina.

8.8 Marina Facilities

In order to become a proper marina, some essential facilities have to be present. All the infrastructure for those facilities will have to be new, since there currently are no facilities at all. Fortunately, this is a small marina and therefore basic facilities will suffice. This section provides a short description of the necessary marina facilities and how they are facilitated in our preliminary design.

Fuel dock

To minimize the amount of construction, a big part of the essential facilities will be centralised in a fuel dock. There will be no permanent mooring at this dock. It is for service only. An example of such a fuel dock can be seen in Figure 8.21From this docking space, there will be access to the following facilities:

- **Fresh water:** Essential to fill up the fresh water tanks of boats in the marina.
- **Fuel:** Since the nearest fuel station is 16 kilometers from the bay, the preliminary design will include a fuel facility. Given that Puerto Pañuelo already has a well-established system, it will serve as a reference model [56]. This approach increases the likelihood of approval from Parques Nacionales. Centralizing fuel services in one location with proper spill prevention measures significantly reduces environmental risks compared to a scenario without a dedicated facility, where boaters would have to carry jerry cans across the docks and refuel their boats throughout the marina.
- **Waste Water disposal:** The fuel dock will also provide the service of waste water disposal. Again, since such a service is already in place successfully at Puerto Panuelo, their system will be used as a reference [56]. There are 3 types of waste water: Bilge water, which is usually a combination of water and oil. Grey water, which is minimally polluted water for example from sinks and showers. Lastly, there is black water, which is basically sewage water. The system allows these different types to be pumped out of the boat and thereafter it is stored separately on the coast. When the storage tanks are full, a private company comes to collect and transport the waste waters to a disposal site.
- **Fire Extinguisher:** A suitable fire extinguisher for fuel fires will be present at the fuel dock.
- **Spill kit: In case of fuel, oil or wastewater spillage.**
- **First aid kit**

Figure 8.21: Example of fuel dock with additional facilities [57]

Safety

To ensure all safety standards are met, there will be an emergency stations around the marina. They will be placed in such a way that there is always one in a range of 22.5 m, complying with the guidelines for marinas of PIANC [58]. An example of such an emergency station can be seen in Figure 8.22. The emergency stations will contain:

- **Life buoy**
- **Spill kit**
- **Fire extinguisher**
- **First Aid kit**

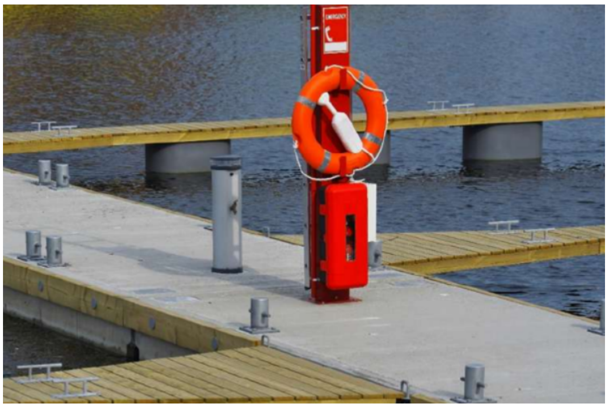


Figure 8.22: Example of Emergency Station [55]

Sanitary facilities

Since it is a small marina with less than 50 berths two toilets is the minimum [59]. For comfort and considering future expansion, the marina will have five toilets. They will be located in the Office Building.

Lighting

Sufficient lighting is necessary for safe operation of the marina. All the docks and walkways should be properly lit. However, lighting consumes a lot of energy and can cause severe light pollution, especially in an area like this with great amounts of avian wildlife and insects. The design choice for lighting is therefore crucial regarding the environmental impact of the preliminary design. The lighting option that was selected is the Papilio street light (Figure 8.23). This street light minimizes environmental impact in multiple ways. It generates its own energy using a Savonius wind rotor that can harness wind energy from every direction. Hereby the strong winds of Bahia Lopez can be used to our advantage. Additionally, it switches on and off using infrared sensors, ensuring that the light is only on when necessary. Light pollution is minimized even further by the downward phasing lamp and insect-friendly light spectrum. This combination makes this street light perfect to light up our marina.

Figure 8.23: Papilio street light [60]

8.9 Gangway

Since the marina will feature floating docks that adjust with water levels, a gangway is required to connect the stationary quay to the floating dock. To ensure safety and ease of use, the gangway is designed with a target slope of approximately 1:8, rather than the maximum allowable 1:4 slope [53]. Given the 2.5-meter fluctuations in water levelsand noting that the marina will primarily be used in summer, when water levels are at their lowestthe gangway is designed to have a slope of 1:6 during these low-water conditions. This results in a total gangway length of approximately 15 meters.

To provide a smooth transition, an additional tread plate is included. A width of 1.2 meters is deemed sufficient for safe and comfortable passage [53]. Handrails will be installed and must extend at least 0.5 meters beyond the start of the dock. Additionally, where necessary, a kerb rail will be added at the docks exit point to enhance safety along the walkways.

Gangways will be installed at two different locations within the marina, improving accessibility to various floating docks and minimizing inefficient walking routes. For optimal use of space, the gangways can be positioned at an angle, as illustrated in Figure 8.24.

Figure 8.24: A gangway connected with a floating dock.

8.10 Marina Wall

To ensure the stability of the dredged side of the marina and prevent collapse, a stone wall is required. Three main types of walls are categorized as options for the wall.

- Vertical wall
- Curved wall
- Mound wall

These wall types are commonly used to protect quays in high-energy marine environments. However, since the marina is located on a lake and the breakwater absorbs most wave energy, wave dissipation is not the primary function of the marina wall. Instead, the key objective is to accommodate the 2.5-meter water level fluctuations.

If a vertical or curved wall is chosen, it would result in a significant drop in summer when water levels are low, creating safety concerns. For this reason, the mound-type wall is preferred. For stability and to protect against collapse, stone revetments will be placed, see Figure 8.25. Also Figure 8.24 gives a good idea of the marina sloped wall.
The revetment stones will come from within the national park, these sandy colored stones not only make the new marina in harmony with the existing coast line, it also saves costs as the stones can come

out of the park. As was explained in subsection 3.4, typical stones that are found are Porphyritic rocks, for that reason the revetments will be out of this type.

Figure 8.25: Dike with revetment.

The quay will be constructed as a sloped dike with a stone revetment. Armour rocks will be placed at the toe for scour protection, while a bedding layer with a geotextile mat will be installed to ensure stability from behind. The core of the quay will be filled with dredged sand. To create a straight walking path, the pavement will be raised by one meter. A slope of 1:1.5 has been selected, providing a horizontal run-up of 4 meters to accommodate fluctuations in water levels of up to 2.5 meters, as shown in Figure 8.26. To maintain the stability of the quay core, vertical drains will be installed along its length. These drains will ensure that rainwater does not accumulate inside the quay, preventing collapse, by directing the water into the subsoil beneath the core [61].

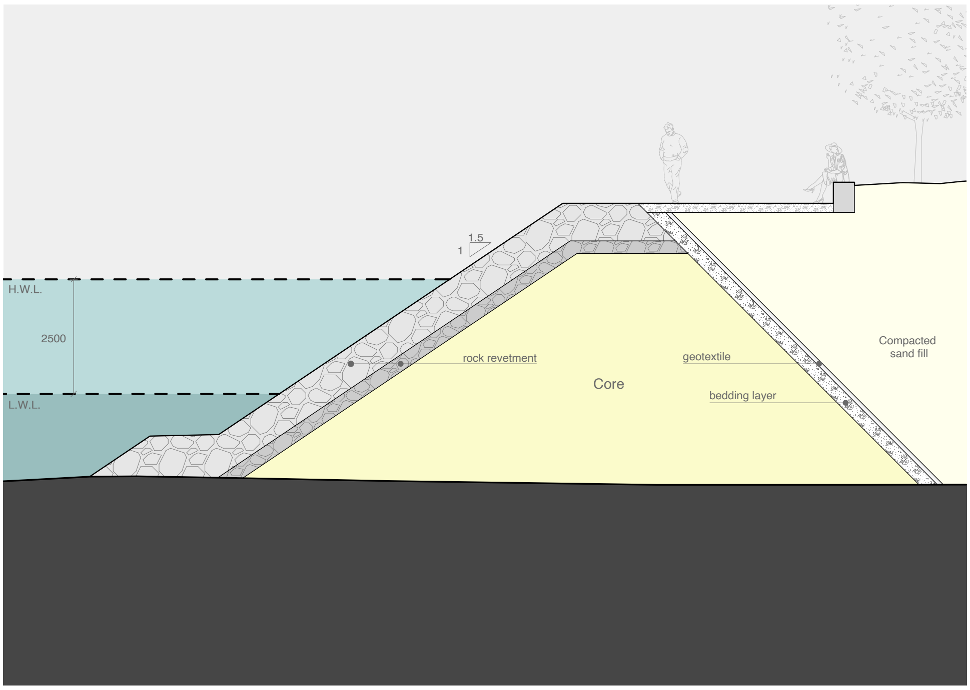


Figure 8.26: Cross section of sloped quay.

8.11 Parking Area

The parking area will be expanded to provide 70 regular parking spaces, including four designated for disabled parking, located directly behind the kiosk building.
To accommodate users of the boat ramp, parking spaces with additional room for trailers will be provided. In line with industry guidelines, each car and trailer parking space will have a minimum length of 12.5 meters to ensure ample space for standard vehicles and trailers [51].
To maximize space efficiency, angled parking will be used, with a 45-degree angle being the most effective for ease of maneuvering and reversing. Where possible, trailers will be permitted to park in designated grass areas, further optimizing the use of paved parking spaces, as shown in Figure 8.27 [51]. See Figure 8.1 for the parking layout.

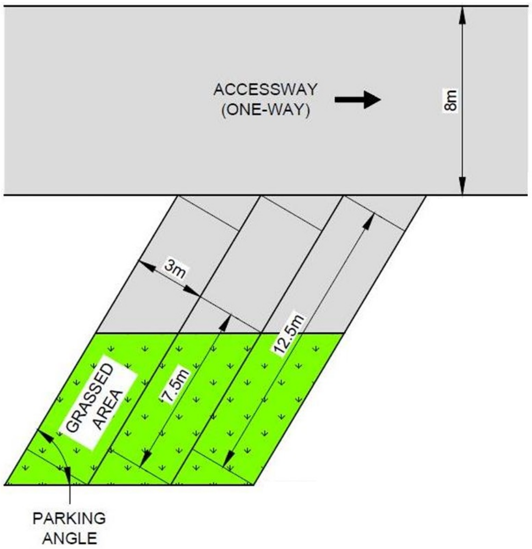


Figure 8.27: Reverse parking with trailers [51].

8.12 Office building

In the general layout for the marina the decision was made to split the indoor program components in two parts: a recreational building containing a kiosk, that is planned to be built next to the beach and parking plot, close to the entrance of the hiking path, and secondly, an operational building, with a reception, offices and toilets, that is to be built in de marina area.

This office building is next to the existing office building of the marina, where we propose to make the office for the Prefuctura, to have quick access to the docks. Adjacent to this, a rotated volume could be realized with at the corner a reception of the marina. Furthermore, by building a storage space next to the parking area, and by allowing this wall to be opened up completely, heavy products can easily be stored.

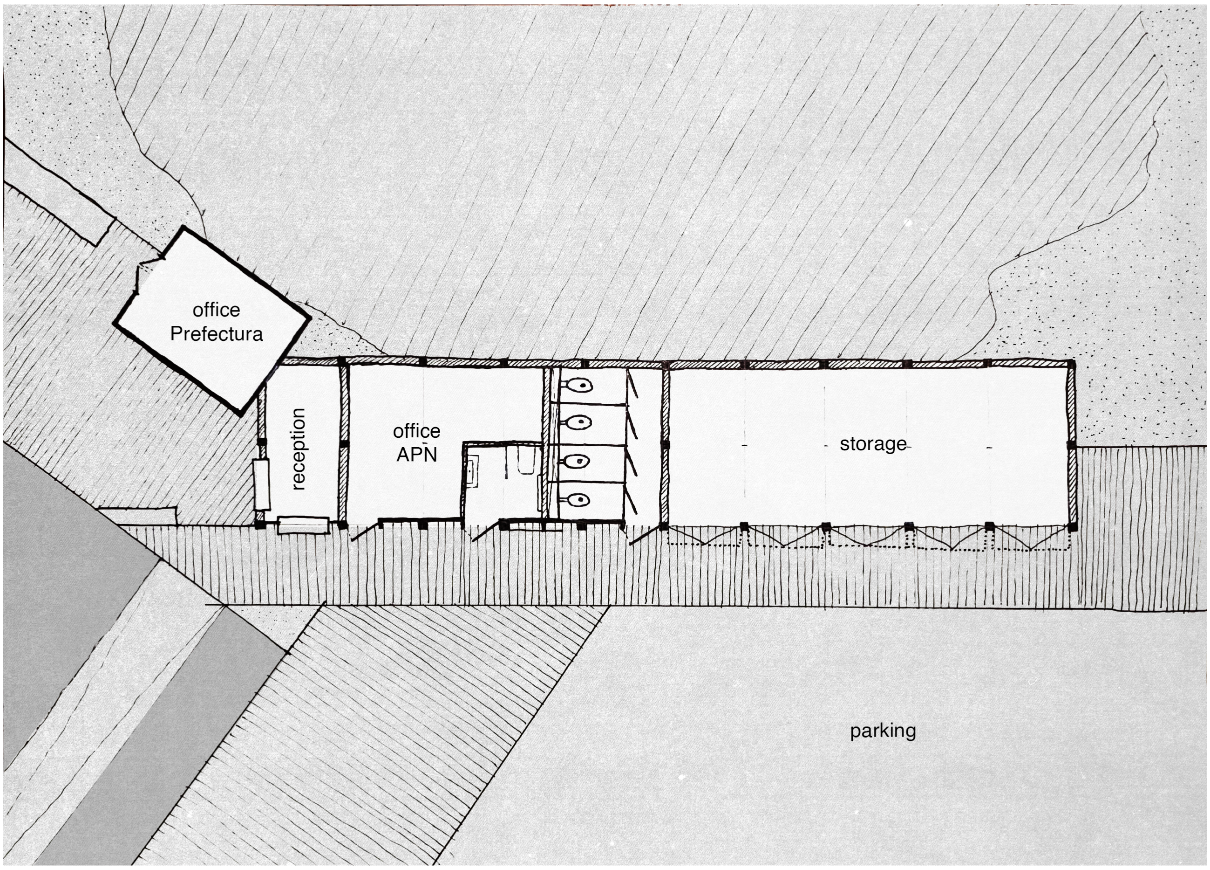


Figure 8.28: Plan of the office building.

8.13 Kiosk

The kiosk is located is in the zone between the parking area and the beach, that is a zone free for vegetation to grow, right alongside the entrance path to the beach, as shown in Figure 8.29.

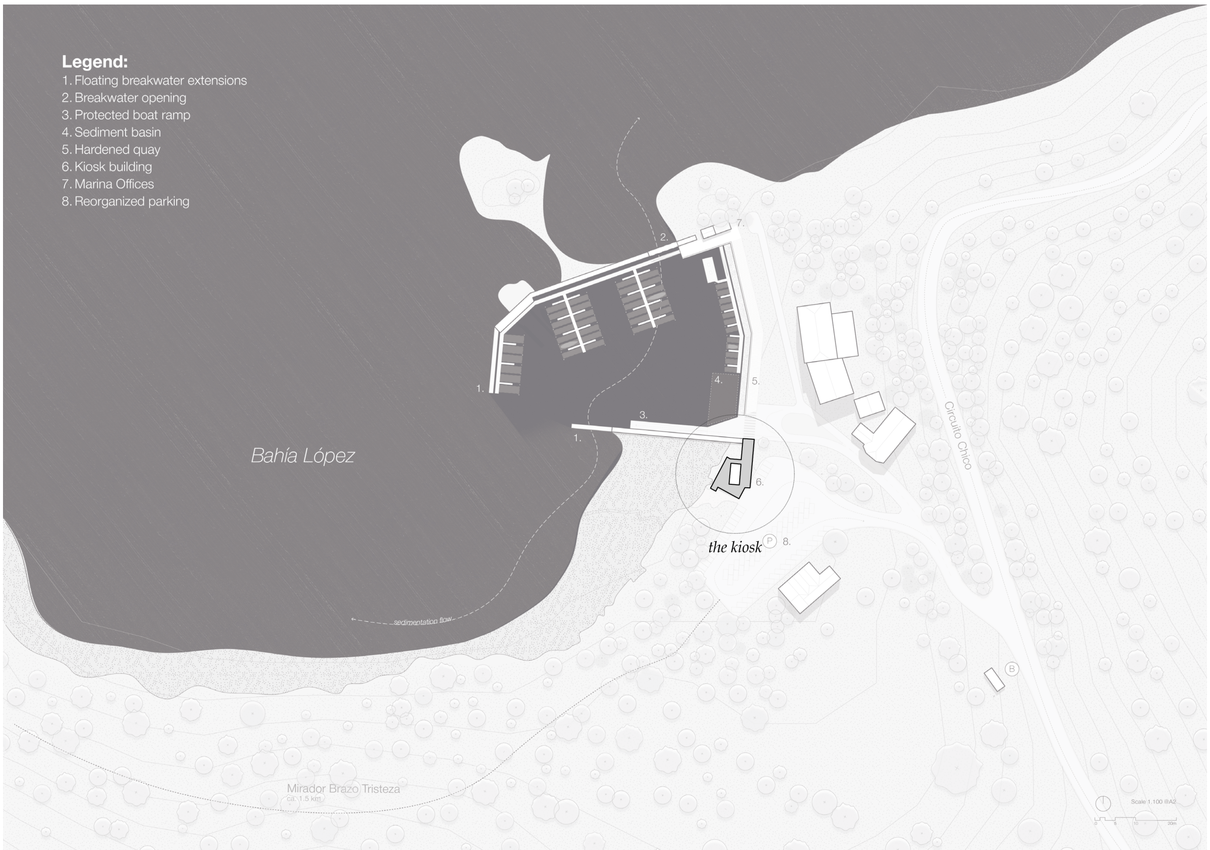


Figure 8.29: Location of the kiosk.

The program for the kiosk is simple: a place to grab some food or drinks after a hike, a swim or a boat tour. This can be consumed indoors, in a covered outdoor area, or completely outdoors.

The kiosk is organized by creating two perfectly squared flooring areas, one for the kiosk, and one for the terrace, that are superimposed. An extension is built towards the boulevard of the marina area, to create an easy access for users of the marina and hotel guests.

Because of layering one square over the other, hight differences appear. Stairs are made, from the parking area to the kiosk level. In the kiosk there is space for some dining tables, with views over the Bahía, a kitchen with a desk for taking orders and a closed of storage space.

If customers wish to eat or drink outside, they can go out again and take the stairs to the terrace, where there are tables under a cantilevered roof or completely out in the open. After this the visitor can use the stairs to descend down to the beach. These same stairs also allow a quick access for beach visitors.

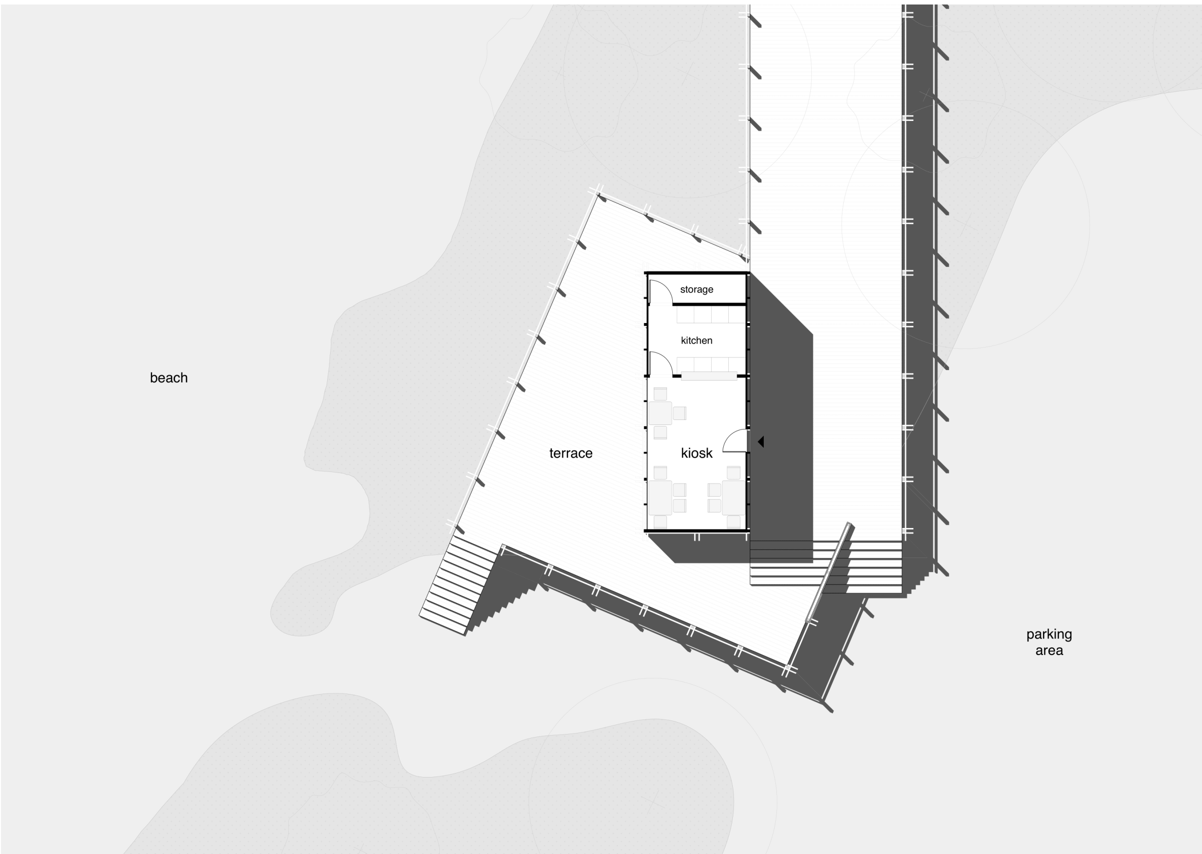


Figure 8.30: Plan of the kiosk.

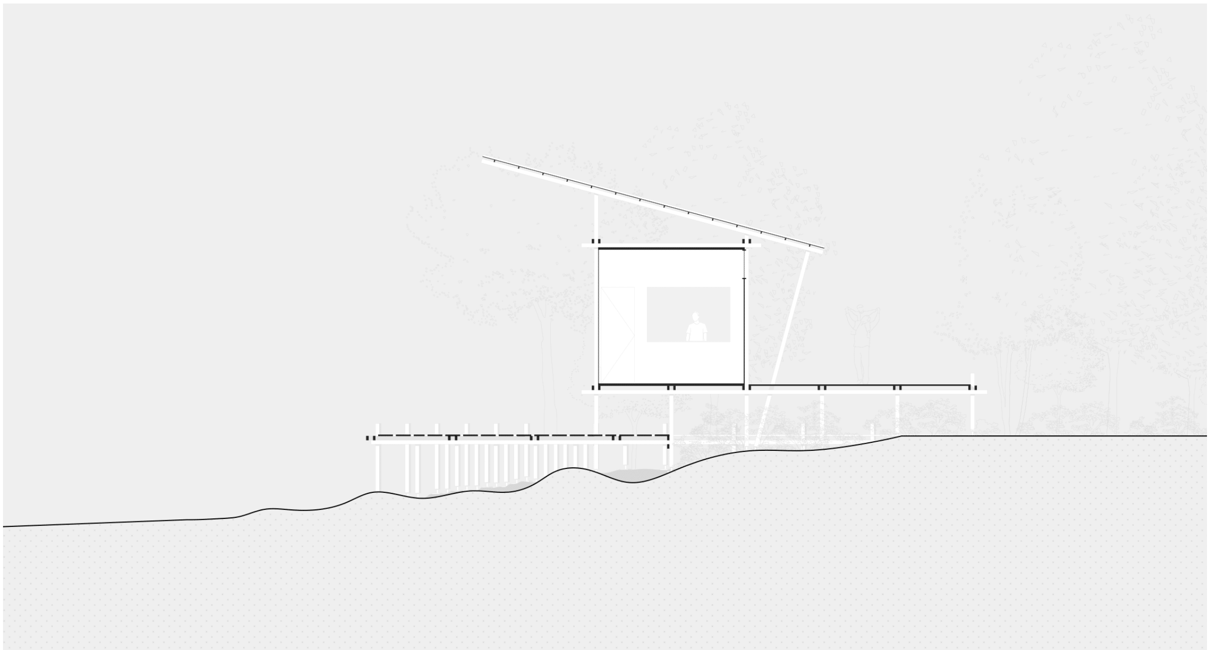


Figure 8.31: Section of the kiosk.

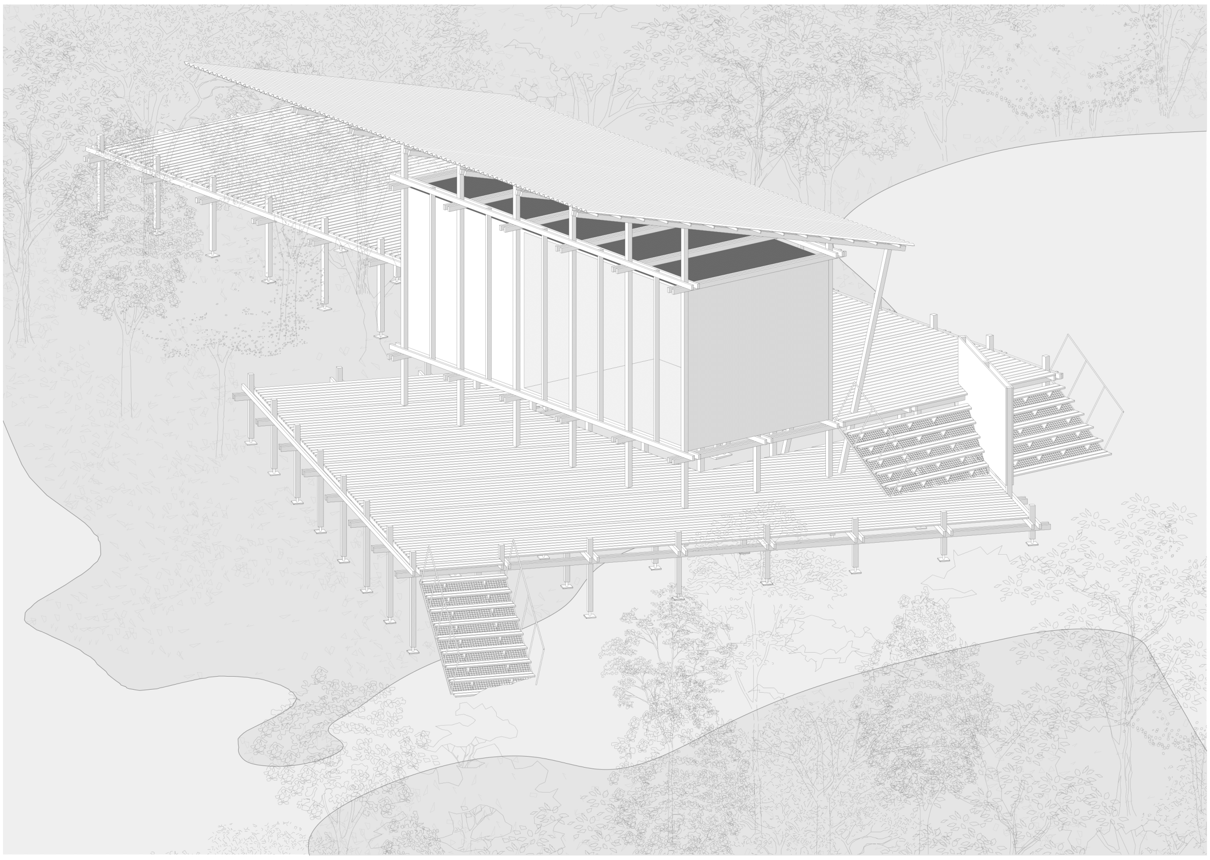


Figure 8.32: Axonometry of the kiosk.

Figure 8.33: Impression of the kiosk as seen from the beach.

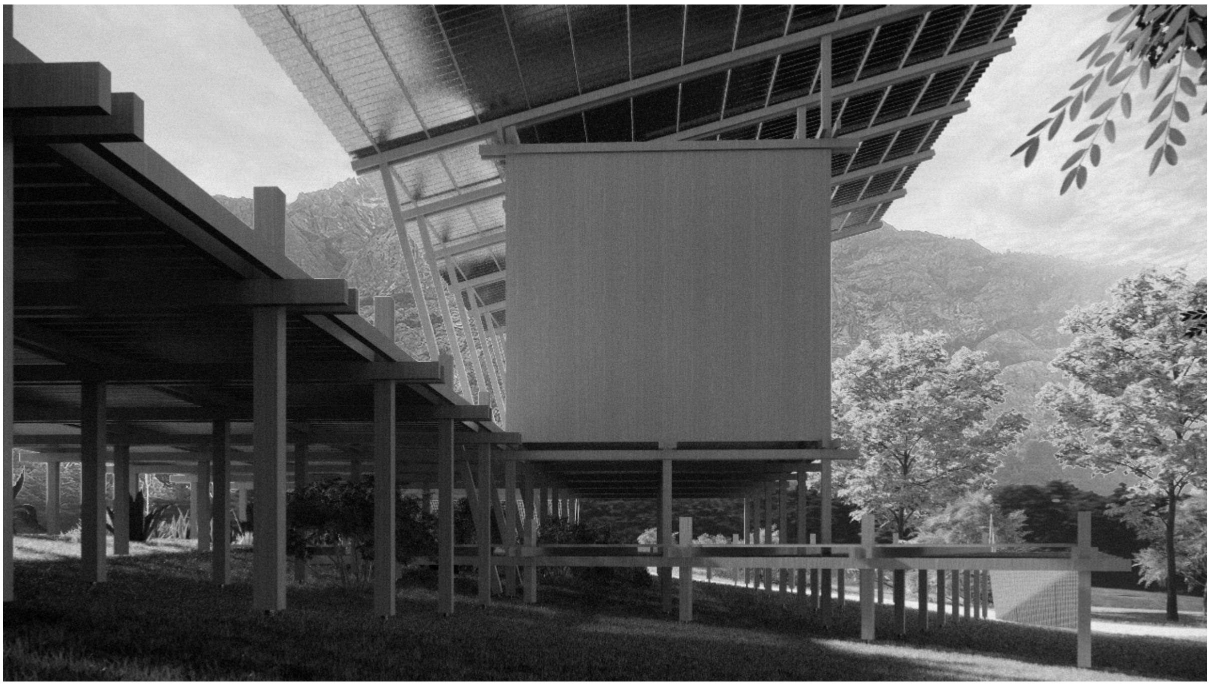


Figure 8.34: Impression of the side and area under the kiosk.

In order to minimize the impact of this program on the environment, a wooden structure is proposed, that is lift up from the ground, to leave space for flora and fauna to conquer the area under the kiosk. By raising the structure, it also becomes resilient against extremely high tides, that would in normal conditions not occur. Lastly, the elevation from the ground also enables looking out over the marina, to the spectacular views of the Bahía, see Figure 8.35.

Figure 8.35: Impression of the kiosk providing optimized views over Bahía López.

The wooden structure, consisting of beams and girders, would be mounted in such a way that the demolition of the building would not result in damaging the individual components, allowing the reuse of these resources. Furthermore, the concept of a tropical roof is implemented, in which a double roof is made where the wind can flow through, in order to passively cool the building.

8.14 Environmental Awareness

Because the Bahia is such a sensitive area, it is important that the visitors behave in an environmentally friendly way. To encourage this, there will be information signs across the recreational part of the bay. These signs will provide important information about the local ecosystem, like the endangered species that live there and interesting relationships between different species. Most importantly though, they will emphasize how human behavior can impact the local nature and encourage people to be aware of the local environment. This education of visitors is highly encouraged by the municipality of Bariloche.

8.15 CAPEX

To conclude our preliminary design, a prediction of costs was made. We will start off with the expected cost of the initial construction and then move on to the expected operational costs. Since available data is limited, this will be class 5 estimation according to the AACE cost estimate classification system [62]. Typical ranges for the class 5 accuracy are on the low side -20% to -50% and +30% to +100% on the high side. Due to lack of data, only an estimation of the structural elements of the marina were done excluding infrastructure like electricity and sewage systems. All the prices are in dollars.

Pier

The pier will be made out of local stones. The surface will be 64 meters long and 2.4 meters wide, so 153.6 square meters. The height of the pier will be 5 meters on the end and will gradually decrease when it is in between the beach and the boat ramp. For a more detailed overview, see Figure 8.18. The total volume of stones needed will be 445 cubic meters. The estimated cost of this is material is $150 per cubic meter [63]. The total cost of the wall will therefore be $66.750.

Boat Ramp

The cost estimation of the boat ramp is based on the report of a ramp with very much the same sizes as ours [64]. The boat ramp of this project cost +/- $16.500, but it is slightly smaller than our ramp. Therefore we have rounded the cost estimation up to $20.000.

Piles

The marina will need a lot of wooden piles. The piles are needed to moor the boats and to keep the docks in place. The piles will each be 7 metres long and have a diameter of 20 centimetres. This will result in an average cost of about $150 per pile [65]. The total costs can be seen in Table **??**.

Floating Docks

The total area covered with floating docks will be 230 square meters, including the fingers. Using an average commercial price of $500 per square meter [66], this comes down to $115,000 total for the docks.

Floating Breakwater

The floating breakwater will be big concrete floating pontoons. An estimate using data from SF Marina [67] was made of $550 per square meter. The breakwaters will be 30 x 2.4 and 20 x 2.4. This results in a total surface of 120 square meters and total cost of $66,000.

Dredging

Dredging typically costs between 5 and 50 per cubic meter [68]. In this case, a dredging vessel is available in Bariloche and was already stationed in the marina during our site visit. The largest expenses associated with dredging generally involve rental, transportation, and operational costs. However, since the vessel was already on site and mostly non-operative during our site visit, we assume these costs to be relatively low. For this reason, we estimate a dredging cost of $ 10 per cubic meter, resulting in a total estimated cost of $30,000 for the dredging works.

Marina Wall

Typical costs for a quay with rock revetments like the one in this project are between $600 and $3000 per meter. Fortunately, the sand from the dredging can be reused as a base for this wall, saving costs. The stones for the revetments can be sourced locally as well. With this in mind $1000 per meter was used in the estimation of the total costs resulting in $90,000 for a quay of 90 meters.

Kiosk

To estimate the cost of construction of the kiosk, average prices for the construction of wooden houses are taken. These are $700 per square meter [69]. The deck has a surface of 150 square meters. Since the kiosk is only a small part of this simple terrace, therefore using the price for the construction of houses is sufficiently conservative. The total estimated costs come down to $105,000.

Marina Offices

The will be a very basic building. To estimate its construction cost the Construction Cost Index per Country [70] is used, which comes down to $1,790 per square meter. The building will be 65 square metres so the total estimated costs are $116.350.

Quay

According to a study by de Gijt [**quay**], a quay of 90 meters long and 4 meters would be $300.800. It is considered that the sand will be free since it will come from the dredging of the marina.

Table 8.9: Cost breakdown for the marina construction project in USD.

Item	Unit	Quantity	Unit Price ($)	Subtotal ($)
1. Pier				
Gabion Rock	m^3	445	150	66,750
2. Boat ramp				
Boat Ramp	-	1	$20.000	$20.000
3. Piling				
Wooden piles (7m, 20cm)	pile	99	150	14,850
4. Floating Docks				
Aluminum Floating Dock	m^2	230	500	115,000
5. Floating Breakwater				
Concrete floating breakwater	m^2	124	550	66,000
Anchoring system	unit	2	6,000	12,000
6. Dredging				
Dredging	m^3	3000	40	30,000
7. Marina Wall				
Rock Revetment	m	90	1000	90,000
8.Kiosk				
Wooden Construction	m^2	150	700	105,000
9. Marina offices				
Basic Construction	m^2	1,790	65	116,350
9. Quay				
Construction	m	3,342	90	300,800
Total				**936.750**

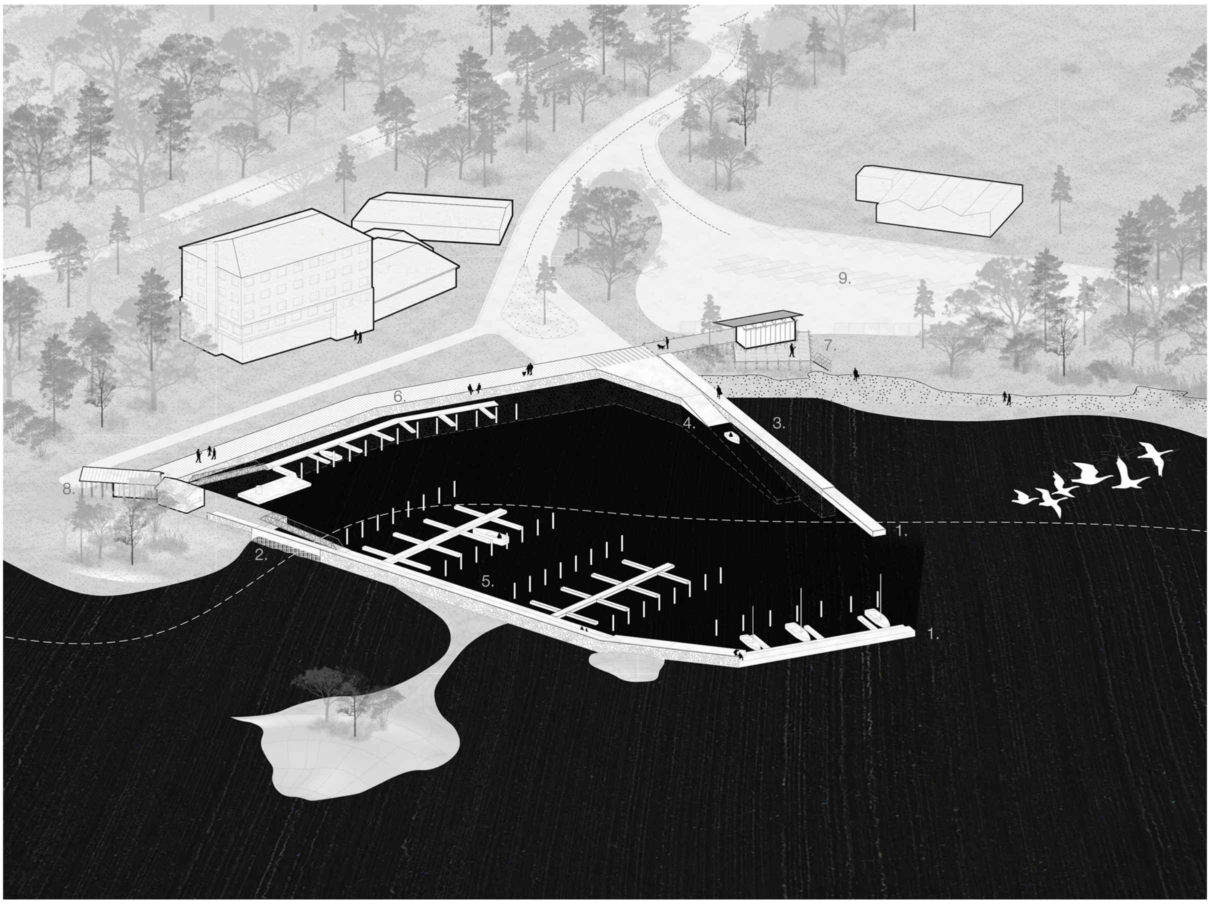


Figure 8.36: Isometric view marina

Legend:

1. Floating breakwater extensions
2. Opening in existing breakwater with wavescreen
3. Pier
4. Protected boat ramp
5. Piled double berthings with fingers
6. Hardened quay
7. Kiosk building
8. Marina entrance building
9. Parking rearrangement

9

Future Development Suggestions

As mentioned in subsection 6.2, there is still potential for improvement in the marina's future development, which could take place in Phase 2. This section outlines various facilities that could be incorporated into further expansions of the marina, along with a masterplan to visualize these additions.

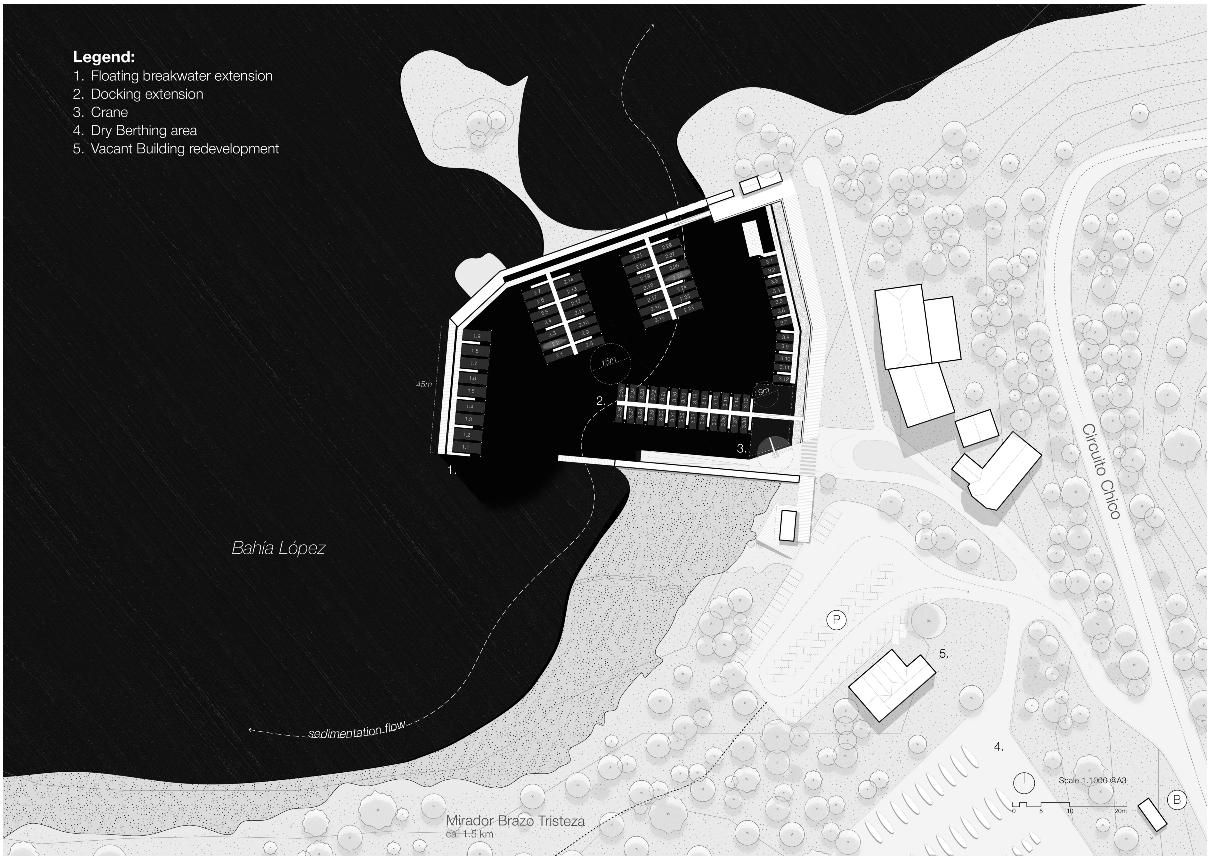


Figure 9.1: Proposed Masterplan Phase 2

9.1 Masterplan Phase 2

In the second phase of the project five significant developments can be realized to improve the marina's services and expand the marina's capacity. These developments build further upon the developments proposed in the first phase.

9.2 Expansion of Mooring Points

As visible in the masterplan above (Figure 9.1), in phase two interventions will be performed to increase the amount of mooring points. Firstly, by expanding the northern floating breakwater with prefabricated modules an additional 10m of breakwater is created. This results in the possibility to moor three new large vessels, or create multiple passenger moorings.
Secondly, by including an extra docking arm in the marina its capacity increases with 26 mooring places, maximizing the marina's useable surface area.

This demonstrates the flexibility and long-term viability of the Phase 1 design. By extending the floating breakwater and adding a new floating dock, the marina would increase its mooring spaces and, in total, allow 77 boats to berth. Further expanding the marinas capacity with 30 births.

9.3 Addition of Dry Berthing Area

Behind the vacant building is a large, underutilized grass field, that has previously functioned as a dry berthing area. This function could be re-assigned to the area, adding a significant amount of berthing spaces to the marina.

These would be particularly useful for major maintenance work or during the winter season when owners may choose to store their boats out of the water. Dry stacking also provides greater security for boat owners who are away for extended periods.
With the addition of a small boat crane next to the ramp, the boats are easily lifted out of the water and transported to the dry berthing area.

9.4 Redevelopment of Vacant Building

The building at the edge of the parking area is currently unused and in decay. It has previously served as a kiosk. There is significant potential in this building, because of its location right at the entrance of the trail towards Mirador Brazo Tristeza and its location next to the proposed dry berthing area.
Multiple suggestions are outlined below, they inlcude repurposing the existing structure and demolishing the building.

Maintenance Facility

With the development of the dry berthing area, a logical transformation would be towards a maintenance building. A dedicated workshop building could be established to support boat maintenance for marina users and boat owners. This facility would include dry-stack spaces for sanding and painting boats in an environmentally safe manner. A nautical shop could also be incorporated, where boat owners could purchase repair materials and other boating equipment.

New Dining Venue or Bar

The building could be repurposed into a restaurant with a bar, providing a space for beachgoers and marina users to enjoy meals. This concept has proven successful at places like Club Náutico, where a popular restaurant is open to the public. Additionally, there is a small hotdog kiosk located at the beginning of the trail to Cerro López, where hikers stop for a well deserved snack at the end of their day, an example of how a casual dining venue can attract visitors.

Water Sports Equipment Rental

To further enhance recreation at Bahía López, a water sports equipment rental service could be introduced. This could include small sailing boats, such as Optimists and Lasers, and could even expand into offering sailing lessons. Additionally, rentals of kayaks, SUPs, and kiteboards could be made available. This would create more reasons for people to visit Bahía López and enjoy a day at the beach. During the site visit, it became clear that this type of service is uncommon around Nahuel Huapi, which presents an excellent opportunity for implementation at Bahía López.

10

Conclusion

This report outlined the development process for a marina in Bahía López, Patagonia, presenting a preliminary design for the concessionaire of the existing marina. Background studies were conducted to evaluate environmental constraints, market conditions, and key stakeholders. Based on these studies, the design requirements were established, which led to the creation of the proposed design.

The growing trend of tourism in San Carlos de Bariloche, combined with the lack of adequate facilities for boat owners, resulting in illegal decantralized boat launching facilities. Highlighting the urgent need for a well-equipped marina in Bahía López. The research revealed several constraints that require innovative solutions for the marina's successful development. Key challenges include significant water level fluctuations and stringent regulations due to the location within a national park. APNs primary focus is to preserve the natural state of the park, limiting expansion, and minimizing environmental impact. While this is a logical approach, it presents an interesting paradox. This is captured in the design statement, outlining the design philosophy: *An intervention without interfering*. This emphasizes the need to find a balance between minimizing environmental impact, yet improving the current facilities.

While APN's concerns are valid, other stakeholders, such as the municipality, are more supportive of the marina development. The municipality is eager to see an increase in tourism in Bariloche and actively supports the development of new facilities that meet the increasing demand, including parking spaces and a boat ramp. Currently, Bahía López is one of the last remaining publicly accessible boat launching areas for local residents. Whilst this is an important function of the bay, it often disrupts beachgoers as boats are launched directly onto the beach. Therefore, a central design priority was to separate the operational area from the recreational area. The proposed design creates a clear programmatic division, by including the boat ramp inside the marina. The pier, which also serves as a scenic viewpoint, marks the division between the operational marina and the recreational beach.

The marina design in phase one accommodates 48 mooring spaces for a variety of vessel sizes, addressing the diverse needs of boat owners. One major challenge identified during the research phase was the significant sediment transport in Bahía López. The construction of a breakwater in 1929 disrupted the natural water flow, causing sand buildup and vegetation growth within the marina. To address this, the design proposes to break open a part of the existing breakwater to re-allow the natural flow through the marina. Aditionally, by extending the exisiting breakwater with a floating breakwater, the diffraction point is relocated, ensuring protected mooring conditions. A sediment trap, in the form of a wall with a basin behind it, has been incorporated to capture sediment. This will ensure that sediment accumulates in a designated area of the marina, while most of the sediment will follow the natural flow. Occasional dredging will be necessary to maintain a minimum water depth of 1.5 meter for deeper boats, and 1.0 meter for smaller boats. To enhance the experience for both marina users and beachgoers, a kiosk offering snacks and drinks has been included in the design, with a beautiful terrace overlooking both the marina and the beach.

In line with the "Working with Nature" philosophy, materials sourced from the surrounding area will be used throughout the marina. The kiosk will be constructed using local wood, and the quay wall will incorporate stones found in the region, ensuring the design blends harmoniously with the natural environment. Additionally, the design restores the natural water flow within the marina, allowing for the original sediment transport to resume.

A phase two masterplan was developed as a long-term vision for the marina. In this second phase the mooring points are increased, allowing for 77 mooring points. Additionally, a crane and dry dock are included to allow further growth of the marina. This could be combined with the redevelopment of the vacant building. This second phase demonstrates the flexibility and long-term viability of the phase one design.

This proposed marina development plan presents a thoughtful design approach that balances both the needs of the concessionaire, the local community and the environment. It proposes a design that enhances the quality of the current bay, whilst respecting the unique environmental conditions.

11 Discussion

The goal of this report was to develop a preliminary design for a marina development in Bahía López, showcasing the key components involved in such a project. While this report provides a strong foundation, several limitations were encountered that need further elaboration in future continuation of the project.

One major obstacle was the lack of available environmental data. With almost no bathymetric data (the last set from 1971), and limited topographic and hydrodynamic information, making accurate calculations was challenging. For instance, knowing the precise depth is needed to determine dredging requirements, mooring system configurations, and the types of boats the marina can accommodate. For the calculations of the wave height and the wave period wind data was used from San Carlos de Bariloche, since there was no data of Bahía López. As a result it remains difficult to make accurate determinations about breakwater positioning and structural strength.
The sediment analysis and proposed solution are grounded in both theoretical understanding and observations gathered during the site visit. While we are confident in our assessment and the proposed solution, it is important to note that the problem cannot yet be quantified with precision. Field testing will be required to determine sediment transport rates and the sedimentation rate within the marina. Additionally, flow measurements within the marina are recommended to support and validate the proposed solution of restoring water circulation.
Additionally, the market study was constrained by the absence of reliable data on boat ownership, vessel distribution, and market size. As a result, the demand for a new marina in Bahía López was mostly based on input from stakeholders and locals with some additional research. While these insights are valuable, they need to be supplemented by more concrete, quantitative data in future studies to improve the accuracy of demand projections.

Environmental regulations, particularly those enforced by APN, could pose a significant challenge. Their conservative approach to permitting means that obtaining approval could delay the development. This could affect the proposed marina design, as certain modifications to the natural environment may be met with resistance. To facilitate smoother approval, building a strong working relationship with the relevant authorities would be beneficial.

Future design stages should focus on refining the facilities with detailed technical drawings and structural analysis. This report lays the initial groundwork, with preliminary calculations that require further development. The primary focus here is the architectural design of the marina layout and the kiosk building, though the structural integrity of the kiosk has not yet been assessed and will need to be addressed in later stages. Additionally, the office building requires further design work.

The capital expenditure calculation serves as an initial estimate but contains significant uncertainty. The economic projections currently fall within a Class 5 accuracy range, meaning there is considerable room for refinement. Future work will need to incorporate more precise cost assessments and financial models.

To conclude, this report presents the first steps toward the development of a marina at Bahía López. The proposed design demonstrates the potential for a beautiful and functional marina. However, further refinement of environmental, technical, and economic data is necessary to ensure that the project progresses successfully and sustainably.

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A

Government Structure

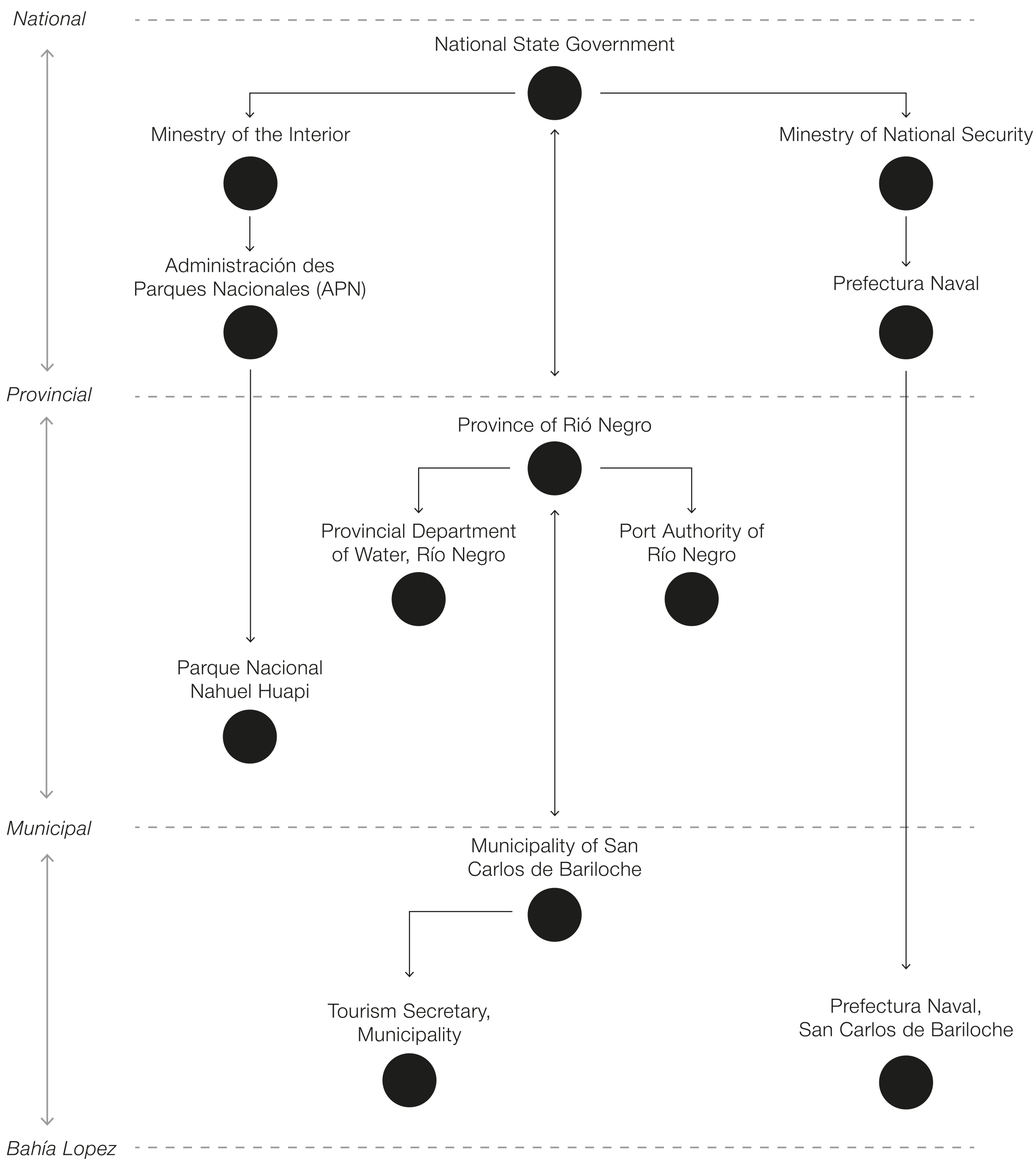


Figure A.1: Government Actors Structure

B
Interviews

B.1 Meeting with Parques Nacionales (February 19, 2025)

Attendees

- Damián Horacio Mujica, Director from Parques Nacionales
- Juan Andrés Aguirre, Parques Nacionales
- Miriam Bezic, Director Port Authority Río Negro
- Juan Bautista Antoninin, Besna
- Project Team

Role of the Director of Operations

The Director oversees 17 national parks across Argentina, from La Pampa to Tierra del Fuego. Their role includes coordinating operations, managing resources, and implementing conservation efforts to ensure the sustainable maintenance of these protected areas.

Development of the Bahía López Marina

Tourism development in Bahía López began in 2009. Initially, hotel Hotel Alun Nehuen was considered to manage the marina, but they declined the opportunity. In 2015, a private party proposed a marina project, and after several legal and bureaucratic delays, a concession was approved under Administracion Parques Nacionales in 2024.

Information on Bariloche

Bariloche receives approximately 500,000 tourists annually and has 4,000 registered boats. Historically, Puerto Pañuelo and Villa La Angostura were the only formal ports in the area. Due to the lack of proper infrastructure, unauthorized boat launches became common, posing environmental risks. A debate continues regarding whether centralized marinas or private docking areas offer the best approach. APN now supports the development of centralized marinas, as they provide better environmental control, waste management, and fuel regulation.

Jurisdiction and Regulatory Challenges

Administracion de Parques Nacionales has jurisdiction over water areas, while land access falls under municipal control. Puerto Pañuelo is entirely under APN's authority, whereas Bahía López falls under shared jurisdiction between APN and the Municipality of Bariloche. As a result, marina development must adhere to both APN's and municipal regulations. Internally, discussions continue on how to balance tourism expansion with conservation objectives.

Environmental Conservation Strategies

Any developer looking to build in the area must submit an Environmental Impact Study (EIS). Key concerns include sediment build-up and reed growth, both of which can impact water flow and the broader ecosystem. Some advocate for restricting tourism development to specific areas to protect the larger environment. Certain protected zones, such as Brazo Tristeza, Isla Victoria, and Millaqueo, already restrict boat access. Additionally, a zoning plan is being developed to regulate activities like boating, kayaking, and water sports for certain branches of the Lake.

Technical and Infrastructure Challenges

Marina development is subject to strict infrastructure limitations, with dock sizes restricted to a maximum length of 30 meters and a width of 2 meters. It would possible to construct multiple small docks instead of a single long structure (against regulations), but this has to be accepted by APN. Any future expansion will depend on demand, environmental studies, and private sector interest. Given the region's strong winds, careful design of wave breakers is essential. Furthermore, Prefectura Naval is responsible for overseeing safety and navigation; however, they do not have the authority to approve port construction.

B.2 Meeting with London Supply Group, (February 19, 2025)

Attendees

- Carlos Salgado, Manager of Puerto Pañuelo, representing London Supply Group
- Mirjam Bezic, Director Port Authority Rio Negro
- Bautista Saint Antonin, Besna
- Project Team

Operations & Management of Puerto Panuelo

Puerto Panuelo is managed under a concession from Parques Nacionales and is overseen by London Supply Group. The port handles both tourist and private boat docking while also serving as a collection point for various taxes and fees. These include entry fees to Parques Nacionales, port usage fees, and embarkation taxes. Additionally, Puerto Panuelo is responsible for environmental waste management, collecting and treating gray water, sewage, and hydrocarbon waste from boats. The marina operates a dedicated waste treatment plant, one of only four in Argentina, using a wetland filtration system. Waste disposal is managed by a nationally authorized company, which processes 9,000 liters of hydrocarbon waste at a time. Puerto Panuelo is among the few marinas in the country with a self-contained waste management system, making it a model for environmental responsibility.

Future Expansion & Infrastructure Development

Puerto Pañuelo is considered a strategic location for maritime tourism and has strong potential for further development. Planned projects include expanding marina capacity by adding more docking positions, developing boat storage facilities (*guardería náutica*), and establishing fuel supply stations for small boats. Previous attempts to obtain authorization for fuel stations were unsuccessful due to environmental restrictions. Additional improvements in waste collection, disposal, and environmental management infrastructure are also planned. However, regulatory processes pose significant challenges, as all expansion projects require approvals from multiple authorities, including Parques Nacionales, the municipality, and Prefectura Naval Argentina. Even minor projects, such as fiber-optic cable installation, have taken six months or more to receive approval due to strict environmental assessments.

Relation Between Puerto Panuelo & Bahía López

Puerto Pañuelo and Bahía López are not competitors but rather complementary ports. Bahía López could serve as a secondary port, focusing on smaller vessels and private boats, as well as excursions that cannot operate from Puerto Pañuelo due to congestion or regulatory restrictions. Puerto Pañuelo remains the primary departure point for major lake excursions, including trips to Isla Victoria, Bosque de Arrayanes, and Brazo Tristeza. However, Bahía López could accommodate new routes and activities, particularly for smaller, non-motorized water sports and excursions restricted in Puerto Pañuelo due to protected areas.

Tourism & Market Trends

The nautical tourism sector in Bariloche has grown significantly over the past 4–5 years, with an increasing number of boats and tourists seeking new services and destinations. Private marinas and new boat storage facilities are emerging, intensifying competition. There is a growing demand for improved infrastructure, including more docking space, additional restaurants, restrooms, and maintenance services, as well as guided nautical tours to enhance visitor experiences.

Challenges & Recommendations

Puerto Pañuelo and the broader marina development plans face several challenges. There is a lack of skilled labor, with a shortage of professionals trained in boat handling, maintenance, and marina operations. Regulatory complexity further complicates matters, as Parques Nacionales and other authorities impose strict environmental controls, making development projects slow and difficult to approve. Sustainable expansion is also a key concern, requiring careful planning to balance tourism growth with environmental conservation to ensure long-term ecological protection. Despite these challenges, Puerto Pañuelo remains a prime location for investment, and its expansion could improve services while maintaining high environmental standards.

Environmental & Regulatory Considerations

The current maximum dock size is 30 meters, with ongoing discussions about whether multiple 30-meter docks could be permitted. A previous request to install a fuel station for small boats was denied due to environmental concerns, though discussions on this topic continue. The marinas location exposes it to strong currents and winds, necessitating careful planning for breakwater structures and safe docking. Potential infrastructure additions include more structured docking spaces, enhanced boat service facilities, and improved visitor amenities to support the growing demand for nautical tourism in the region.

B.3 Meeting Prefectura Naval (February 20, 2025)

Attendees

- Prefectura Naval Argentina en San Carlos de Bariloche:
  - Prefecto: José Rafael Sánchez
  - Ayudante de Segunda: Pedro Alberto Salva
  - Ayudante de Tercera: Roxana Araceli Oyarzo
- Mirjam Bezic, Director Port Authority Rio Negro
- Bautista Saint Antonin, Besna

Jurisdiction & Navigation Control

The meeting covered navigation regulations and jurisdictional limits within Nahuel Huapi National Park and surrounding water bodies. The primary responsibilities discussed included regulating commercial and recreational navigation within the park, ensuring compliance with navigation safety laws and environmental policies, and coordinating efforts between Prefectura Naval, Parques Nacionales, and port operators. Specific jurisdictional aspects were discussed for key areas, such as Río Grande and other river networks defining the park boundaries, Nahuel Huapi Lake with its multiple port access points, and Lago Moreno, which falls under municipal management but remains within park limits.

Key Navigation Routes & Ports

Multiple navigation routes and ports fall under jurisdictional control. Puerto Pañuelo serves as the main commercial port, facilitating excursions to Puerto Anchorena, Isla Victoria, and other tourist destinations. Puerto Blest and Puerto Frías are significant due to their role in international crossings to Chile. Additionally, Lago Puelo and Lago Verde are important lakes that support both commercial and recreational activities. A key challenge in managing these areas is balancing commercial tourism, recreational boating, and conservation. Some locations are experiencing significant pressure from high tourist traffic, whereas others remain relatively undisturbed.

Regulatory Framework & Safety Measures

Navigation and port operations in the region are governed by Ordenanza 5/2001, which establishes safety and operational standards for docks and ports, defines permitted activities in different areas, and outlines environmental and security measures for commercial navigation. However, some ports and docks, particularly those in remote areas used for family-based or local transport services, are exempt from this regulation. There is an ongoing discussion regarding the need to standardize regulations across all ports to ensure consistency and safety.

Infrastructure & Environmental Impact Considerations

A significant factor influencing navigation in the region is the artificial connection of three lakes due to dam construction, which altered historical navigation patterns. The increase in commercial navigation and tourism has raised environmental concerns in certain areas. Discussions on infrastructure improvements centered around enhancing port facilities to support safer navigation, mitigating environmental risks associated with growing boat traffic, and assessing the long-term sustainability of commercial tourism in ecologically sensitive zones.

Challenges & Recommendations

Effective coordination between Prefectura Naval, Parques Nacionales, and municipal authorities remains a key challenge in aligning navigation and environmental policies. The increasing pressure from tourism on certain lakes highlights the need for zoning or restrictions to prevent environmental degradation. Additionally, regulatory gaps exist, as not all docks fall under Ordenanza 5/2001, leading to inconsistencies in enforcement. Infrastructure improvements, including modernization and enhanced safety measures for key ports, are necessary to accommodate the growing demand while maintaining environmental and operational standards.

B.4 Meeting with Municipalidad de Bariloche (February 20, 2025)

Attendees

- Municipalidad de Bariloche
  - Secretario de Turismo: Sergio Herrero
  - Secretaria de Planeamiento: Sofía Maggi
- Mirjam Bezic, Director Port Authority Rio Negro
- Bautista Saint Antonin, Besna
- Project Team

Ownership of Bahía López

The municipality acknowledges that Bahía López is a public space and must remain accessible to everyone. There is an existing pathway that must be maintained for public use. While the private sector invests significantly in infrastructure and services, there is concern that some private entities may attempt to limit access through physical barriers such as fences. Instances have been noted where hotels and businesses restrict entry, creating an exclusive atmosphere. To prevent privatization of common spaces, the municipality aims to take a more active role in ensuring public access. However, enforcement of these policies has been inconsistent, and certain transportation restrictions, such as limited bus routes, further complicate accessibility. Legal and institutional interventions are being considered to prevent excessive privatization while still encouraging private investment.

Policies & Land Management

The municipality is responsible for Lake Moreno, whereas the surrounding land, including road maintenance, tree cutting, and general upkeep, is managed by a separate entity. This distinction underscores the need for coordination between agencies. Currently, the only marina in the area is not in an optimal state of conservation. A new marina is necessary to support tourism and recreational activities, though strict environmental measures must be implemented to protect natural resources. Environmental risks have been highlighted by past incidents, such as a major fire caused by visitors ignoring fire safety regulations, reinforcing the need for strong control mechanisms in managing a new marina.

Similar Marina Project in San Carlos

The municipality has experience with a similar marina project in San Carlos. Initially, the proposal was not approved due to regulatory issues. However, after fulfilling all legal and environmental requirements, the project was eventually approved. Due to financial constraints, the municipality lacks the budget to build and operate the marina independently. Instead, a concession will be granted to a private entity for development and management. This experience offers valuable lessons for the Bahía López project, particularly in navigating approval processes and securing funding.

Key Considerations for Marina Design

The marina must be designed with inclusivity and accessibility in mind. It should be open to the entire community rather than serving only high-end users. Port Pañuelo serves as a negative example due to its restricted access. The lack of public-access marinas is a significant issue, making Bahía López the only marina in the region where anyone can launch a boat. The municipality is open to incorporating diverse social activities, including rowing, kayaking, stand-up paddling (SUP), and improving hiking routes. Weather conditions must also be accounted for, as strong gusts of wind and sudden temperature changes pose potential risks. Infrastructure should prioritize safety features to prevent accidents related to unpredictable natural elements.

Ownership & Public Access

In Argentina, coastal areas are public, ensuring that everyone has the right to access the marina and nearby beaches. As such, the marina cannot be privatized in a way that restricts public entry. While a nearby hotel is situated close to the marina, it does not have control over access to the beach or port. However, the hotel maintains a positive relationship with local authorities and could be a stakeholder in tourism initiatives. The municipality reinforced that the hotel cannot install gates or block public access to the area.

Tourism Growth & Environmental Sustainability

Bariloche is a major tourism hub, attracting both domestic and international visitors. The trend suggests continued growth, necessitating infrastructure expansion to accommodate increasing tourist numbers while safeguarding the environment. The key challenge is balancing tourism development with conservation efforts, particularly in fire prevention, as wildfires caused by tourists are becoming more frequent. To mitigate risks, the municipality plans to install warning signs and raise awareness about fire hazards (*Borden met vuurgevaar Fire danger warnings*). During peak season, Bariloche reaches an 80–85% hotel occupancy rate across 30,000 available accommodations. More detailed tourism statistics are available from ANAC (Administración Nacional de Aviación Civil), which monitors visitor arrivals and transportation data.

Impact of the New Marina on Tourism

The new marina is expected to provide a significant boost to tourism, mirroring the positive effects observed in the San Carlos marina project. A key benefit will be the increase in mooring points, allowing for more boating excursions and recreational activities. However, transportation infrastructure remains a concern. Currently, there is no direct boat connection across the lake, limiting transport options. A separate project aims to establish a lake-based transport system to alleviate road congestion in Bariloche. Traffic issues in Bahía López are particularly severe, with cars parking along narrow roads, restricting access. While road infrastructure is outside the scope of the marina project, its impact should be considered in future urban planning efforts.

Potential for a Ferry to Puerto Blest

Although not an immediate priority, a ferry connection to Puerto Blest could be considered in a future development phase. The current focus is on marina infrastructure and enhancing local tourism offerings. Expanding transportation options by water could help reduce road congestion and provide alternative routes for visitors in the long term.

B.5 Meeting with Club Náutico Bariloche (February 20, 2025)

Attendees

- Club Náutico Bariloche:
  - Socio: Carlos Burgoa
  - Vice Comodoro: Alejandro Fernandez
- Mirjam Bezic, Director Port Authority Rio Negro
- Bautista Saint Antonin, Besna
- Proejct Team

Role of Club Náutico in Bariloche

Club Náutico Bariloche is a private, non-commercial institution that has existed for nearly 80 years. It plays a key role in promoting recreational sailing and water sports, maintaining a strong focus on non-commercial nautical activities. The club has over 400 active members and operates exclusively under a sports and recreational framework. Over the years, its relationship with Parques Nacionales has fluctuated, sometimes facing strict regulations while at other times benefiting from policy flexibility. In the past 7–10 years, the expansion of nautical activities has led to increased demand for marina space and services.

Jurisdiction & Regulatory Challenges

The club operates under a complex mix of jurisdictional authorities. The municipality controls a narrow strip of land (3–4m) along the shore, while Parques Nacionales governs the lake and water use regulations. Additionally, provincial authorities oversee provincial water regulations. These overlapping jurisdictions often create conflicts, particularly regarding permissions for infrastructure development and marina expansions. The club holds a renewable 30-year concession from Parques Nacionales, but renewal requires strict compliance with evolving regulations.

Infrastructure & Expansion Limitations

Obtaining permits for marina expansion and infrastructure projects has been a challenge for the club. A recent dredging project took over two years to gain approval, highlighting the slow bureaucratic process. The club currently cannot accommodate larger boats (over 30 feet) due to space and equipment limitations, particularly the lack of lifting gear. Furthermore, Bariloche lacks large-scale boat repair or maintenance facilities, restricting services for bigger vessels.

Growth in Nautical Tourism & Demand for Services

The number of boats in Bariloche has grown significantly, but infrastructure development has not kept pace with this increase. The absence of a large-capacity fuel station creates operational difficulties, as the club previously had a fuel pump, but regulatory changes forced its closure. Additionally, there is no central facility for boat repairs, winter storage, or technical maintenance for larger boats. While the current facilities mainly cater to small sailboats, there is a rising demand for services catering to larger vessels.

Debate Over Private Marinas vs. Centralized Regulation

An ongoing debate exists regarding whether to allow private marinas or to centralize maritime services under regulated institutions like Club Náutico. Parques Nacionales and Prefectura Naval Argentina favor centralized control to ensure proper environmental and safety oversight. However, many private docks and moorings have already been established informally, making enforcement difficult. While the club supports centralized regulation, it also acknowledges that private property owners frequently bypass regulations to create independent docking areas.

Environmental & Safety Concerns

The lack of an official nautical chart for the lake creates navigation risks. Additionally, there is an absence of navigational aids such as buoys and channel markers, further complicating safe passage. Some areas also lack proper environmental monitoring, leading to unregulated moorings and waste disposal issues.

Lessons for Bahía López Marina Development

Bahía López presents unique challenges compared to Club Náutico Bariloche. Its smaller size and greater exposure to strong westerly winds make it less suitable for large-scale marina operations. The navigational difficulties also limit its viability as a training location for beginner sailors. A protective breakwater is essential to make the site functional for boats. Additionally, services for boats over 30 feet should be considered, given the increasing demand for larger vessel accommodations. Establishing a proper boat maintenance and repair facility would be a valuable addition, as such services are currently unavailable in Bariloche.

B.6 Meeting with Turisur (February 20, 2025)

Attendees

- Martin Baciocc, Gerente Comercialo Turi Sur
- Miriam Bezic, Director of the Port Authority, Rio Negro
- Bautista Saint Antonin, Besna
- Project Team

Turisurs Operations & Services

Turisur is one of the leading tourism companies in Northern Patagonia, specializing in nautical tourism. The company offers three main services: excursions to Isla Victoria and Bosque de Arrayanes, which rank among the most popular regional tours; trips to Puerto Blest and Lago Frías, a destination that has steadily grown over the past decade; and the Andean Crossing (Cruce Andino), an international route that connects Bariloche with Puerto Varas, Chile, through a combination of four boat crossings and three land transfers.

Interest in Bahía López Development

At present, Turisur does not view Bahía López as a relevant location for its operations. Although its proximity to Brazo Tristeza and other destinations presents an advantage, the company's existing licenses and permits are strictly tied to Puerto Pañuelo, restricting its ability to expand elsewhere. Any new concessions for tourist excursions will be controlled by Parques Nacionales, making it unlikely that Turisur will shift its operational hub. Future expansion could be considered if new government licenses become available, but there are currently no such plans.

Regulatory & Concession Constraints

Turisur operates under a government concession that grants exclusive rights to provide services from Puerto Pañuelo. This concession is set to expire in 2–3 years, at which point another company could take over operations. Since Puerto Pañuelo is owned by Parques Nacionales, relocating operations elsewhere is challenging. Given the extensive infrastructure and high capacity of Puerto Pañueloserving 300–400 passengers dailyBahía López would require significant development to match its capabilities.

Potential for Alternative Tourism Services

Although Turisur does not foresee operating from Bahía López, the company acknowledges that smaller tour operators could benefit from the area. Small boats and independent operators could run excursions from Bahía López, particularly for fishing and private charterstwo growing segments of nautical tourism. Currently, around 30 private tour boats are licensed for passenger transport, most of which operate independently from various locations on the lake. However, the lack of clear regulations and oversight for smaller operators creates unfair competition with established companies.

Growth in Nautical Tourism & Infrastructure Needs

The pandemic triggered a surge in domestic tourism, leading to a significant increase in boat ownership and lake activity. Many new boat owners relocated to Bariloche, which has intensified the demand for mooring, maintenance, and supporting infrastructure. Existing marina capacity is insufficient, resulting in long waitlists for available spaces. Additionally, there are very few properly regulated marinas, contributing to a rise in unregulated moorings.

Challenges in Boat Maintenance & Infrastructure

One of the most pressing challenges in Bariloches nautical sector is the lack of a proper boat maintenance facility. There is no dedicated dry dock for large vessels, making maintenance tasks difficult. The only existing dry dock, which is owned by Parques Nacionales, is in poor condition and not fully operational. Turisur also struggles to find skilled labor for boat repairs, often having to bring in workers from Buenos Aires for specialized maintenance. Larger boats (over 15 meters) have difficulty accessing services, as local infrastructure is mainly designed for smaller vessels. Regulations require periodic inspections, yet the absence of proper dry docking facilities complicates compliance.

Lessons for Bahía López Marina Development

Bahía López could serve as a hub for small independent operators rather than large-scale tour companies. Establishing a well-maintained dry dock or boatyard would be a valuable addition to the region. Wind conditions and environmental factors must be taken into account, as Bahía López is highly exposed to strong westerly winds. Additionally, a regulatory framework should be developed to prevent unregulated boat launches and moorings, ensuring sustainable and organized marina operations.

B.7 Meeting with Concessionaire (February 21, 2025)

Attendees

- Federico Coulin, Concessionaire
- Bautista Saint Antonin, Besna
- Project Team

Location and Strategic Importance of Bahía López

Bahía López serves as an ideal launching point for exploring the branches of Lake Nahuel Huapi. Its natural setting makes it a suitable site for recreational boating and marina operations.

Environmental & Operational Challenges

Water level variations are a significant challenge due to fluctuations primarily caused by rainfall and snowmelt, with levels varying by approximately $\pm 2.5m$. The high-water season occurs between June and September, while summer, which coincides with low tide, is the peak demand period. To maintain functionality during peak usage, the marina must ensure a minimum depth of 1m for boat access.
Wind and current conditions add another layer of complexity. Strong winds blowing frontally into the bay create difficult docking conditions, particularly for larger boats. The valleys wind tunnel effect exacerbates the challenge, requiring boats to dock facing the wind for better stability. Additionally, the current within Bahía López moves in the opposite direction of the wind, further complicating maneuvering.
Sedimentation is an ongoing issue caused by wind-driven currents and the breakwaters positioning, which channels sediment into the marina. Regular maintenance dredging is required to ensure navigability, and a sustainable system to maintain water depth year-round is a key challenge.

Marina Infrastructure & Expansion Plans

The current docking facilities consist of temporary test structures, with plans to establish three floating docks terminating at wooden poles. Initially, the concessionaire proposed an alternative layout with 51 mooring points, but this was declined by Parques Nacionales. The recently approved plan permits 31 mooring points; however, the layout remains suboptimal. The main challenges include developing a more operationally efficient docking layout and finding ways to accommodate more boats while maintaining safety and accessibility.
The breakwater, originally constructed in 1929 from stone and concrete, plays a crucial role in protecting the marina. The concessionaire intends to widen it to approximately 1400mm to enhance accessibility. However, sediment accumulation on the northern side, caused by wind and current patterns, requires careful evaluation. A key consideration is whether expanding the breakwater further would improve conditions or exacerbate sedimentation issues.

Entrance & Access Control

The marina will be divided into two distinct areas: an operational area and a recreational area. The operational area will serve boats and marina visitors, with designated office spaces for Prefectura, APN, and the concessionaire. Visitors will be required to pay for access to this section, and boat ramp usage will be subject to fees based on the concessionaires plans. The recreational area, in contrast, will cater to beachgoers and hotel guests. A major challenge is ensuring clear separation between these areas to avoid conflicts in usage.

Planned Facilities & Services

The proposed marina development includes essential facilities and services to improve functionality and user experience. These include office spaces for APN, the concessionaire, and Prefectura; a kiosk limited to heating pre-prepared food; a terrace area for visitors; sanitary amenities; a gas refueling station for boats; a boat ramp for launching and retrieval; and a parking area to accommodate marina users. These enhancements aim to improve the operational efficiency of Bahía López while balancing recreational and commercial use.

B.8 Meeting with Hotel Alun Nehuen (February 21, 2025)

Attendees

- Domingo Ollarzo, Hotel Alun Nehuen Manager
- Bautista Saint Antonin, BESNA
- Project Team

Hotels Perspective on Bahía López Development

The hotel manager is supportive of the marina development and views it as a valuable addition to the region. The project is seen as an opportunity to enhance the overall experience of hotel guests by offering high-quality services and better access to water-based recreational activities.

Collaboration with the Concessionaire

There is a strong cooperative relationship between the hotel and the marina concessionaire. Most users of the marina services are hotel guests, making it a shared interest for both parties. The hotel manager does not view the introduction of an eatery, kiosk, or food truck as competition but rather as a complementary service that could improve visitor satisfaction.

Infrastructure & Utility Considerations

The hotel is open to integrating the marinas sewage system with its own for a small fee, though the details of this arrangement need to be worked out at a later stage. The manager believes that all additional marina services will contribute to enhancing the hotels appeal and service quality. Suggested infrastructure improvements include expanding parking facilities, better organization of the beach area, and improving the boat ramp to facilitate easier access for guests and marina users.

Hotel Occupancy & Facilities

Peak occupancy at the hotel occurs during the summer months, with approximately 90% of its 130-room capacity filled. The hotel currently has 30 parking spaces and does not see an immediate need for expansion, though future demand may warrant reconsideration. The overall expectation is that the marina project will improve the quality of available services and further attract visitors to the area.

C

Bathymetry

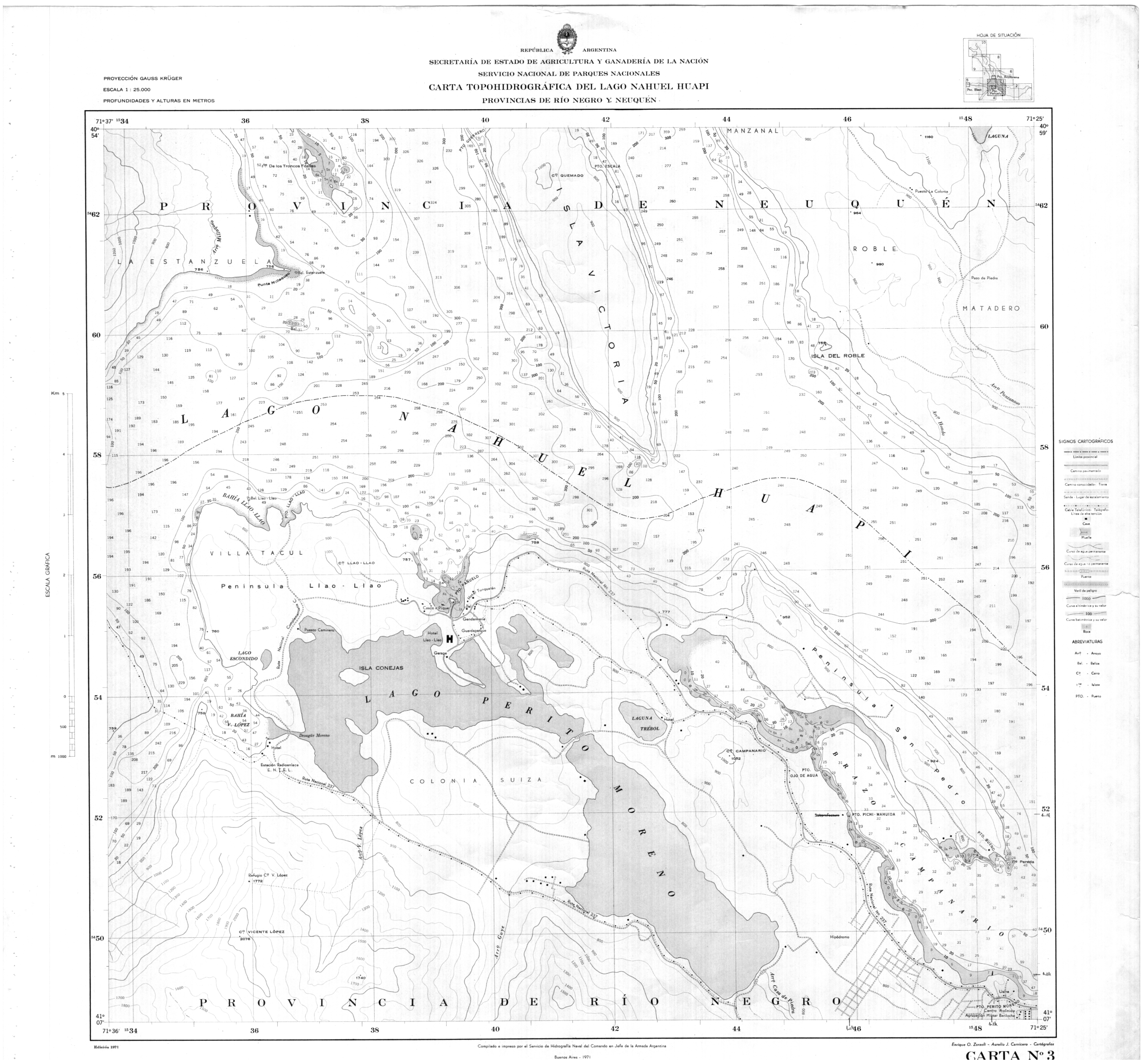


Figure C.1: Bathymetry Lago Nahuel Huapi, Servicio Nacional de Parques Nacionales (1971)

D

Additional research

D.1 Types of Mooring systems

Criteria for Selecting Mooring Systems

The following criteria are set up using PIANC Mooring systems for recreational craft (2002) [71].

1. **Water Depth & Bottom Conditions**
   The selection of a mooring system depends on whether the water is deep or shallow. Additionally, the seabed typewhether sand, mud, or rockaffects the effectiveness of anchoring solutions.

   For the marina in Bahía Lopez, there has to be accounted for the fact that that there is are predominant Anidsols and plutonic rocks present, which provide a reasonable stable foundation, as discussed in subsection 3.4. The water depth of the marina is considered to be shallow.

2. **Environmental Factors**
   Wind, waves, and currents play a crucial role in determining the stability of a mooring system. Seasonal variations in water levels, especially in lakes, must also be taken into account.

   The current layout of the marina with the breakwater provides shelter to waves, boats in the marina are still influenced by winds. The waterlevel fluctuations pose a challenge as the mooirng systems has to be operable under varying waterlevels.

3. **Boat Size & Type**
   The weight and length of the vessel influence the forces exerted on the mooring. Displacement hulls and planing hulls may require different mooring solutions to ensure security.

   Three different sizes of mooring spaces are accounted for in the marina: 10m $\times$ 3.5m, 10m $\times$ 2.5m and 8m $\times$ 2.5m.

4. **Mooring Load & Holding Capacity**
   The tensile strength of chains, ropes, and anchors must be sufficient to handle environmental forces. The system should be able to withstand storm surges and high winds without failure.

5. **Accessibility & Ease of Use**
   Mooring should allow for convenient docking and undocking of the vessel. In cases where buoy moorings are used, dinghy access may be necessary.

6. **Maintenance & Durability**
   The lifespan of mooring components depends on material quality. Corrosion resistance, such as using galvanized or stainless steel materials, is critical for long-term reliability.

7. **Cost & Installation Complexity**
   The initial investment and ongoing maintenance costs should be considered. Some systems may require professional installation, while others offer simpler, do-it-yourself setups.

8. **Regulatory & Environmental Considerations**
   Mooring systems must comply with local harbor or lake regulations. Additionally, environmental impact should be minimized to protect marine ecosystems and sensitive habitats.

Table D.1: Mooring Types for Lakes [71]

Mooring Type	Description	Pros and Cons
Anchorages	Suitable where water depth allows anchoring within a boats capability.	**Pros:** Inexpensive, flexible for different locations. **Cons:** Less secure in strong currents or winds.
Buoyed Moorings	Provides mooring facilities in deeper water beyond the reach of boat anchors.	**Pros:** Allows mooring in deeper water, easy access. **Cons:** Requires regular maintenance, limited protection from waves.
Pile Moorings	Effective in shallow water where piles can be driven into the lakebed.	**Pros:** Strong and stable, suitable for various boat sizes. **Cons:** Expensive installation, not suitable for deep water.
Pontoons	Floating mooring structures that may require shelter for stability.	**Pros:** Adaptable to changing water levels, user-friendly. **Cons:** Can be costly, needs anchoring for stability.
Drying Berths	Not suitable for lakes due to the absence of tidal movement for drying.	**Pros:** Works well in tidal environments. **Cons:** Ineffective in non-tidal lakes, limited access when dry.
Jetties & Stagings	Commonly used in shallower fringes as fixed structures for mooring.	**Pros:** Stable access for boarding, long-lasting structures. **Cons:** High construction costs, can be affected by strong currents.
Marina Berths	Designed docking areas in marinas, providing structured and secure berths.	**Pros:** Highly secure, provides additional services (e.g., fuel, power). **Cons:** Expensive berthing fees, limited availability.
Dry Stacking	A widely used method for boat storage on land, reducing maintenance.	**Pros:** Protects boats from water exposure, reduces maintenance. **Cons:** Requires lifting equipment, not suitable for quick access to water.
Stern to Pier (Mediterranean)	Common method where boats moor stern-first, often alongside pontoons or fixed jetties.	**Pros:** Efficient use of space, easy to tie up. **Cons:** Requires anchors or mooring lines, may be difficult in rough conditions.
Linear Mooring	Subject to land ownership rights and the suitability of the bank for mooring.	**Pros:** Simple and low-cost. **Cons:** Exposure to weather, limited accessibility.

For the marina at Bahía López, the following mooring options, shown in Figure D.1 through Figure D.4, are considered relevant based on local environmental conditions and operational requirements, such as water levels and wind conditions.

- Piled moorings provide a stable and secure mooring option, particularly in shallow waters. The structure consists of vertical piles driven into the lakebed, allowing boats to be secured between them. This type of mooring offers high durability and resistance to water movement, making it suitable for long-term berthing in areas with moderate wave activity.

Figure D.1: Piled Moorings [54]

- Berthing moorings are fixed docking spaces within the marina, typically using floating or fixed docks. These moorings provide convenience and security for recreational vessels, offering facilities such as walkway access, power supply, and water services. They are particularly well-suited for frequent users who require stable and accessible docking.

Figure D.2: Berthing mooring [72]

- Pontoons are floating platforms secured with anchor systems or pilings, allowing for adaptability to water level changes. They provide flexible berthing solutions, accommodating a variety of boat sizes. Pontoons are ideal for dynamic marina environments, as they allow for easy adjustments and minimize impact from fluctuating water levels.

Figure D.3: Pontoon mooring [73]

- Buoyed moorings consist of floating buoys anchored to the lakebed, offering a cost-effective alternative to fixed structures. They are particularly useful for deeper waters where other mooring solutions may not be feasible. This would be a very interesting option, as these moorings are less intrusive to the environment and provide a safe holding point for boats. As the limits of the concession do not reach further up the lake this will not be feasible.

Figure D.4: Buoyed mooring [74]

D.2 Types of Floating Breakwaters

The design of floating breakwaters has evolved over time, with various types being developed to address specific needs and challenges. Each type of floating breakwater operates on different principles of wave attenuation, including reflection, energy dissipation, and drag forces. Some designs are better suited for moderate wave conditions, while others are tailored for environments with more severe wave action. The choice of breakwater depends on factors such as environmental impact, installation ease, cost, and the specific wave conditions at the location. Table D.2 gives an overview of the main types of floating breakwaters, their characteristics and the advantages they offer.

Table D.2: Types of Floating Breakwaters [75]

Breakwater Type	Description	Pros and Cons
Box-Type	A simple, prismatic rectangular shape, often made of concrete or other durable materials. It primarily attenuates waves through reflection.	**Pros:** Easy to design and construct, cost-effective and performs well in moderate wave conditions. Also has a simple geometry, making it easy to predict its performance. **Cons:** Requires a sufficient width (usually greater than one-third of the wave length) for effective wave attenuation, and can become less effective for very long waves.
Pontoon-Type	Composed of two or more pontoons connected by a rigid deck, sometimes in a catamaran configuration.	**Pros:** Provides increased inertia and stability without significantly adding to the weight. Effective at attenuating moderate to long waves. **Cons:** Requires more space compared to box-type breakwaters, leading to higher construction costs.
Frame-Type	A combination of pontoons and frames. Attenuates through both reflection by pontoons as well as turbulence and disturbance by frames.	**Pros:** Effective at wave attenuation through multiple mechanisms. **Cons:** More complex and expensive to construct. Also may require more maintenance compared to simpler designs.
Mat-Type	Often made from recycled materials like scrap tires, arranged in large mats that dissipate wave energy through friction and disturbance of wave particle orbits.	**Pros:** Cost-effective, environmentally friendly, and easy to construct with unskilled labor. **Cons:** Design requires the width to be in the same order of the incoming wave length, resulting in a large footprint in order to reduce the height of long waves. Also, it may suffer from material degradation in harsh marine environments.
Tethered Float-Type	Consists of multiple floaters tethered to the seabed, moving like inverted pendulums under wave action. The primary wave attenuation mechanism is drag caused by the buoy motion.	**Pros:**Effective for broadband wave attenuation and can be tailored to meet specific performance requirements. **Cons:** Design requires careful consideration of mooring lines and their maintenance, especially in severe conditions where mooring forces can be high.
Horizontal Plate-Type	Floating horizontal plates that attenuate waves by suppressing vertical motion and breaking waves through collision with the plate.	**Pros:** Effective for reducing wave transmission, especially for larger waves. **Cons:** Requires large dimensions to be effective, which increases the footprint and can complicate installation.

D.3 Types of floating docks

There are 3 main types of positioning systems for floating docks: Pile driven, chain-anchor and shore brooms. The following research is focused on selecting the best option for our marina in Bahia Lopez. Figure D.5 shows the difference between these types.

D.3.1 Pile driven

In this option, the floating dock is held in place by piles located along the dock. The dock is able to slide up and down these piles. Pile driven floating docks are considered to offer the greatest stability in terms of lateral movement. [76] This makes them very resilient against strong winds and currents. A big limitation is water depth, they are not feasible for marinas that are very deep. However, they do allow for quite some fluctuation. Other limitations are environmental impact and possibly soil. As they must be driven into the ground they have a significant environmental impact and the ground should be suitable.

D.3.2 Anchor and chain

In this option, the floating dock is held in place by anchors on the bottom of the water body. They offer mediocre lateral support and are not very resilient to harsh environmental conditions, but have a small environmental impact and are less expensive to install than pile driven floating docks.

D.3.3 Shore Brooms

In this option, the docks are held in place by arms coming from the shore. As this option typically does not allow for the seasonal water level changes in our marina, this option is disregarded.

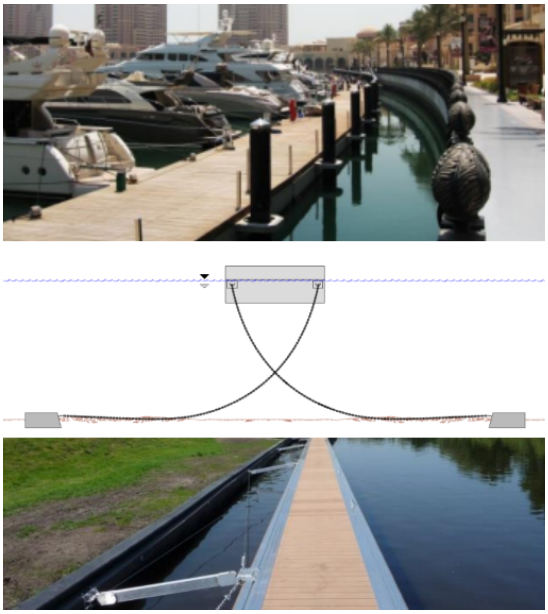


Figure D.5: Pile driven, anchor and chain and shore broom floating docks [31]

D.3.4 Conclusion

In the end, the pile driven solution for floating docks was selected to implement in our design. They offer the best support against the strong winds in the Bahia, allow for the seasonal water level changes and since there are already piles in place that can be used, there is little additional environmental impact.

D.3.5 Material

Material	Applications	Water Conditions	Benefits	Drawbacks	Average Cost	Upkeep Requirements	Durability (out of 10)	Environmental Considerations	Safety Hazards
Aluminum	Residential, Industrial, Light Commercial, Industrial	Fresh & saltwater (aluminum will oxidize over time in saltwater)	Lightweight, Durable, Comfortable, Maintenance Free	May oxidize in saltwater	$$	Minimal buffing & scrubbing w/ soap & water	9/10	Pile driven docks may disrupt sediment	Can overheat in direct sun w/out decking ventilation
Plastic	Residential, Industrial, Light Commercial, Industrial	Fresh & saltwater	Lightweight, durable, comfortable, Maintenance Free	None notable	$$	Scrubbing w/ soap & water	9/10	Recyclable; not 100% ice-resistant	None notable
Wood	Residential, Marina	Fresh & saltwater	Durable (if treated)	Heavy, Environmental impact, Splinters	$	Sanding, Sealing, Replacing rotted boards	6/10	Pressure-treated wood can contaminate waterways; pile driven docks may disrupt sediment	Splinters
Steel	Commercial, Industrial	Fresh & saltwater; rough waters	Durable, Strength	Heavy, Corrosive	$	Corrosive	8/10	Pile driven docks may disrupt sediment	Can overheat in direct sun w/out decking ventilation
Composite Decking	Residential, Marina, Public access	Fresh & saltwater	Durable, Comfortable	None notable	$$	Scrubbing w/ soap & water	8/10	None notable	None notable
Concrete	Commercial, Industrial	Fresh & saltwater; rough waters	Durable, Strength	Disruptive to environment	$$$	Power-washing	10/10	Can disrupt water flow, affect wildlife; withstands storms & choppy waters	Extremely hard surface

Figure D.6: Comparison of materials for floating docks

E

Mooring Line Configuration

The shape of a catenary mooring line is determined by integrating the slope of the line following from Schreier (2024) [77], which is given by Equation 15:

$$\frac{dz}{dx} = \sinh\left(\frac{w}{F_x}x\right) \tag{15}$$

To obtain the shape of the line, the equation is integrated with respect to x from 0 to x, resulting in the following expression for the vertical position z:

$$z(x) = \int_0^x \sinh\left(\frac{w}{F_x}x'\right)dx' = \frac{F_x}{w}\left(\cosh\left(\frac{w}{F_x}x\right) - 1\right) \tag{16}$$

Where:

- F_x : Horizontal force acting on the mooring line (N)
- w : Weight per unit length of the mooring line (N/m)
- x : Horizontal distance along the mooring line (m)
- $z(x)$: Vertical position of the mooring line at distance x (m)

This equation describes the shape of the mooring line, starting from the touch-down point at $x = 0$, where $z = 0$, and moving to its position $z(x)$. The equation can be applied to varying conditions,

such as the water level height h, and is commonly used for catenary mooring systems, which adjust to different wave heights and water depths.
At a specific waterline height, for example, when $h = 40\,m$, the equation can describe the mooring line's position at the water surface, taking into account both the buoyancy and weight of the mooring line in its shape.
The maximum distance x_{max} is reached when the mooring line arrives at the waterline $z = h$. Therefore, the relationship is given by:

$$h = \frac{F_x}{w}\left(\cosh\left(\frac{w}{F_x}x_{\text{max}}\right) - 1\right) \tag{17}$$

Using arccosh() as the inverse of cosh(), the maximum horizontal distance x_{max} from the touch-down point is calculated as a function of water depth h, line weight in water w, and horizontal force F_x:

$$x_{\text{max}} = \frac{F_x}{w}\,\text{arccosh}\left(\frac{hw}{F_x} + 1\right) \tag{18}$$

Where:

- x_{max} : Maximum horizontal distance from the touch-down point to the waterline (m)
- h : Water depth at the waterline (m)

The distance x_{max} describes how far the mooring line extends horizontally from the anchor to the point where the line meets the waterline. This is crucial for determining the positioning and tension of the mooring system based on varying wave heights and water depths.
With the requirement that there must not be a vertical force on the anchor, there should always be some length of mooring line (in this case mostly mooring chain) resting on the seabed. Thus only a portion of the total line length S_{tot} is suspended above the ground. Let us call the part of the line on the bottom S_0 and the suspended part S.
Then the total length becomes:

$$S_{\text{tot}} = S_0 + S \tag{19}$$

The total length is fixed and specified, for example, in the mooring design. The suspended length can be calculated by solving the integral from $x = 0$ to $x = x_{\text{max}}$:

$$S = \int_0^{x_{\text{max}}} \sqrt{1 + \left(\frac{dz}{dx}\right)^2}\,dx = \frac{F_x}{w}\int_0^{x_{\text{max}}} \sinh\left(\frac{w}{F_x}x\right)dx \tag{20}$$

Where:

- F_x : Horizontal force acting on the mooring line (N)
- w : Weight per unit length of the mooring line (N/m)
- x_{max} : Maximum horizontal distance from the touch-down point to the waterline (m)

So the horizontal distance x_{tot} between the anchor and the fairlead on the ship becomes:

$$x_{\text{tot}} = S_{\text{tot}} - S + x_{\text{max}} \tag{21}$$

Where:

- x_{tot} : Total horizontal distance between the anchor and the fairlead on the ship (m)
- x_{max} : Maximum horizontal distance from the touch-down point (m)

This equation accounts for the total mooring line length, the suspended portion, and the horizontal extension to the fairlead, helping define the mooring system's overall layout and tension.
The force on the mooring line increases from $F = F_x$ at the bottom to the maximum force at the fairlead of the floater.
At the fairlead, the horizontal force F_x is still the same as at the bottom. The vertical force $F_{z,\text{max}} = F_z(x_{\text{max}})$ at the fairlead is equal to the total weight in water of the suspended line.

$$F_{z,\max} = wS = F_x \sinh\left(\frac{w}{F_x} x_{\max}\right) = F_x \sinh\left(\operatorname{arccosh}\left(\frac{hw}{F_x} + 1\right)\right) \tag{22}$$

Then the line tension F_t is calculated by combining F_x and $F_{z,\max}$:

$$F_t := \sqrt{F_x^2 + F_{z,\max}^2} \tag{23}$$

The equations above are used to model the required length and weight of the mooring lines to keep the floating breakwater in position under the various conditions discussed earlier. Additionally, they help model the horizontal x-position of the breakwater and determine the tension in the mooringline (F_t) under different conditions and varying water depths.

The Python code where this model is applied can be found in subsection J.3 and the plots the shape of the mooring line can be found in Figure 8.6 and Figure 8.7.

F

Regulatory Framework APN

F.1 Regulations

F.1.1 Required Documentation for Permit

Any construction within a national park requires prior approval from Parques Nacionales. The level of approval depends on the type and scale of the project. As the development of a marina involves substantial modifications, it falls under *Project Type 1 regulations* (Anexo V - Tipologia de proyectos, 2023) [35]. The following documentation is required for permit approval:

- **Proof of ownership**, such as a land title, lease agreement, or use permit.
- **Professional registration** of all architects, engineers, and contractors involved.
- **Design and technical plans**, including:
  - Site layout and topography.
  - Architectural plans (floor plans, elevations, sections).
  - Structural details and sanitary system designs.
- **Environmental Impact Assessment (EIA)**, determining potential ecological impacts and necessary mitigation measures.
- **Construction license application form**, signed by the owner and professionals responsible for the project.
- **Payment of permit fees** to obtain official approval from APN.

For specific marina elements such as ramps, docks and dredging activities for instance, additional approval is required. These approvals again involve the submission of architectural plans, an environmental impact analysis, bathymetric and topographic details, structural specifications, and liability insurance. Any existing unauthorized structures must undergo a regularization process through APN.

F.1.2 Environmental Regulations & Mitigation Measures

To conserve the natural environment, all construction within national parks must comply with APNs environmental regulations. These regulations aim to minimize the ecological impact of development and ensure the long-term conservation of protected areas.
A key requirement is the implementation of mitigation measures throughout the planning, construction, and operational phases. These measures include:

- **Minimizing land disruption** and preserving natural vegetation to reduce soil erosion and habitat loss.
- **Preventing water contamination** through effective wastewater treatment systems and fuel containment measures.
- **Controlling noise and disturbances** by restricting construction hours and implementing measures to protect wildlife.

- **Ensuring fire safety and risk prevention**, including the installation of fire suppression systems and proper storage of hazardous materials such as fuels.
- **Restoring the site post-construction** through landscaping with native species and erosion control strategies.

In addition to these mitigation measures, APN requires all projects within national parks to undergo an Environmental Impact Assessment (EIA) in accordance with (Anexo I - Reglamento de Evaluación de Impacto Ambiental [78]). The level of assessment depends on the project's scale and potential environmental impact, which APN classifies into four categories:

- **Type 1 (High Impact)** Requires a full **Environmental Impact Study (EsIA)**, including comprehensive risk assessments, mitigation strategies, and public consultation. This applies to *large-scale marina infrastructure*, such as new docks, major port developments, and projects involving dredging or significant land modification.
- **Type 2 (Medium Impact)** Requires an **Environmental Impact Report (IIA)**, which is a simplified evaluation focusing on specific environmental concerns. Medium-scale marina expansions or modifications that do not significantly alter natural ecosystems may fall under this category.
- **Type 3 (Low Impact)** Requires an **Environmental Report (IMA)**, a basic review process applicable to small-scale projects with minimal environmental impact.
- **Type 4 (Minimal Impact)** Exempt from formal environmental assessments. Only projects explicitly listed in **Annex IV of the regulation** qualify for this exemption.

Given the scale and nature of the marina development, the project is expected to be classified as either Type 1 requiring a full EsIA before APN approval.
Not following these environmental regulations can result in permit delays, legal penalties, or project suspension. Regular APN inspections will be conducted during construction and operation to ensure compliance with approved mitigation measures.

F.1.3 Detailed requirements EsIA

Section	Description
	Project Description
General Overview	Purpose, objectives, and justification of the project.
Location Details	Maps with precise geographic coordinates, land and water use classification.
Technical Specifications	Design, construction materials, size, and operational requirements.
Timeline	Construction, implementation, and operational phases.
	Legal and Regulatory Framework
Compliance with APN regulations	Compliance with national environmental laws.
Relevant Permits	Required from federal, provincial, and municipal authorities.
International Environmental Agreements	If applicable.
	Environmental Baseline Study
Physical Environment	
Hydrology	Water movement, sediment transport, and water table effects.
Water Quality	Chemical and biological composition, pollution risks.
Climate Conditions	Wind patterns, temperature variations, seasonal impacts.
Soil and Geological Stability	Risk of erosion, landslides, and land subsidence.
Biological Environment	
Flora and Fauna	Identification of species, presence of endangered or protected species.
Ecosystem Sensitivity	Impact on aquatic and terrestrial biodiversity.
Habitat Disturbance	Effects of dredging, construction, and operational activities.
	Socio-Cultural Environment
Local Communities and Indigenous Groups	Potential displacement, economic impact, social concerns.
Cultural Heritage	Presence of historical or archaeological sites.
Existing Tourism and Recreational Activities	Compatibility with sustainable tourism policies.
	Environmental Impact Assessment
Pollution risks	Potential contamination from fuel spills, sewage, and solid waste.
Habitat alteration	Destruction of natural habitats, vegetation removal, marine life disruption.
Noise and light pollution	Effects on wildlife and nearby communities.
Traffic impact	Increase in boat and vehicle activity affecting environmental stability.
Impact on protected species	Displacement or endangerment of flora and fauna.
	Mitigation Measures
Waste and sewage management	Proper disposal and treatment of solid and liquid waste.
Spill prevention and emergency response plan	Procedures for handling fuel and chemical leaks.
Biodiversity conservation strategies	Relocation of species, habitat restoration, protective barriers.
Noise and light reduction	Use of eco-friendly lighting and soundproofing methods.
Erosion control	Strategies to prevent land degradation and water contamination.
	Plan de Gestión Ambiental (PGA) Environmental Management Plan
	Continuous environmental monitoring protocols
	Compliance measures for sustainable operation
	Emergency response mechanisms Long-term conservation strategies
	Public Consultation and Stakeholder Engagement

Meetings with affected communities and stakeholders
Documentation of public objections and adjustments made to the project

F.1.4 Permit Approval Process

The approval process consists of multiple stages to ensure compliance with legal, environmental, and technical requirements.
Before submitting a full permit application, preliminary verification is required. Developers must provide proof of land ownership, a conceptual design, and an initial environmental evaluation. APN reviews the submission and determines whether a full Environmental Impact Assessment is necessary.

Once preliminary verification is approved, developers must submit a full set of technical and legal documents. This includes detailed architectural, structural, and engineering plans, as well as the final EIA with mitigation measures if applicable. APN evaluates the project to ensure it aligns with conservation policies, environmental regulations, and legal requirements. If modifications are required, they must be addressed before the final permit is granted.

If the project receives approval, the developer must pay the required permit fees. Only after this payment is received does APN issue the official construction permit.

Before work can begin, APN and Prefectura conduct a final site inspection to confirm compliance with the approved plans. Environmental protection measures must be in place, and all contractors must be registered. Once these conditions are met, APN grants formal authorization to begin construction.

During construction, APN conducts regular inspections to ensure compliance with permit conditions. These inspections verify that the project follows approved designs and meets environmental and safety requirements. If non-compliance is detected, APN has the authority to impose penalties, halt construction, or mandate corrective actions.

F.1.5 Relevance to the Marina Development

Since the marina project involves significant alterations to land and water areas, it is subject to strict regulatory oversight. Compliance with APNs permit approval process is essential for obtaining construction authorization and ensuring that the development aligns with national park conservation and environmental standards. The approval process also serves to mitigate any potential negative impacts on the natural environment, ensuring that the marina operates within the legal framework of protected areas.

F.2 Regulations for specific facilities Resolución 773 / 2023

Parques Nacionales has specific regulations about maritime infrastructure, here an overview of the important regulations is shown [8].

- Docks:
  - Docks should allow water flow underneath, so no concrete walls.
  - Maximum dock length: 30 m .
  - Maximum dock width: 2 m.
  - Minimal end-of-dock depth: 1.5 m.
  - Docks can be fixed or floating.
  - Floating dock is accessible via gangway.
  - L or T shapes cannot extend more than 5 m on each side.
  - Allowed materials: Wood, polymers, concrete, or metal (must be specified in the project)
  - Fenders must be made of PVC, GRP, or rubber (not car tires)
  - No warehouses, sheds, or fuel storage allowed on docks

- Boat ramp:
  - Maximum slope of 15%.
  - Must reach historical water levels, both low and high.

The Available Mooring Area (AAD) is determined based on three key factors as outlined in Article 11.2.5 of Resolution 773/2023. These factors define the space within which mooring can take place while considering environmental and operational constraints.

- **Environmental impact and service availability**, which modify the effective usable space.

Definition of the Available Mooring Area (AAD)

The AAD is calculated using:

- Shoreline frontage of the lot (or combined lots if multiple owners apply jointly).
- Water depth range:
  - Minimum depth: 0.5 meters
  - Maximum depth: 5 meters

Effectiveness Factors (Factores de Eficiencia)

The Effective Mooring Area (AEA), or the area that is allowed to be used for mooring spaces, is derived from the AAD by applying specific effectiveness factors based on the marina's services:

$$AEA = AAD \times Fe \times Fs \times Fc \times Fms \tag{24}$$

Where:

- Fe (Effluent Treatment Factor)
  - $Fe = 1$ if the marina has wastewater discharge and treatment services
  - $Fe = 0.5$ if there is no wastewater treatment
- Fs (Bilge Water Disposal Factor)
  - $Fs = 1$ if the marina provides bilge water disposal
  - $Fs = 0.5$ if there is no bilge disposal system
- Fc (Fueling Services Factor)
  - $Fc = 1$ if the marina provides fuel loading services
  - $Fc = 0.5$ if no fuel services are available
- Fms (Dry Marina Factor)
  - $Fms = 1$ if a dry marina is available
  - $Fms = 0.5$ if no dry marina is present

Action Project Executor

Explanation action Project Executor

Action Administración de Parques Nacionales

Explanation action Administración de Parques Nacionales

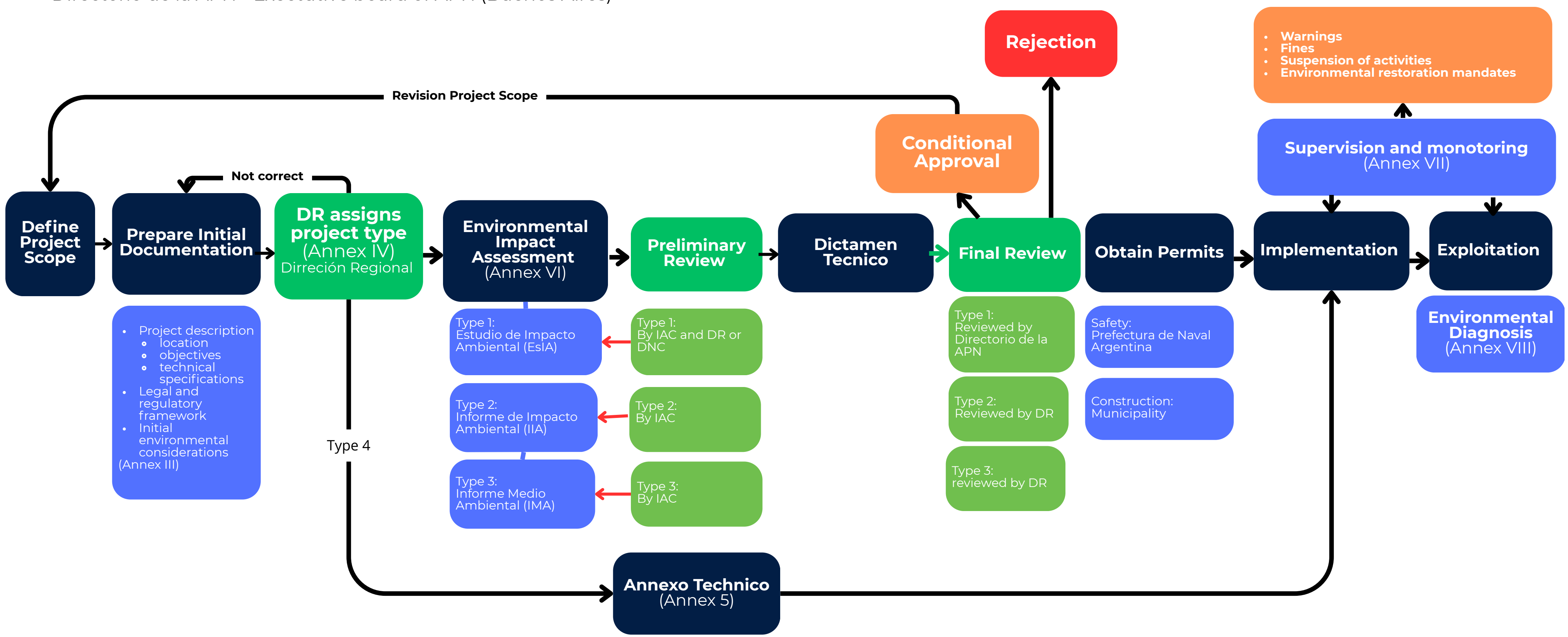
Bodies of APN:

Intendencia del AC (IAC) - local park administration

Dirreción Regional (DR) - Local authority Parques Nacionales

Dirección Nacional de Conservación (DNC) - National Directorate of Conservation (Buenos Aires)

Directorio de la APN - Exectutive board of APN (Buenos Aires)



G

Multi Criteria Concept Selection

Table G.1: Morphological Chart

Element				
Breakwater	Reuse Existing	Reuse and extend existing	Demolish and re-build	Additional (floating) breakwater
Boat launching	Ramp (Beach)	Ramp (begin breakwater North)	Ramp (breakwater South)	Crane
Sediment control	Maintenance Dredging	Breakwater South (littoral drift)	Breakwater North (move diffraction point)	Silt Curtain
Building Zone	Combined at existing location	Combined at other location	Split Offices (operational) + Hospitality (recreational)	
Mooring Types	Floating Dock (Berthing Mooring)	Fixed dock (Berthing mooring)	Buoyed anchoring	Piled mooring
Parking	Expand at current location	Switched to location behind vacant building	Expand to marina	
Entrance (Access)	Keep Existing	Reroute I: Axial	Reroute II: Slinger	

H

MCA Robustness

Criteria	Subcriteria	Weight	Concept I		Concept II		Concept III	
			Score	Average	Score	Avarage	Score	Avarage
1. Environmental Impact		**1,3**		***1,3***		***3,466666667***		***2,6***
	Reuse of existing infrastructure		2		2		2	
	Minimal use of resources		1		3		2	
	Minimal operations invading ecological systems		0		3		2	
2. Technical Feasibility		**1**		***2***		***1,666666667***		***1,666666667***
	Resilience to Environmental Conditions		3		1		2	
	Ease of Construction		1		3		2	
	Sedimentation Control present		2		1		1	
3. Operability		**1**		***2,666666667***		***1,666666667***		***1,666666667***
	Layout Efficiency		3		2		1	
	Accessibility		3		1		2	
	Expansion Potential (Flexibility)		2		2		2	
4. Service Quality & User Experience		**1**		***2,666666667***		***1,333333333***		***1,666666667***
	Clear distinction between area's		3		1		2	
	Aestetic appeal		3		2		1	
	Public and private facilities present		2		1		2	
5. Economic Feasibility		**1**		***1,5***		***2***		***2***
	Construction Costs		1		3		2	
	Maintenance Costs		2		1		2	
Total Score		**5,3**		**10,13333333**		**10,13333333**		**9,6**

Figure H.1: Robustness Test Environmental Impact

Criteria	Subcriteria	Weight	Concept I		Concept II		Concept III	
			Score	Average	Score	Avarage	Score	Avarage
1. Environmental Impact		**1**		***1***		***2,666666667***		***2***
	Reuse of existing infrastructure		2		2		2	
	Minimal use of resources		1		3		2	
	Minimal operations invading ecological systems		0		3		2	
2. Technical Feasibility		**1**		***2***		***1,666666667***		***1,666666667***
	Resilience to Environmental Conditions		3		1		2	
	Ease of Construction		1		3		2	
	Sedimentation Control present		2		1		1	
3. Operability		**1**		***2,666666667***		***1,666666667***		***1,666666667***
	Layout Efficiency		3		2		1	
	Accessibility		3		1		2	
	Expansion Potential (Flexibility)		2		2		2	
4. Service Quality & User Experience		**1**		***2,666666667***		***1,333333333***		***1,666666667***
	Clear distinction between area's		3		1		2	
	Aestetic appeal		3		2		1	
	Public and private facilities present		2		1		2	
5. Economic Feasibility		**2**		***3***		***4***		***4***
	Construction Costs		1		3		2	
	Maintenance Costs		2		1		2	
Total Score		**6**		**11,33333333**		**11,33333333**		**11**

Figure H.2: Robustness Test Economic Feasibitlity

I

Anti-Sedimentation Measures

This section outlines various potential measures to combat sedimentation in the marina Bahía López, with the aim of reducing sediment accumulation and the costs involved associated with maintenance dredging. Based on PIANC's Anti-sedimentation systems for Marinas and Yacht Harbours (2015) [47] an overview of the most effective anti-sedimentation strategies applied to the marina in Bahía López.
It is important to follow a sequence of steps/options in preventing sedimentation in a marina.

1. Prevent sediment from approaching the marina: this can be achieved by retaining sediment upstream and using physical barriers like groynes.
2. Prevent sediment from entering the marina: options include sediment traps, sediment curtains, deflection methods, and sills at the entrance.
3. Design the marina to promote sediment deposition at specific locations: this can be done by using sediment traps, sloping the marina floor, or creating a circular water flow.
4. Design the marina for cost-effective maintenance and sediment removal: methods like stirring sediment, using water injection dredging or ploughing.
5. Prevent the enhancement of density currents, particularly when silt is present: avoid allowing fresh water inflow into the marina basin, such as from small streams or surface drainage channels.

However, it is important to note that the appropriate design measures depend on the type and location of the marina, potential measures in Bahía López are discussed below.

Marina Configuration and Entrance Design:

Minimizing the entrance width reduces sediment entry by limiting the volume of water flowing into the marina. A smaller entrance width helps control the amount of sediment transported into the marina, thereby reducing maintenance dredging needs. The entrance should be aligned with the dominant current or wave direction to reduce sediment trapping, following van van Rijn (2012) [45]. This ensures that sediments naturally bypass the entrance rather than accumulating at the marina's mouth. Breakwaters should have a smooth, curved design to allow sediments to bypass the marina. This minimizes the formation of eddies and uncontrolled sediment settling close to the marina and its entrance. This could be applied at Bahía López, as displayed in Figure I.1.

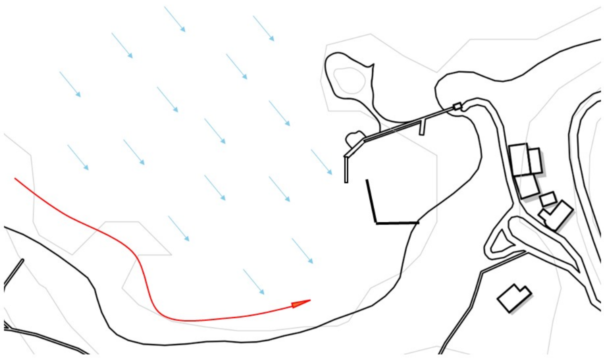


Figure I.1: Bahía López Marina Configuration

In this way, the sediments flowing into the marina due to the dominant current and the sediments resulting from the longshore current, as discussed in subsection 3.6, are kept out of the marina.

Sediment Deflection and Trapping

Sand traps are typically placed up-drift of the marina to capture sediments before they enter the basin. These traps must be periodically dredged to remove the accumulated sediment. This reduces the volume of sediment reaching the marina and minimizes the need for dredging inside the basin. Sediment curtains or barriers, such as silt curtains, can be used to limit sediment inflow, especially in tidal or riverine environments. These barriers allow water and vessels to pass but prevent suspended sediments from entering the marina. In areas where sediment transport alongshore is significant, sediment bypassing systems can be used to redirect sediment around the marina. These systems are designed to prevent sediment accumulation inside the marina while maintaining the natural sediment supply to the surrounding coastline, Bosboom (2023) [18].

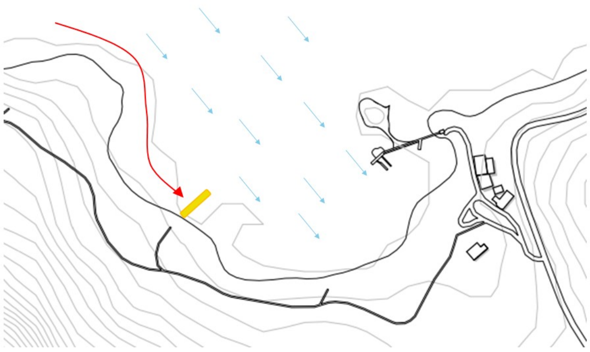


Figure I.2: Sediment trap updrift Bahía López

In the case of Bahía López, sediment traps updrift could be applied to capture sediment transport caused by the longshore drift occurring in the bay. This would allow the sediments to be trapped at a designated location away from the marina, creating a more manageable area for maintenance dredging, as displayed in Figure I.2. A difficulty here will be that the water depths increase very fast and at bigger water depth it will not be possible to do maintenance dredging.

Sediment Deposition Inside the Marina

Sediment traps inside the marina can be strategically placed to collect sediment at designated locations. This approach helps in keeping the main navigation channels clear, reducing the frequency and cost of dredging operations inside the marina basin. A sloping water bottom can facilitate the formation of density flows that naturally carry sediment to preferred locations for removal. This design encourages sediment deposition in specific areas, making it easier to manage sediment accumulation. In Bahía López Marina, it is feasible to designate a specific area for sediment accumulation, where water flow naturally slows down or comes to a halt. This area can be strategically located to take advantage of low-velocity zones, promoting the settling of suspended sediments. By carefully positioning this accumulation zone, we can minimize the risk of sediment deposition in critical marina areas, such as navigational channels and docking zones, which are vital for safe and efficient operation.
Furthermore, this designated area would allow for controlled maintenance dredging, ensuring that the sediment is removed regularly without disrupting the overall marina operations. This proactive sediment management strategy would help maintain water quality, prevent sediment build-up in high-traffic areas, and reduce the need for more disruptive and costly dredging interventions elsewhere in the marina.

Flow Circulation

Flow circulation is crucial to maintaining sediment transport and preventing sediment from settling in unwanted locations. The design of the marina should aim to maintain hydrodynamic intensity, which can help keep sediments suspended and prevent large gradients in water velocity that might lead to sediment deposition. Maintaining circulation within the marina involves minimizing stagnant water areas where sediment can accumulate. This can be achieved by streamlining the layout of the berthing lines and avoiding oblong water bodies or poorly designed marina shapes that encourage stagnation. Sloping water bottoms are one design feature that can facilitate density flow inside the marina. The sloping floor encourages the natural movement of water, which can carry sediments to designated areas, including sediment traps. This method utilizes the dynamics of water flow to direct sediments to preferred deposition areas, rather than allowing them to settle in the middle of the basin. The ability to keep sediments in motion reduces the need for mechanical dredging and makes sediment management more efficient. This method works well in marinas with sufficient water exchange and circulation.

Maintenance Dredging

Maintenance dredging is a commonly applied sediment control measure aimed at managing the gradual accumulation of sediment in navigational and operational areas. By periodically removing deposited material, it helps to maintain sufficient water depth and ensure continued functionality of the marina. Although it does not prevent sedimentation, it is an effective method to manage its impact over time. The frequency and extent of dredging depend on local sedimentation rates, which highlights the importance of monitoring and adaptive planning.

J

Python Codes

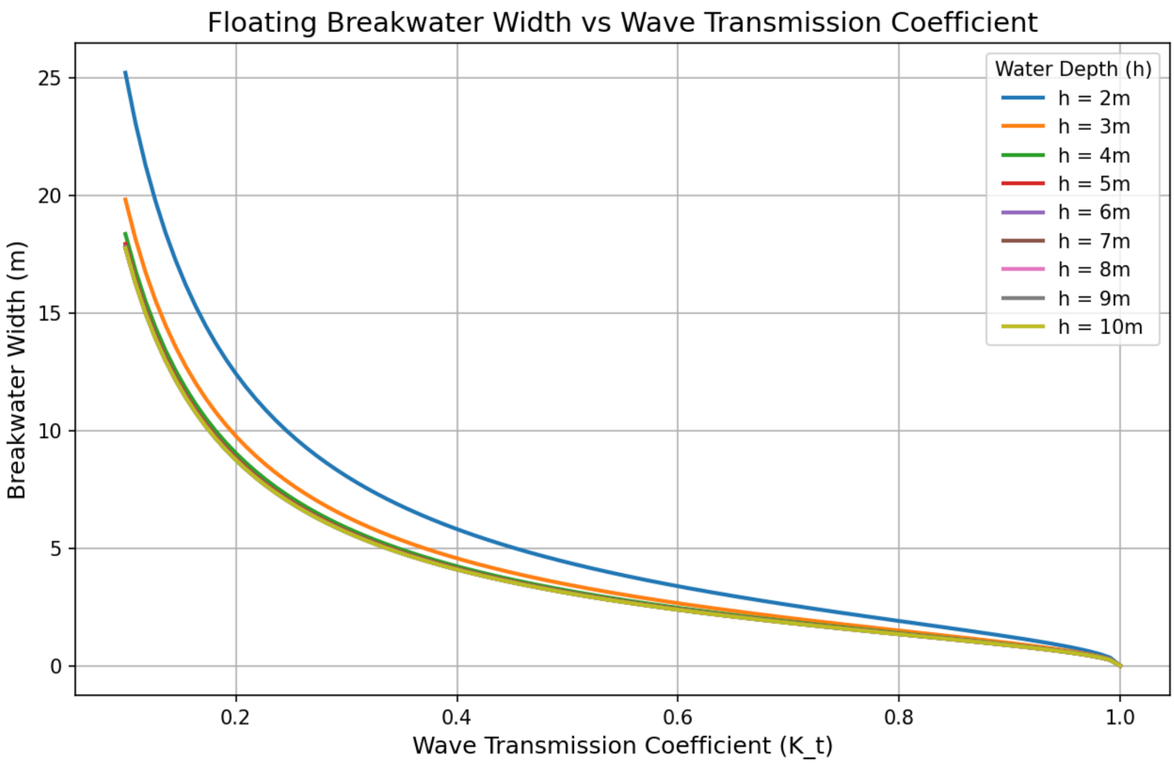
J.1 Floating Breakwater Dimensions

```
import numpy as np

# Function to calculate the width of the floating breakwater B
def calculate_B(g, h, d, K_t):
    # Calculate wavelength (L) using the given formula: L = T^2 * g / (2 * pi)
    # Calculate the wave number k_i: k_i = 2 * pi / L
    k_i = (2 * np.pi) / L

    # Formula for K_t: K_t = 1 / sqrt(1 + (k_i * B * sinh(k_i * h) / (2 * cosh(k_i * h - k_i * d)))^2)
    # Rearranging the formula to solve for B:
    B = (2*np.cosh(k_i*h - k_i*d) * np.sqrt(1/K_t**2 - 1)) / (k_i * np.sinh(k_i*h))
    return B, k_i

# Example inputs
g = 9.81  # acceleration due to gravity (in m/s^2)
h = 10  # water depth (in meters)
d = 1  # draft (in meters)
K_t = 0.60  # wave transmission coefficient
L = 10.31229636

# Calculate the width B
B, k_i = calculate_B(g, h, d, K_t)
print("The floating breakwater width i B =", B, "m")
```

```
The floating breakwater width i B = 2.3798106949362747 m
```

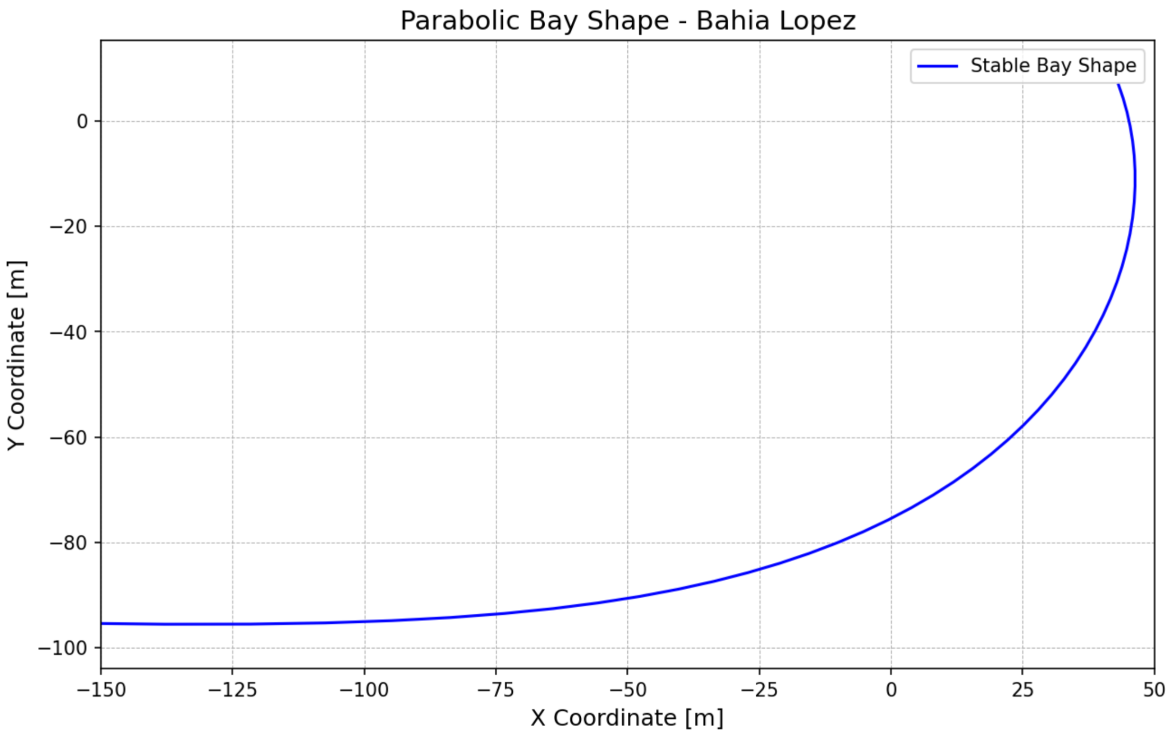
```
import numpy as np
import matplotlib.pyplot as plt

# Function to calculate the width of the floating breakwater B
def calculate_B(g, h, d, K_t, L):
    # Calculate wave number k_i: k_i = 2 * pi / L
    k_i = (2 * np.pi) / L

    # Formula for K_t: K_t = 1 / sqrt(1 + (k_i * B * sinh(k_i * h) / (2 * cosh(k_i * h - k_i * d)))^2)
    # Rearranging the formula to solve for B:
    B = (2 * np.cosh(k_i * h - k_i * d) * np.sqrt(1 / K_t**2 - 1)) / (k_i * np.sinh(k_i * h))
    return B

# Example inputs
g = 9.81  # acceleration due to gravity (in m/s^2)
d = 1  # draft (in meters)
L = 10.31229636  # wavelength constant (example)

# Create an array of water depths
h_values = np.linspace(1, 20, 1000)  # water depths from 1m to 20m

# Create an array for K_t values
K_t_values = np.linspace(0.1, 1.0, 10)

# Create the plot
plt.figure(figsize=(10, 6), dpi=150)  # Increase size and DPI for higher resolution

# Plot for different K_t values
for K_t in K_t_values:
    B_values = [calculate_B(g, h, d, K_t, L) for h in h_values]
    plt.plot(h_values, B_values, label=f'K_t = {K_t:.2f}', linewidth=2)  # Set linewidth for sharpness

plt.title('Floating Breakwater Width vs Water Depth (for d=1m)', fontsize=14)
plt.xlabel('Water Depth (m)', fontsize=12)
plt.ylabel('Breakwater Width (m)', fontsize=12)

# Move the legend to the upper right corner
plt.legend(title='Wave Transmission Coefficient (K_t)', fontsize=10, loc='upper right')

plt.grid(True)  # Add gridlines for better readability
plt.ylim(0,20)
plt.xlim(0,10)

# Show the plot
plt.show()
```

```python
import numpy as np
import matplotlib.pyplot as plt

# Function to calculate the width of the floating breakwater B
def calculate_B(g, h, d, K_t, L):
    # Calculate wave number k_i: k_i = 2 * pi / L
    k_i = (2 * np.pi) / L

    # Formula for K_t: K_t = 1 / sqrt(1 + (k_i * B * sinh(k_i * h) / (2 * cosh(k_i * h - k_i * d)))^2)
    # Rearranging the formula to solve for B:
    B = (2 * np.cosh(k_i * h - k_i * d) * np.sqrt(1 / K_t**2 - 1)) / (k_i * np.sinh(k_i * h))
    return B

# Example inputs
g = 9.81  # acceleration due to gravity (in m/s^2)
d = 1  # draft (in meters)
L = 10.31229636  # wavelength constant (example)

# Create an array of K_t values
K_t_values = np.linspace(0.1, 1.0, 100)  # Wave transmission coefficient range

# Create an array for height (water depth) values
h_values = [2,3, 4,5, 6,7, 8, 9,10]  # Different heights for plotting

# Create the plot
plt.figure(figsize=(10, 6), dpi=150)  # Increase size and DPI for higher resolution

# Plot for different water depths (h values)
for h in h_values:
    B_values = [calculate_B(g, h, d, K_t, L) for K_t in K_t_values]
    plt.plot(K_t_values, B_values, label=f'h = {h}m', linewidth=2)  # Set linewidth for sharpness

plt.title('Floating Breakwater Width vs Wave Transmission Coefficient', fontsize=14)
plt.xlabel('Wave Transmission Coefficient (K_t)', fontsize=12)
plt.ylabel('Breakwater Width (m)', fontsize=12)
plt.legend(title='Water Depth (h)', fontsize=10)
plt.grid(True)  # Add gridlines for better readability

# Show the plot
plt.show()
```



J.2 Bay Shape

```
import numpy as np
import matplotlib.pyplot as plt

# Define constants
R_0 = 260  # Reference length
beta_rad = 0.366519  # Given beta value in radians

# Define theta range in radians (avoid zero to prevent division issues)
theta = np.linspace(0.366519, np.pi * 1.05, 50)  # Theta from beta to 180 degrees

# Compute r values using the given equation
r_ratio = 0.055 + 1.029 * (beta_rad / theta) - 0.088 * (beta_rad / theta) ** 2
r = -1 * R_0 * r_ratio  # Apply the given equation

# Convert to Cartesian coordinates
x = r * np.cos(theta)
y = r * np.sin(theta)

# Plot the curve
plt.figure(figsize=(10, 6), dpi=150)
plt.plot(x, y, label="Stable Bay Shape", color='b')

# Formatting
plt.grid(True, linestyle="--", linewidth=0.5)
plt.title("Parabolic Bay Shape - Bahia Lopez", fontsize=14)
plt.xlabel("X Coordinate [m]", fontsize=12)
plt.ylabel("Y Coordinate [m]", fontsize=12)
plt.legend()
plt.axis("equal")  # Keep the aspect ratio equal

# Set x-axis limits
plt.xlim(-150, 50)

# Show the plot
plt.show()
```



J.3 Mooring Line

```
import matplotlib.pyplot as plt
from scipy.integrate import quad

def calculate_x_max(F_x, w_avg, h):

    argument = (h * w_avg / F_x) + 1
    if argument < 1:
        raise ValueError(f"Invalid input: arccosh argument must be >= 1, got {argument}")

    x_max = (F_x / w_avg) * np.arccosh(argument)
    return x_max

def calculate_z(x, F_x, w_avg):
    return (F_x / w_avg) * (np.cosh((w_avg / F_x) * x) - 1)

def arc_length_integrand(x, F_x, w_avg):
    dz_dx = np.sinh((w_avg / F_x) * x)  # Derivative of z(x)
    return np.sqrt(1 + dz_dx**2)

def calculate_arc_length(F_x, w_avg, x_max):
    arc_length, _ = quad(arc_length_integrand, 0, x_max, args=(F_x, w_avg), epsabs=1e-5, epsrel=1e-5)
    return arc_length

def calculate_Fz_max(F_x, w_avg, h, S_0, S):
    # Compute the weight in the suspended section by integrating the weight function
    def weight_function(x):
        return w_avg  # Only using w_avg here; clamped weights applied to S

    # Integrate to calculate vertical force Fz_max
    Fz_max, _ = quad(weight_function, 0, S)
    return Fz_max

def calculate_tension(F_x, Fz_max):
    return np.sqrt(F_x**2 + Fz_max**2)

# Given Total Mooring Line Length (Constant)
S_tot = 55  # Fixed total mooring line length

# Constant Force in x-direction
F_x = 90000  # Constant horizontal force

# Base weight per unit length (without local loads)
w_base = 5000  # Base weight in N/m

clamped_weight_positions = {
    25: 0,   # Weight at 5m along S_tot
    30: 0,  # Weight at 12m along S_tot
    40: 0   # Weight at 25m along S_tot
}

# Compute average weight along the suspended length
def compute_weight_average(S_0, S):
    """Computes the effective average weight considering local loads at positions in S_tot."""
    num_points = 100
    x_values = np.linspace(0, S, num_points)  # Now based on suspended part S

    # Ensure weights array is initialized as float
    weights = np.full(num_points, w_base, dtype=np.float64)

    # Apply local weights **only if they are within the suspended part S**
    for pos_tot, extra_weight in clamped_weight_positions.items():
        if pos_tot > S_0:  # Only apply if within the suspended portion
            pos_s = pos_tot - S_0  # Convert to relative position in S
            weights += float(extra_weight) * np.exp(-((x_values - pos_s) ** 2) / 2)  # Smooth Gaussian-like effect

    return np.mean(weights)

# Heights to compare
heights = [25, 27.5]
colors = ['b', 'g']  # Different colors for the plots

plt.figure(figsize=(8, 5))

for h, color in zip(heights, colors):
    try:
        # Initial estimation of x_max using base weight
        x_max = calculate_x_max(F_x, w_base, h)

        # First estimation of S using base weight
        S = calculate_arc_length(F_x, w_base, x_max)

        # Compute length on seabed (S0)
        S_0 = S_tot - S  # Since S_tot = S_0 + S

        # Compute the effective weight considering local loads **along S_tot**
        w_avg = compute_weight_average(S_0, S)

        # Recalculate x_max with adjusted weight
        x_max = calculate_x_max(F_x, w_avg, h)

        # Recalculate suspended arc length (S) using variable w_avg
        S = calculate_arc_length(F_x, w_avg, x_max)
```

```python
        # Recalculate seabed length S0
        S_0 = S_tot - S

        # Compute total horizontal extent x_tot
        x_tot = S_0 + x_max  # Total x distance from anchor

        # Compute max vertical force (Fz_max) including clamped weights
        Fz_max = calculate_Fz_max(F_x, w_avg, h, S_0, S)

        # Compute total mooring line tension (Ft)
        Ft = calculate_tension(F_x, Fz_max)

        # Ensure S_0 is non-negative
        if S_0 < 0:
            raise ValueError(f"S_0 is negative ({S_0:.4f}) for h={h}, check input values.")

        # Generate x values ensuring (0,0) is the start point
        x_values = np.linspace(-S_0, x_max, 200) + S_0  # Shift x so anchor is at (0,0)
        z_values = np.piecewise(
            x_values,
            [x_values < S_0, x_values >= S_0],
            [lambda x: 0, lambda x: calculate_z(x - S_0, F_x, w_avg)]  # Shift z calculation
        )

        # Plot the mooring line profile
        plt.plot(x_values, z_values, label=f'h = {h} m', color=color)

        # **NEW: Draw the waterline for each height (h)**
        plt.axhline(y=h, color='blue', linestyle='-', linewidth=2, alpha=0.5, label=f'Waterline (h={h}m)')

        # Print results including x_tot and tension
        print(f"For h = {h} meters:")
        print(f"  x_max = {x_max:.4f}")
        print(f"  Suspended Length (S) = {S:.4f}")
        print(f"  Seabed Length (S_0) = {S_0:.4f}")
        print(f"  Total Length (S_tot) = {S_tot:.4f} (Constant)")
        print(f"  Total Horizontal Distance (x_tot) = {x_tot:.4f}")
        print(f"  Maximum Vertical Force (Fz_max) = {Fz_max:.2f} N")
        print(f"  Total Line Tension (Ft) = {Ft:.2f} N\n")

    except ValueError as e:
        print(f"Error for h={h}: {e}")

# Formatting the plot
plt.axhline(y=0, color='r', linestyle='--', label='Seabed (z=0)')
plt.axvline(x=0, color='black', linestyle='--', label='Anchor Point (0,0)')

plt.xlabel("x (horizontal distance from anchor)")
plt.ylabel("z (height above seabed)")
plt.legend()
plt.grid()
plt.show()
```

```
For h = 25 meters:
  x_max = 27.3055
  Suspended Length (S) = 39.0512
  Seabed Length (S_0) = 15.9488
  Total Length (S_tot) = 55.0000 (Constant)
  Total Horizontal Distance (x_tot) = 43.2543
  Maximum Vertical Force (Fz_max) = 195256.24 N
  Total Line Tension (Ft) = 215000.00 N

For h = 27.5 meters:
  x_max = 28.4192
  Suspended Length (S) = 41.7882
  Seabed Length (S_0) = 13.2118
  Total Length (S_tot) = 55.0000 (Constant)
  Total Horizontal Distance (x_tot) = 41.6310
  Maximum Vertical Force (Fz_max) = 208940.78 N
  Total Line Tension (Ft) = 227500.00 N
```

J.4 Wave Estimation and Environmental Loads

```python
import math

# Given data
fetches = [4305.58, 3440, 1910]  # fetch distances in meters
angles = [0, -12, 12]  # angles in degrees


angles_rad = [math.radians(angle) for angle in angles]


numerator = sum(fetches[i] * math.cos(angles_rad[i])**2 for i in range(len(fetches)))
denominator = sum(math.cos(angles_rad[i]) for i in range(len(fetches)))


fetch_length = numerator / denominator

# Print the result
print(f"Effective Fetch Length: {fetch_length:.2f} meters")

# Define constants
g = 9.81  # Acceleration due to gravity (m/s^2)

# Define wind speed categories (m/s)
wind_speeds = {
    "Average Winds": [13/3.6],  # Low wind speeds
    "Mediocre Winds": [35/3.6],  # Medium-range winds
    "Strong Winds": [60/3.6]  # High wind speeds
}

# Default fetch length and water depth (adjustable)
F = fetch_length  # Fetch length in meters
d = 30  # Water depth in meters

# Wave characteristics
def calculate_wave_properties(u, F, d):
    # Dimensionless parameters
    F_tilde = (F * g) / (u ** 2)
    d_tilde = (d * g) / (u ** 2)

    # Dimensionless wave height (H~)
    H_tilde = 0.283 * np.tanh(0.35 * d_tilde ** 0.75) * np.tanh((0.0125 * F_tilde ** 0.42) / np.tanh(0.35 * d_tilde ** 0.75))

    # Dimensionless wave period (T~)
    T_tilde = 2 * np.pi * np.tanh(0.833 * d_tilde ** 0.375) * np.tanh((0.077 * F_tilde ** 0.25) / np.tanh(0.833 * d_tilde ** 0.375))

    # Convert to actual wave height (H1/3) and wave period (T1/3)
    H = (H_tilde * u**2) / g
    T = (T_tilde * u) / g

    return H_tilde, T_tilde, H, T


for category, speeds in wind_speeds.items():
    print(f"\n--- {category} ---")
    for u in speeds:
        H_tilde, T_tilde, H, T = calculate_wave_properties(u, F, d)
        print(f"Wind Speed: {u} m/s")
        print(f"  - Significant Wave Height (H1/3): {H:.4f} m")
        print(f"  - Significant Wave Period (T1/3): {T:.4f} s\n")


def calculate_wind_force(CD, rho, V, A):

    # Wind force formula
    F_w = CD * (rho * V**2) / 2 * A
    return F_w

# Example Usage (convert units as needed)
CD = 2.0  # Drag coefficient
rho = 1.225  # Air density in kg/m³ for SI units
V = [60/3.6, 35/3.6 , 13/3.6]  # Wind velocities in m/s (converted from km/h to m/s)
A = 42  # Area exposed to wind in m²

# Loop through the list of wind velocities and calculate the wind force for each one
for v in V:
    wind_force = calculate_wind_force(CD, rho, v, A)
    print(f"Wind Force for V = {v:.2f} m/s: {wind_force:.2f} N")

import math

# Define functions as provided in the original code
def calculate_wavelength(T):
    """Calculate the wavelength L based on deep water formula."""
    g = 9.81  # acceleration due to gravity in m/s^2
    return (g * T**2) / (2 * math.pi)

def calculate_wave_number(L):
    """Calculate the wave number k from the wavelength L."""
    return 2 * math.pi / L

def calculate_angular_frequency(k):
    """Calculate the angular frequency omega based on the deepwater dispersion relation."""
    g = 9.81  # acceleration due to gravity in m/s^2
    return math.sqrt(g * k)
```

```python
def velocity(z, H, h, k, omega):
    """Calculate the velocity u(z) based on the provided formula (cos(omega t) = 1)."""
    return (omega * H / 2) * (math.cosh(k * (z + h)) / math.sinh(k * h))

def acceleration(z, H, h, k, omega):
    """Calculate the acceleration u'(z) based on the provided formula (sin(omega t) = 1)."""
    return (omega**2 * H / 2) * (math.cosh(k * (z + h)) / math.sinh(k * h))

def force(rho, C_M, C_D, A, H, h, k, omega):
    """Calculate the force F using the modified formula."""
    # Calculate velocity at z=0 (surface) and no time dependence (cos(omega t) = 1)
    u_z = velocity(0, H, h, k, omega)
    # Calculate acceleration at z=0 (surface) and no time dependence (sin(omega t) = 1)
    u_prime_z = acceleration(0, H, h, k, omega)

    # Print velocity and acceleration at surface (z=0)
    print(f"Velocity at z=0: {u_z:.4f} m/s")
    print(f"Acceleration at z=0: {u_prime_z:.4f} m/s²")

    # First term: rho * C_M * V * u'(z)
    term1 = rho * C_M * V * u_prime_z

    # Second term: 1/2 * rho * C_D * A * u(z) * |u(z)|
    term2 = (1 / 2) * rho * C_D * A * u_z * abs(u_z)

    # Print the terms separately
    print(f"Term 1 (Inertial Force): {term1:.4f} N")
    print(f"Term 2 (Drag Force): {term2:.4f} N")

    # Combine terms for final force
    return term1 + term2

# Define wind conditions for average, mediocre, and strong winds
wind_conditions = [
    (3.611111111111111, 0.1193, 1.1364),  # Average Winds (Wind Speed, H1/3, T1/3)
    (9.722222222222221, 0.3840, 1.9500),  # Mediocre Winds
    (16.666666666666668, 0.7124, 2.5660)   # Strong Winds
]

# Parameters for the force calculation
rho = 1000  # density in kg/m^3 (example value)
C_M = 2  # correction factor (example)
C_D = 2  # drag coefficient (example)
A = 30  *math.cos(math.radians(45))
V = 30 * 2.4 *math.cos(math.radians(45))
h = 27.5  # reference depth (still water level) in meters (example)

# Calculate and print force for each wind condition
for wind_condition in wind_conditions:
    wind_speed, H, T = wind_condition

    # Calculate wavelength (L) using the deep water wave formula
    L = calculate_wavelength(T)

    # Calculate wave number (k)
    k = calculate_wave_number(L)

    # Calculate angular frequency (omega)
    omega = calculate_angular_frequency(k)

    # Print omega for this wind condition
    print(f"Calculated omega (angular frequency): {omega:.4f} rad/s")

    # Calculate the force
    F_t = force(rho, C_M, C_D, A, H, h, k, omega)

    print(f"--- Wind Condition ---")
    print(f"Wind Speed: {wind_speed} m/s")
    print(f"Significant Wave Height (H1/3): {H} m")
    print(f"Significant Wave Period (T1/3): {T} s")
    print(f"Calculated Force: {F_t:.4f} N\n")
```

```
Effective Fetch Length: 3187.88 meters

--- Average Winds ---
Wind Speed: 3.611111111111111 m/s
  - Significant Wave Height (H1/3): 0.1193 m
  - Significant Wave Period (T1/3): 1.1364 s


--- Mediocre Winds ---
Wind Speed: 9.722222222222221 m/s
  - Significant Wave Height (H1/3): 0.3840 m
  - Significant Wave Period (T1/3): 1.9500 s


--- Strong Winds ---
Wind Speed: 16.666666666666668 m/s
  - Significant Wave Height (H1/3): 0.7124 m
  - Significant Wave Period (T1/3): 2.5660 s

Wind Force for V = 16.67 m/s: 14291.67 N
Wind Force for V = 9.72 m/s: 4863.14 N
Wind Force for V = 3.61 m/s: 670.91 N
Calculated omega (angular frequency): 5.5290 rad/s
Velocity at z=0: 0.3298 m/s
Acceleration at z=0: 1.8235 m/s²
Term 1 (Inertial Force): 185675.7680 N
Term 2 (Drag Force): 2307.4082 N
```

```
--- Wind Condition ---
Wind Speed: 3.611111111111111 m/s
Significant Wave Height (H1/3): 0.1193 m
Significant Wave Period (T1/3): 1.1364 s
Calculated Force: 187983.1762 N

Calculated omega (angular frequency): 3.2221 rad/s
Velocity at z=0: 0.6187 m/s
Acceleration at z=0: 1.9934 m/s²
Term 1 (Inertial Force): 202973.4516 N
Term 2 (Drag Force): 8118.9381 N
--- Wind Condition ---
Wind Speed: 9.722222222222221 m/s
Significant Wave Height (H1/3): 0.384 m
Significant Wave Period (T1/3): 1.95 s
Calculated Force: 211092.3896 N

Calculated omega (angular frequency): 2.4486 rad/s
Velocity at z=0: 0.8722 m/s
Acceleration at z=0: 2.1357 m/s²
Term 1 (Inertial Force): 217464.2353 N
Term 2 (Drag Force): 16137.6585 N
--- Wind Condition ---
Wind Speed: 16.666666666666668 m/s
Significant Wave Height (H1/3): 0.7124 m
Significant Wave Period (T1/3): 2.566 s
Calculated Force: 233601.8938 N
```