Plan of Approach for sustainable management of the Queule River mouth

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Executive Summary

Queule, a town in Chile's Araucanía Region, faces navigation challenges due to a dynamic spit (sandbar) at the Queule River mouth. This spit has become larger resulting in less water depth. This limited water depth affects local fishermen to access the sea and as a result safe navigation and the economy. Previous studies for DOP identified sedimentation at the river mouth as the main issue, proposing breakwaters and dredging. These solutions faced opposition from indigenous communities and possibly have environmental impact assessment challenges.

The Dirección de Obras Portuarias (DOP) asked the Dutch Embassy and Netherlands Enterprise Agency for support to find a sustainable solution for the fishermen to access the sea. The objective of this project is to create a roadmap considering natural processes, stakeholder interests, and legislation, which can be replicated in similar coves (Caletas).

As stated, the sedimentation problem has worsened over the past decades, particularly after the 2010 earthquake. The sedimentation issue is influenced by a probable decreased river discharge due to lower precipitation and increased temperatures, and potential changes in sediment flux from reduced tree cover. Climate change is expected to worsen the problem. Key economic activities are fishing and mussel cultivation and collection. Environmental laws require indigenous community involvement and impact assessments for interventions.

The natural, socio-economic and institutional systems are assessed and based on the understanding of these systems a comprehensive list of potential solutions is created, including measures to reduce sediment input, increase channel flow, and adaptive management strategies. These solutions are evaluated on goal achievement, feasibility, additional benefits, and costs. First a high-level evaluation was conducted followed by a more detailed score. This resulted in three recommended solutions:

- **Longitudinal Breakwater**: Expected to be effective in both short and long term for enhancing flow and washing out sediments. It involves local workers and could provide economic and social benefits. Add benefits like creating enriched revetments to enhance biodiversity or planting kelp forest to possibly trap sediments.
- **(Optimized) Dredging**: Techniques like water injection dredging, natural sediment bypassing, and silt curtains offer direct improvement with less ecological harm than standard dredging. However, these alternatives are not always possible in this specific location. Therefore, normal dredging is expected to be more useful. Combining normal dredging with signaling systems and frequent bathymetry surveys ensures safe navigation.
- **Nature-Based and Non-Structural Interventions**: Upstream measures like reforestation and terrace construction, as well as non-structural measures such as relocating the fishing cove and adjusting to shallower draft fishing boats, provide sustainable solutions.

The developed roadmap (plan of approach) for the sustainable management of the Queule river mouth and the activities is based on the existing project life cycle framework from The Ministerio de Desarrollo Social y Familia (MDSF) consisting of the following 3 phases and 7 stages: 1) Pre-investment - Idea, Profile, Pre-feasibility, Feasibility, 2) Investment - Design, Execution, and 3) Operations - Operations.

System understanding is a key activity in each phase and stage of this roadmap. Another key element for sustainable management is the engagement of the stakeholders. Article 6 of Convention No. 169 on Indigenous and Tribal Peoples establishes the obligation to consult indigenous peoples whenever legislative or administrative measures are planned, which may directly affect them. It is recommended to enlarge the stakeholder engagement. Who else to engage comes from mapping stakeholders on their influence/power and interest, and engagement should be in every project phase and stage. For Queule the mapped key stakeholders are community groups, indigenous communities, organized stakeholders and government entities. The level to engaged them is respectively consult, co-decide, consult and co-decide. In this engagement transparency and timely engagement of stakeholders need to be guaranteed. The project can benefit from the public contribution by co-deciding, consulting and co-operating with different groups. This can provide advantages in developing alternatives and selection of realistic and implementable solutions. This process also fosters the support of the stakeholders involved, crucial for later stages of development.

Resume Ejecutivo

Queule, localidad de la Región de la Araucanía chilena, enfrenta dificultades para la navegación debido a un banco de arena dinámico en la desembocadura del río Queule. Este banco de arena se ha expandido, lo que ha reducido la profundidad del agua. Esta limitada profundidad afecta el acceso de los pescadores locales al mar y, en consecuencia, la seguridad de la navegación y la economía. Estudios previos realizados por la DOP identificaron la sedimentación en la desembocadura del río como el principal problema, proponiendo rompeolas y dragado. Estas soluciones se enfrentaron a la oposición de las comunidades indígenas y posiblemente presenten dificultades en la evaluación de impacto ambiental.

La Dirección de Obras Portuarias (DOP) solicitó apoyo a la Embajada de los Países Bajos y a la Agencia Empresarial de los Países Bajos para encontrar una solución sostenible que permita a los pescadores acceder al mar. El objetivo de este proyecto es crear una hoja de ruta que considere los procesos naturales, los intereses de las partes interesadas y la legislación, y que pueda replicarse en caletas similares.

Como se mencionó, el problema de la sedimentación se ha agravado en las últimas décadas, especialmente después del terremoto de 2010. El problema de la sedimentación se ve influenciado por una probable disminución del caudal fluvial debido a la disminución de las precipitaciones y el aumento de las temperaturas, así como por posibles cambios en el flujo de sedimentos debido a la reducción de la cobertura arbórea. Se prevé que el cambio climático agrave el problema. Las actividades económicas clave son la pesca y el cultivo y la recolección de mejillones. La legislación ambiental exige la participación de las comunidades indígenas y evaluaciones de impacto para las intervenciones.

Se evaluaron los sistemas naturales, socioeconómicos e institucionales y, con base en su comprensión, se creó una lista completa de posibles soluciones, que incluye medidas para reducir la entrada de sedimentos, aumentar el caudal del canal y estrategias de gestión adaptativa. Estas soluciones se evalúan en función del logro de los objetivos, la viabilidad, los beneficios adicionales y los costos. Primero se realizó una evaluación general, seguida de una puntuación más detallada. Esto dio como resultado tres soluciones recomendadas:

- **Rompeolas longitudinal**: Se espera que sea eficaz a corto y largo plazo para mejorar el caudal y arrastrar sedimentos. Implica la participación de trabajadores locales y podría generar beneficios económicos y sociales. Se pueden añadir beneficios como la creación de un enrocado enriquecido para mejorar la biodiversidad o la plantación de bosques de algas para la posible captura de sedimentos.
- **Dragado (Optimizado):** Técnicas como el dragado por inyección de agua, la desviación de sedimentos sedimentos y las cortinas de sedimentos ofrecen mejoras directas con menor impacto ecológico que el dragado convencional. Sin embargo, estas alternativas no siempre son posibles en esta ubicación específica. Por lo tanto, se espera que el dragado convencional sea más útil. La combinación del dragado convencional con sistemas de señalización y estudios batimétricos frecuentes garantiza una navegación segura.
- **Intervenciones Naturales y No Estructurales:** Medidas aguas arriba como la reforestación y la construcción de terrazas, así como medidas no estructurales como la reubicación de la caleta de pesca y la adaptación a embarcaciones pesqueras de menor calado, ofrecen soluciones sostenibles.

La hoja de ruta desarrollada (plan de enfoque) para la gestión sostenible de la desembocadura del río Queule y sus actividades se basa en el marco del ciclo de vida del proyecto del Ministerio de Desarrollo Social y Familiar (MDSF), que consta de las siguientes 3 fases y 7 etapas: 1) Preinversión: Idea, Perfil, Prefactibilidad, Factibilidad; 2) Inversión: Diseño, Ejecución; y 3) Operaciones: Operaciones.

La comprensión del sistema es una actividad clave en cada fase y etapa de esta hoja de ruta. Otro elemento clave para la gestión sostenible es la participación de las partes interesadas. El artículo 6 del Convenio núm. 169 sobre Pueblos Indígenas y Tribales establece la obligación de consultar a los pueblos indígenas siempre que se prevean medidas legislativas o administrativas que puedan afectarles directamente. Se recomienda ampliar la participación de las partes interesadas. La participación de otras partes interesadas se basa en el mapeo de su influencia, poder e intereses, y la participación debe estar presente en cada fase y etapa del proyecto. En el caso de Queule, las partes interesadas clave mapeadas son los grupos comunitarios, las comunidades indígenas, las partes interesadas organizadas y las entidades gubernamentales. El nivel de participación es, respectivamente, consultar, codecidir, consultar y codecidir. En esta participación, se debe garantizar la transparencia y la participación oportuna de las partes interesadas. El proyecto puede beneficiarse de la contribución pública mediante la codecisión, la consulta y la cooperación con diferentes grupos. Esto puede resultar ventajoso en el desarrollo de alternativas y la selección de soluciones realistas e implementables. Este proceso también fomenta el apoyo de las partes interesadas, crucial para las etapas posteriores del desarrollo.

1 Introduction

This report is prepared at the end of the process for Queule.
The objective of this report is to provide a roadmap on what need to be done for sustainable management of river mouths, and it sets the scene on Nature-based solutions.
For Queule it has general, high-level suggestions, as modelling and additional analyses was out of scope. The report has not the level of detail for design or advice on interventions.
For other coves (Caletas) the roadmap and longlist will be of use.

1.1 Objective and Approach

The DOP has asked support of the Dutch Embassy in Chile to find an alternative solution to resolve the fishermen's' access to sea. The Netherlands Enterprise Agency supports the Embassy on this request to receive advice for the sustainable management of Queule river mouth.

The objective of this project is to provide a roadmap to reach a viable solution for the fishermen of Queule cove (Caleta), considering the Building with Nature approach and a societal framework as a whole including existing stakeholders, interests, possibilities and restrictions. DOP could replicate this roadmap in other coves (Caletas) facing a similar situation to that of Queule.

To this end, the available information is reviewed and used to analyze and understand the natural, socio-economic and institutional systems. After this, a longlist of potential solutions is proposed. The longlist is discussed with DOP and evaluated based on specific criteria to identify three solutions with potential for implementation. These must consider natural processes, stakeholder interests, and relevant legislation to ensure they are practical, nature-inclusive and accepted by the local community.

The preparation of the Roadmap document was based on the following starting points and assumptions:

- Based on previous/existing studies and available information.
- No further analysis, modeling and detailed design was involved.
- Recommendation of measures with potential higher impact (including traditional Nature-Based Solutions).
- Delivery of fact sheets with conceptual description of selected measures.
- A single solution will not fully mitigate the complex challenge of the Queule river mouth. The proposed combined Nature-Based Solutions/Non-structural measures, needs to be studied in more detail in a later stage to have a better understanding of their impact on the local natural system, both physical and environmentally.

1.2 Report structure

The report begins with an introduction that outlines the problem statement, objectives, scope, and the report structure itself (chapter 1). This is followed by a description and analysis of the system including physical (a-biotic) components like river and coastal processes, environmental factors and ecology, socio-economic elements, stakeholders and institutional frameworks (chapter 2). This is followed by a synthesis, which summarizes the system understanding, contains conclusions on the probable problem causes, and includes recommendations for further analysis and design of interventions (chapter 3). The interventions section (chapter 4) presents a longlist of measures, selection criteria, and a shortlist with factsheets. The phases project in Chile follow are described in the next section (chapter 5). Chapter 6 contains the stakeholder engagement plan. The Roadmap in Chapter 7 describes how proposed solutions can be implemented. General conclusions and recommendations for follow-up are presented (chapter 8). The appendices are A (Chapter 9) showing a longlist of adaptation measures with links, Appendix B (Chapter 10) contains the scores measures of phase one and phase two and Appendix C (Chapter 11) provide add-ons to the longitudinal breakwater, proposed by DOP as well as the recommended Nature-based and non-structural interventions.

1.3 Definitions and terminology

This section defines the terminology and definitions used in this report.

- ***Cove (Caleta):*** Marine resource extraction activities carried out by small fishing boats.
- ***Dirección de Obras Portuarias (DOP):*** Institution of the MOP that is charge of providing citizens with port and coastal, maritime, river and lake infrastructure services necessary to improve the quality of life, the socioeconomic development of the country and its national and international physical integration.
- ***Institución Financiera Internacional (IFI):*** Financial organization established or authorized by more than one country, operating under international law, with the objective of promoting global economic and financial cooperation.
- ***Juntas de Vecinos (JJVV):*** Common abbreviation used to refer to Neighborhood Boards, which are territorial community organizations that represent the residents of the same neighborhood unit.
- ***Ministerio de Desarrollo Social y la Familia (MSDF):*** Responsible of the design and implementation of policies, plans and programs on social development, especially those aimed at eradicating poverty and providing protection to vulnerable people and groups, promoting mobility and social integration.
- ***Ministerio de Obras Públicas (MOP):*** State ministry responsible for planning and building public infrastructure, as well as maintaining and managing it in Chile.
- ***Secretarias Regionales Ministeriales (SEREMI):*** Regional offices or representations of different ministries, serving as the link between the central government and the regions.
- ***Servicio Nacional de Pesca y Acuicultura (SERNAPESCA):*** It oversees compliance with fishing and aquaculture regulations, provides services to facilitate their correct implementation and carry out effective health management, to contribute to the sustainability of the sector and the protection of hydrobiological resources and their environment.
- ***Sociedad de Trabajadores Independientes (STI):*** Society of Independent Workers of artisanal fishermen and divers focuses on artisanal fishing, which is carried out in nearby coastal areas and on a small scale, with the resources obtained destined mainly for direct human consumption.

1.4 Context and problem statement

Queule town is located in the commune of Toltén at the southern end of the coast of the Araucanía Region, at latitude 39° 22' 59.99" S and longitude 73° 13' 60.00" W, adjacent to the Queule River, with the river mouth to the East (Figure 1). Queule has a cove (Caleta), located about 0.5 km from where the river enters the sea, which is important for the economy and transport in Queule. Local fishermen use the natural river channel for navigation between the Queule cove (Caleta) and the sea.

Near the river mouth, a spit (sandbar) extends from the beach into the river channel. This spit is in a state of apparent dynamic equilibrium, moving based on the energy balance between the river flow, wave forces, and tidal forces. During periods with high river discharge the spit recedes northward, opening the mouth. Conversely, when wave energy dominates, the spit advances southward, closing the river mouth. This natural fluctuation causes significant disruptions for local fishermen who need a certain channel depth and width to navigate (Figure 2, green circle).

Due to the natural sediment dynamics, navigating the river channel is challenging and frequently not possible during low tide. This has a direct impact on the activities associated with artisanal fishing, the local economy, and the safety of the fishing boats and fishermen. Furthermore, there is a perception that this problem has worsened in the past 10 years.

Three extensive studies have been carried out to find a solution. A sequentially increasing level of detail and analyses eventually resulted in different proposed design variants of structural interventions and dredging to deepen the connecting channel to the sea. However, the area where the works are proposed has a high ecological value regarding biodiversity, landscape, marine and terrestrial species. Therefore, constructions and activities must comply with strict regulations. Moreover, indigenous communities living in the area need to be consulted for the proposed works. They have expressed concerns about the possibility that dredging and the works could negatively affect the environment and specifically the areas where they harvest mussels and fish. For these reasons, they have rejected the proposed solutions.

At present, there is a solution that is not yet accepted by the indigenous communities and also does not yet have an approved environmental impact assessment.

Figure 1: Project area, Queule in Chile

Figure 2: Important locations in Queule. The green circle is the spit (sandbar), yellow circle is the Queule cove (Caleta), the red circle is the tidal flat/wetland area, the pink arrow indicates the town of Queule

2 System understanding

This chapter provides an overview of the various elements that define and influence the system. In particular, the perception of increased sedimentation at the river mouth in recent years is considered and evaluated. The potential causes may be due to various factors and have different origins, for which a comprehensive analysis of the entire system is required. The aim is to understand the root causes of the problem, a wider context which then offers directions for solutions. The chapter is divided into the following main sections: natural system, socio-economic context, governance and finance, each containing specific sub-sections that describe the critical components of the system.

2.1 Natural System

This section explores the natural aspects of the system, focusing on both physical (a-biotic) and biological (biotic) elements. The physical elements include features such as rivers, coasts, tidal flats, natural hazards, and climate change, which shape the system's dynamics. The biological elements encompass the living components, including bird populations and mussels, which contribute to the ecological balance and health of the system. Besides these natural elements there is also a land use component (included in chapter 2.1.1.1) which is influenced by humans.

2.1.1 Physical aspects (a-biotic)

The landscape around Queule is diverse, featuring coastal plains, river valleys, and tidal flats. This section aims to describe these physical (a-biotic) elements in detail. Additionally, it examines effects of natural hazards on the physical system, the impact of climate change, and discusses future changes.

2.1.1.1 River and catchment

The Rio Boldo O Queule River is a significant feature in the landscape around Queule, contributing to the region's diverse landscape. Stretching approximately 70 kilometers, the river originates in the heart of the mountainous area. Flowing through the valleys, it eventually reaches Los Boldos and bends southward into the coastal plains, where it runs parallel to the Río Toltén. At 18 kilometers from the river mouth, a side branch originating from a wetland area Southeast, joins the main river Rio Boldo O Queule and continues its course. The main river eventually reaches the Queule estuary, where water levels continuously change due to tidal waves from the Pacific Ocean.

The elevation data for the years 2000 and 2023 were compared, along with the watershed areas for the years 1986 and 2013. These comparisons were conducted to analyze potential changes in the Queule area that might influence the discharge of the Rio Boldo or Rio Queule River. Figure 3 illustrates the watershed of Rio Boldo O Queule (HydroSHEDS, 2013). This watershed was delineated using a Digital Elevation Model (DEM) generated after the 2010 earthquake, which the DOP has identified as the onset of issues at the river mouth. These issues may have been caused by changes in the catchment size. To investigate potential changes resulting from the earthquake, a DEM from 2023 was compared with Shuttle Radar Topography Mission (SRTM) data from 2000. Additionally, the resulting watershed was compared to the one created in 1986 by DGA – MOP (Qproject S.A., 2014). No significant changes were found, so the watershed shown in Figure 3 is considered representative of both the pre- and post-earthquake conditions. The river's origin is challenging to determine due to dense forest cover, but it is presumed to originate in the heart of the mountainous area, as indicated by the modelled HydroSHEDS (2013) data.

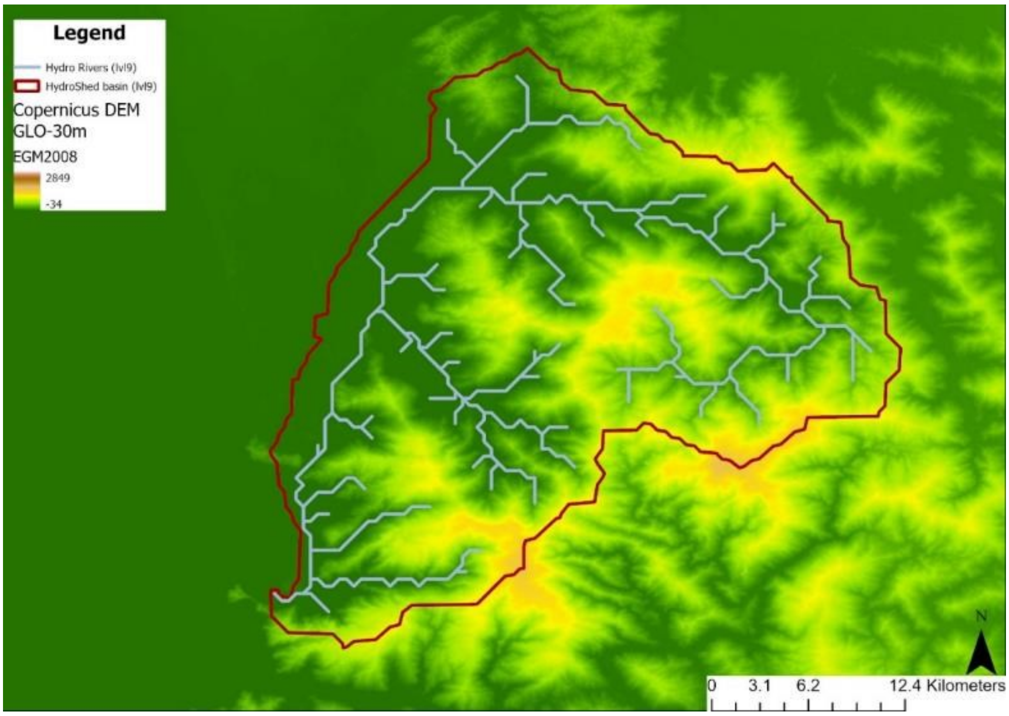


Figure 3: HydroSHEDS basin of Queule with modelled streams according to HydroSHEDS (2013) data based upon the elevation [m referenced to the Earth Gravitational Model 2008 (EGM2008)] of the region

Catchment characteristics and land use

The elevation and slope within the Queule River catchment varies significantly, as depicted in Figure 4, ranging from flatter areas with slopes of less than 10 degrees near the river mouth to steeper mountain ridges with slopes up to 75 degrees further inland. The variation in slope has several important effects on the river system and the surrounding landscape.

In the steeper areas further inland, the steeper slopes cause high runoff velocities, which enhances erosion and sediment transport. The steeper slopes in the mountainous regions contribute to higher rates of erosion, as the fast-moving water can carry larger sediment loads. This sediment is then transported downstream and deposited in the flatter areas (in the last 2 km near the river mouth the slope is close to zero). The deposition downstream created fertile floodplains and tidal flats.

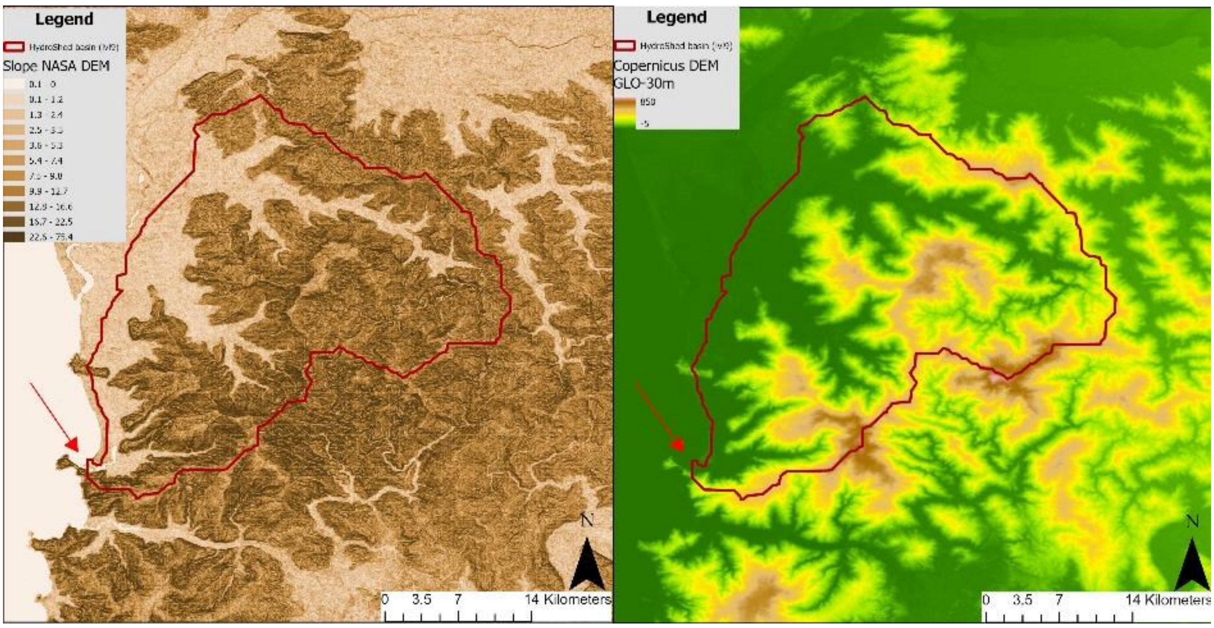


Figure 4: Elevation and slope Queule region, indicated by the red arrow is the town of Queule

Four distinct locations can be observed when further zooming into the waterways as defined by **OpenStreetMap** (OSM) data and shown in Figure 5. The blue circle indicates the probable origin of the river, evaluated based on satellite imagery and modelled HydroSHEDS (2013) data. The green circle marks the river division closest to the river mouth. The yellow circle indicates the second division, known as Rio Negro, which spans about 7 km and leads to a dried-up wetland area. The red circle highlights an old, braided pattern of the river (currently an anastomosing pattern), where some water is visible in satellite imagery, though not all channels are active. This suggests that the river may have previously had a higher sediment load, variable water flow, shallow channels, and erodible banks. For the past 20 years, satellite images show that water has been flowing through a single channel, while the other channels remain inactive.

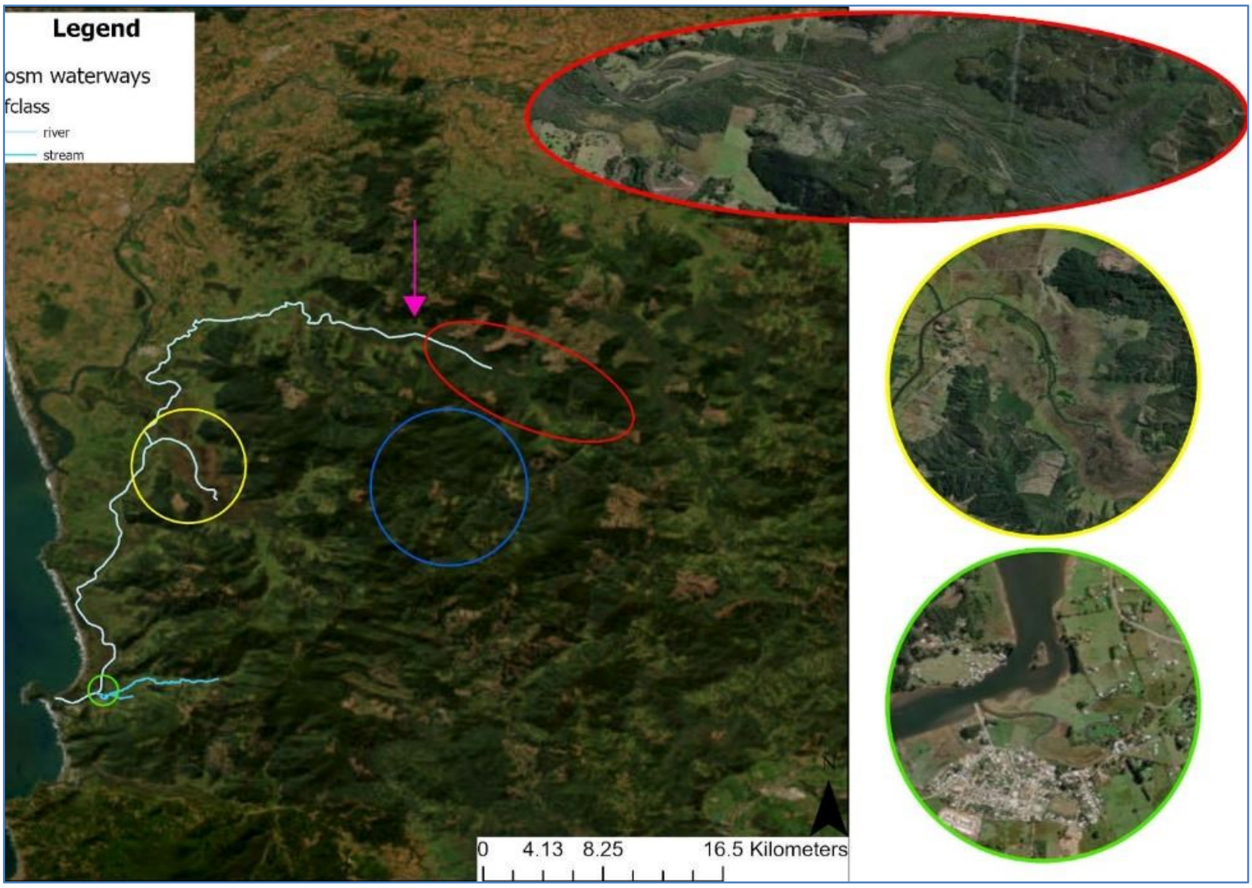


Figure 5: OSM waterways in Queule basin with different points of interest. Green circle is the first side river division, yellow circle is the second division of the river leading to a dried-up wetland area, red circle is old braided pattern of the river (now anastomosing river pattern), blue circle is an estimate of the origin of the river.

Figure 6 shows the land use in the catchment. Around Queule there is mostly grassland or tree cover. Around the river, there are some wetlands. The soil along the Queule River, which flows parallel to the coast, is highly permeable and easily allows water to infiltrate. In contrast, the rest of the basin is composed of metamorphic rocks with very low permeability, making water infiltration nearly impossible (Qproject S.A., 2014).

In Cautin, Araucania (indicated with black line in Figure 7), the region in which Queule is located, there was a natural forest of 1.07 million hectare in 2010, extending over 58 % of its area (Global Forest Watch, 2000-2023). Between 2001 and 2023 0.22 million hectares of this area were lost, which is equivalent for 18 % of the total tree cover. In the area near Queule, indicated in Figure 7, there were some areas where the tree cover increased between 2000 and 2023, but overall, there was net loss in tree cover as well. Tree cover can affect the sediment balance in the region. Vegetation stabilizes the soil and affects erosion, sedimentation and infiltration. The reduction in tree cover could have reduced in decreased infiltration, increased erosion and hence an increase in flow and sediment from the hills towards the river.

A significant area of the Queule River consists of wetlands, especially near the river mouth (12). These areas present high ecological value (see Biological section), some of which are legally protected (see Institutional section).

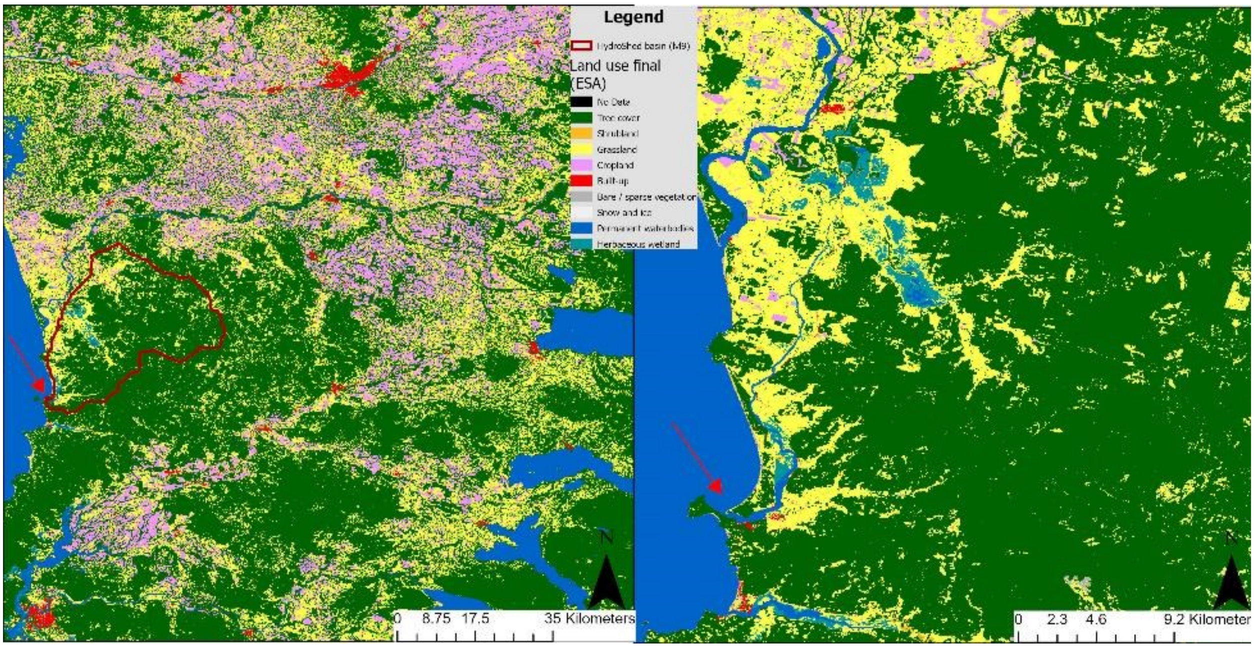


Figure 6: Land use ESA 2021 (10m) (Zanaga, 2022)

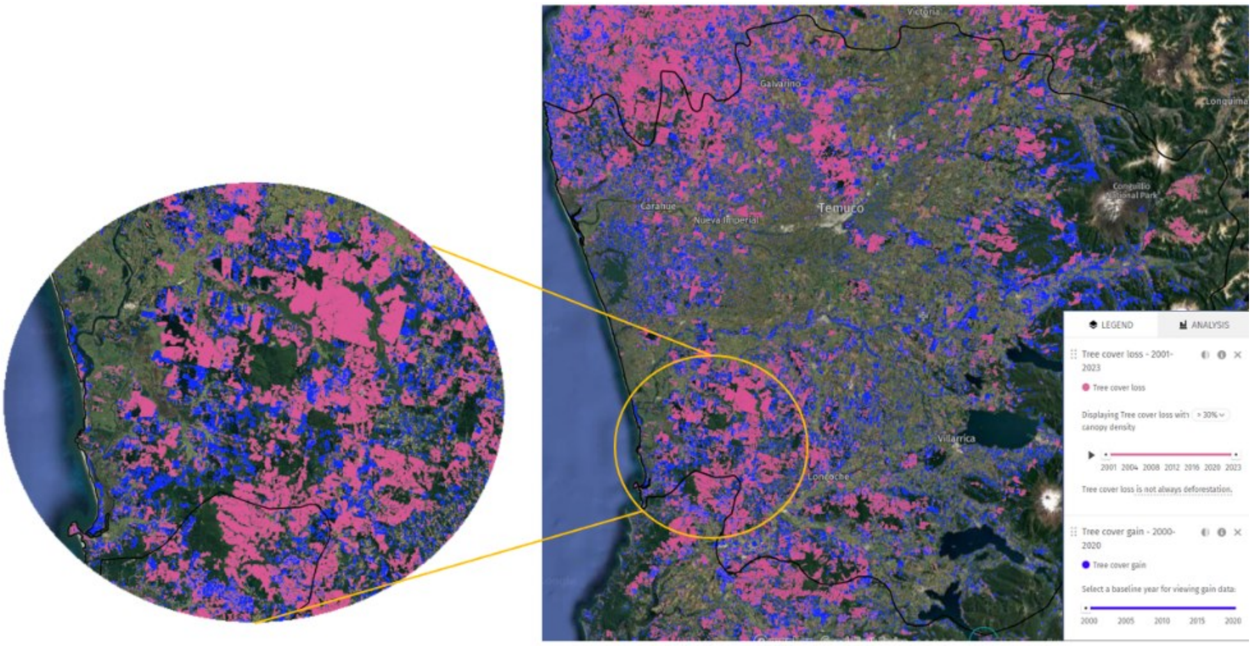


Figure 7: Tree cover loss and gain. Pink means tree cover loss, blue means tree cover gain over the last 25 years (Global Forest Watch, 2000-2023)

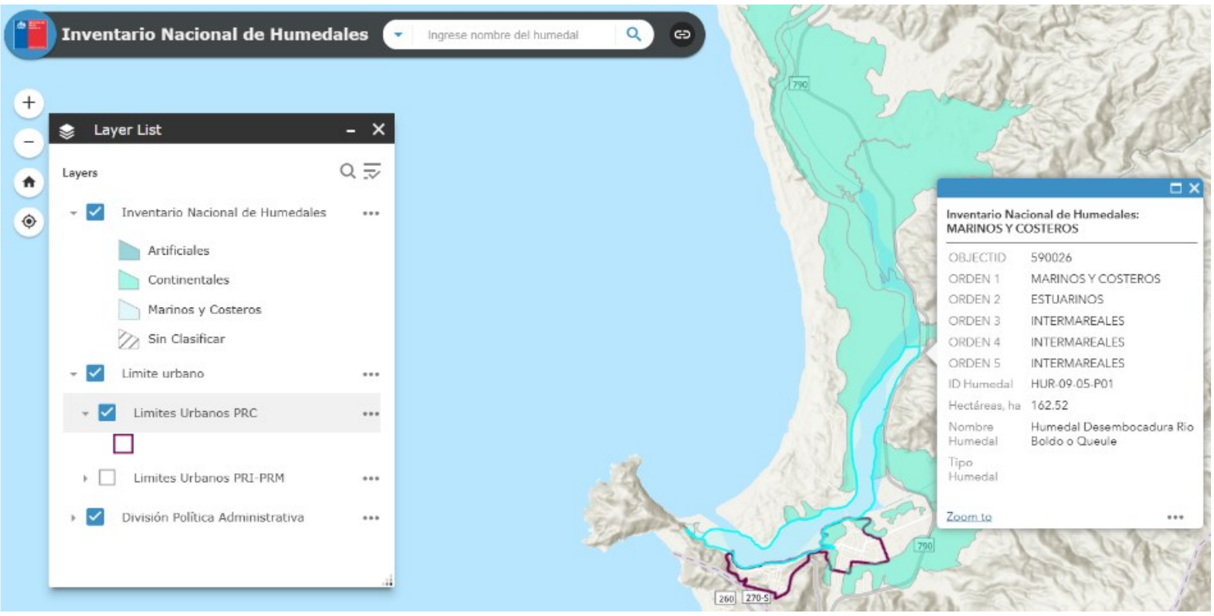


Figure 8 Inland and coastal wetlands identified in the National Inventory of Wetlands (Ministerio del medio ambiente, n.d.)

Precipitation

Queule is located in the mediterranean climate zone. The annual precipitation has varied over the last 24 years but shows a decreasing trend (Figure 9). Following this trend, the total precipitation decreased by about 500 to 1000 mm, which is significant compared to the total precipitation amount. Figure 9 shows the annual trend and does not reflect seasonal changes within the year. However, the influence of El Niño Southern Oscillation (ENSO) can be observed in the lower yearly precipitation amounts. ENSO influences precipitation and temperature in Central Chile, including the Queule region. El Niño events generally lead to warmer surface air temperature and increased rainfall in the Queule region while La Niña generally resulting in drier conditions in the region.

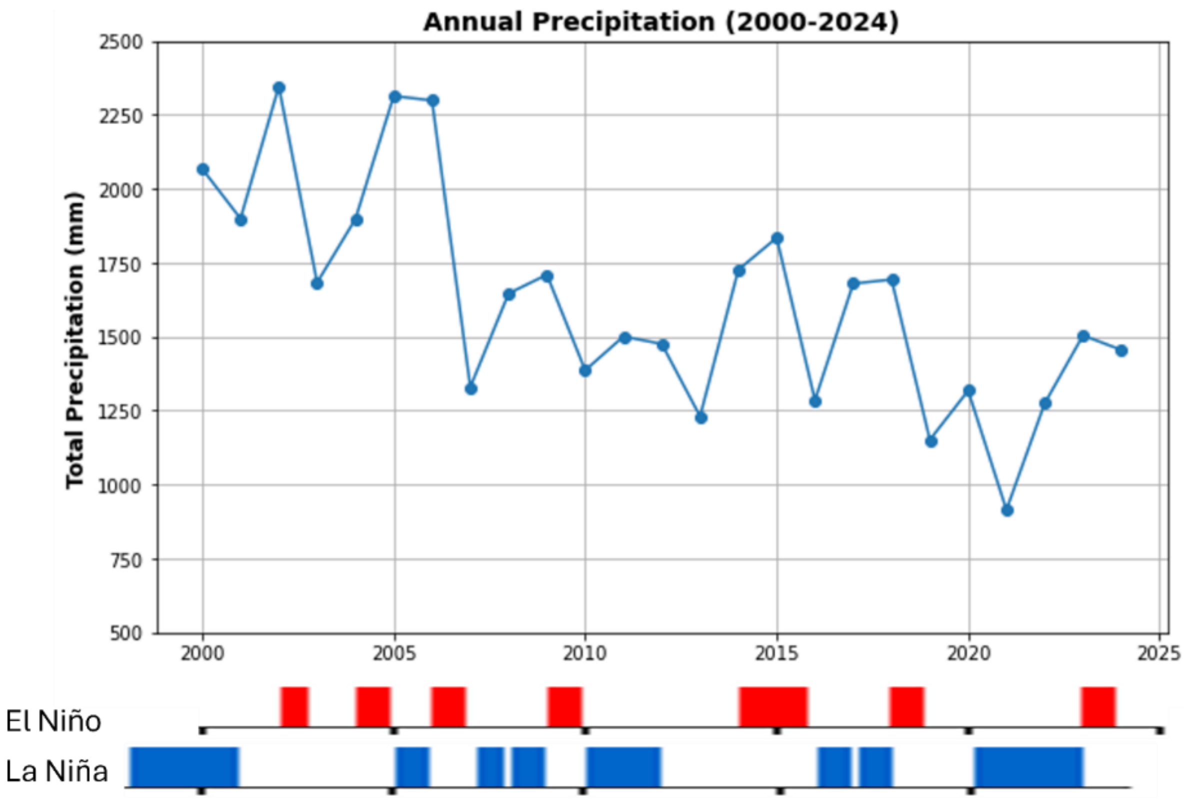


Figure 9: Historic precipitation (GPM) (Huffman, 2019) with past El Niño and La Niña events (National Oceanic and Atmospheric Administration, 2025)

Discharge

The river discharge depends on the amount of precipitation and shows seasonal fluctuations, being higher during the summer months and lower in the winter. Although there is no annual record of discharges available, some modelled data and an average discharge calculated from another study provide insight in the river's characteristics (González, 1999). The average freshwater discharge is approximately 50 m³/s, ranging from 17 m³/s during dry summers to 200 m³/s during rainy winters (González, 1999). Figure 10 presents the modelled streamflow data of the Queule River from 1940 to 2024, indicating a gradual increase in average discharge during the 1900s, followed by a clear decrease in the last 20 years (GEOGLOWS, 2024). Since this is modelled data and not based on direct measurements, the discharge values should not be taken as exact. However, the trend, influenced by climatological aspects, shows a decrease in discharge.

The presence of water upstream (first 20 km of the river) throughout the year, as visible via satellite imagery, suggests that the river does not completely dry up during the summer. In the mountainous areas, it was not possible to assess if there is water in the river all year, as the vegetation blocks the satellite imagery. Based on imagery between 1985 and 2016 it seems that some wet areas within the basin have changed to dry areas. These changes are particularly noticeable in the wetland area and the upstream meandering sections of the river. Additionally, the larger Tolten River also seems to have a reduced discharge based on the imagery. This suggests that the discharge variations of the Rio Queule are influenced not only by the catchment characteristics of Queule but also by broader climatological changes in the region.

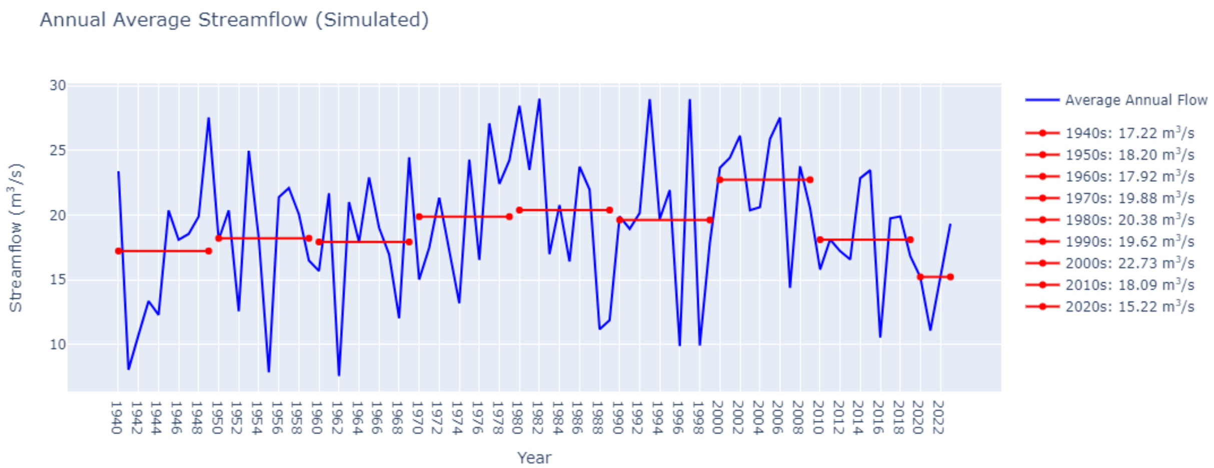


Figure 10: GEOGLOWS annual average Streamflow modelled from Queule river from 1940 to 2024 with 10-year averages (GEOGLOWS, 2024)

Sediments, erosion and sedimentation

Figure 11 and Table 1 shows the results of the sediment analysis in the river (Aguas Consultores SpA, 2022). The river sediment is mostly sand. Upstream areas exhibit a more varied grain size distribution, including mud. Locally, a large gravel component is found. This variation reflects the dynamic processes and environmental conditions influencing sediment deposition along the river.

Figure 11 indicates the amount of bed level erosion and accretion in winter and summer. Locations. Generally, sedimentation occurs during summer as discharges and flow velocities are low. At some locations near the river mouth there is erosion also in summer. Here, the tidal influence may be larger.

Figure 11: Coastal and riverine measurement points

Table 1: Sediment distribution [%] at riverine measurement points. For locations see Figure 11

Station		Decreasing size of sediments					
		Gravel		Sand		Mud	
		Summer	Winter	Summer	Winter	Summer	Winter
Distance from river mouth →	E13	0.76	2.46	99.23	97.31	0.01	0.23
	E14	7.02	0	92.97	99.67	0.01	0.33
	E15	0.28	0.04	99.71	99.84	0.01	0.12
	E16	0.80	0	99.18	99.93	0.02	0.07
	E17	0.61	0	98.82	99.93	0.57	0.07
	E18	0.21	0.01	99.46	89.74	0.33	10.25
	E19	1.97	2.22	92.23	77.34	5.8	20.44
	E20	1.41	0.01	95.07	89.69	3.52	10.3
	E21	0.58	0.25	98.71	92.69	0.71	7.06
	E22	16.32	0.5	65.6	59.36	18.08	40.14
	E23	7.13	0.01	86.59	84.46	6.28	15.53
	E24	3.96	0.03	81.47	73.37	14.57	26.6
	E25	1.72	0.18	85.37	60.33	12.91	39.49
	E26	5.23	1.85	91.97	93.75	2.8	4.4
	E27	5.82	0.01	89.18	89.78	5	10.21
	E28	25.54	1.46	73.89	80.1	0.57	18.44
	E29	6.12	11.3	93.77	85.03	0.11	3.67
	E30	5.09	0.09	81.79	70.79	13.12	29.12

0% — 100%

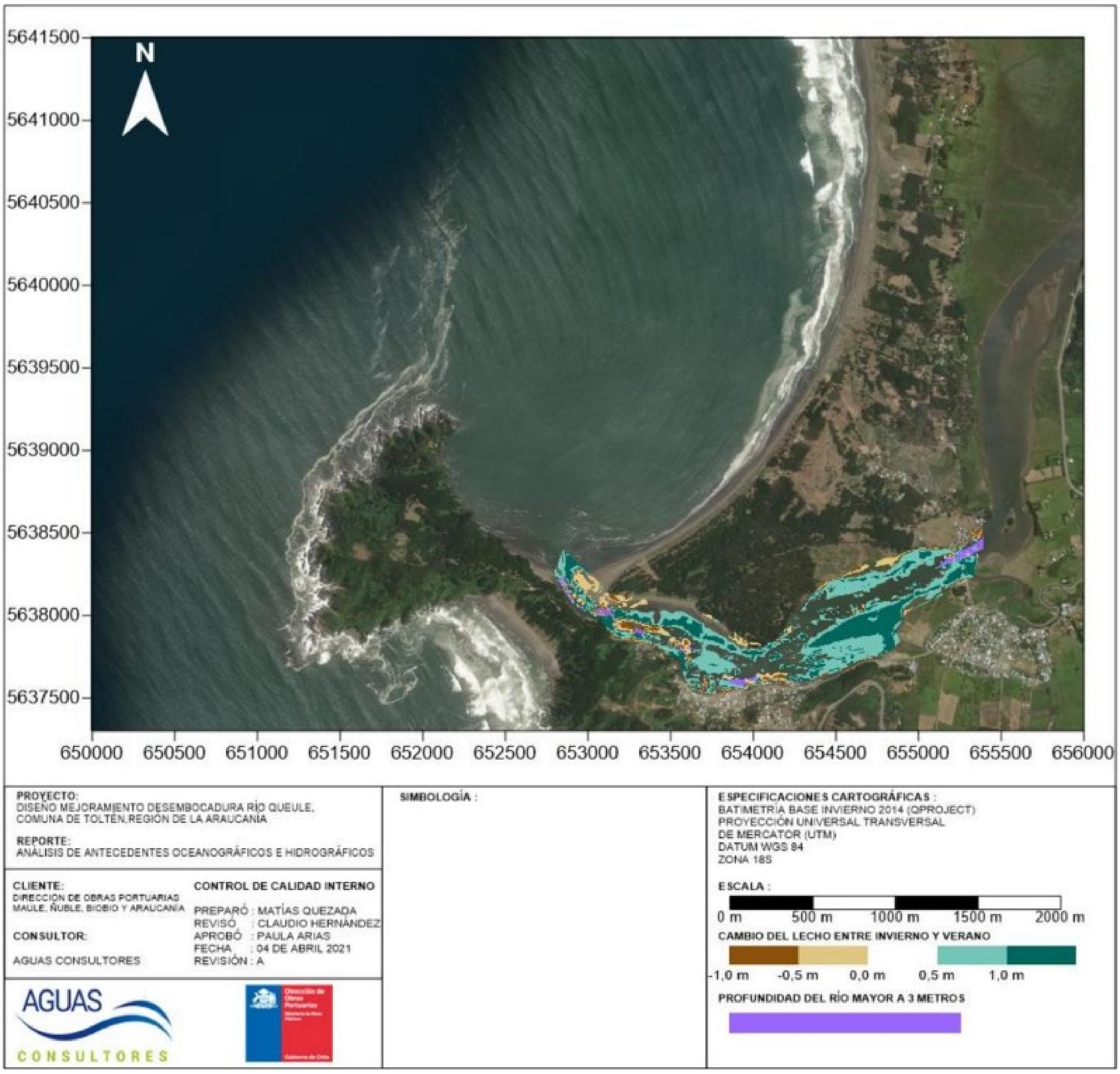


Figure 12: Difference in riverbed elevation in winter (brown) and summer (blue) (Aguas Consultores SpA, 2022)

2.1.1.2 Coast

Bathymetry
The coastal system around Queule is crucial for local fishermen, who rely on accessible waterways to reach the sea. A bathymetric survey conducted in 2014, shown in Figure 13, reveals limited water depth north of Punta Ronca and at the river mouth of Río Queule, causing challenges for fishing boats leaving the Queule cove (Caleta) (Qproject S.A., 2014).

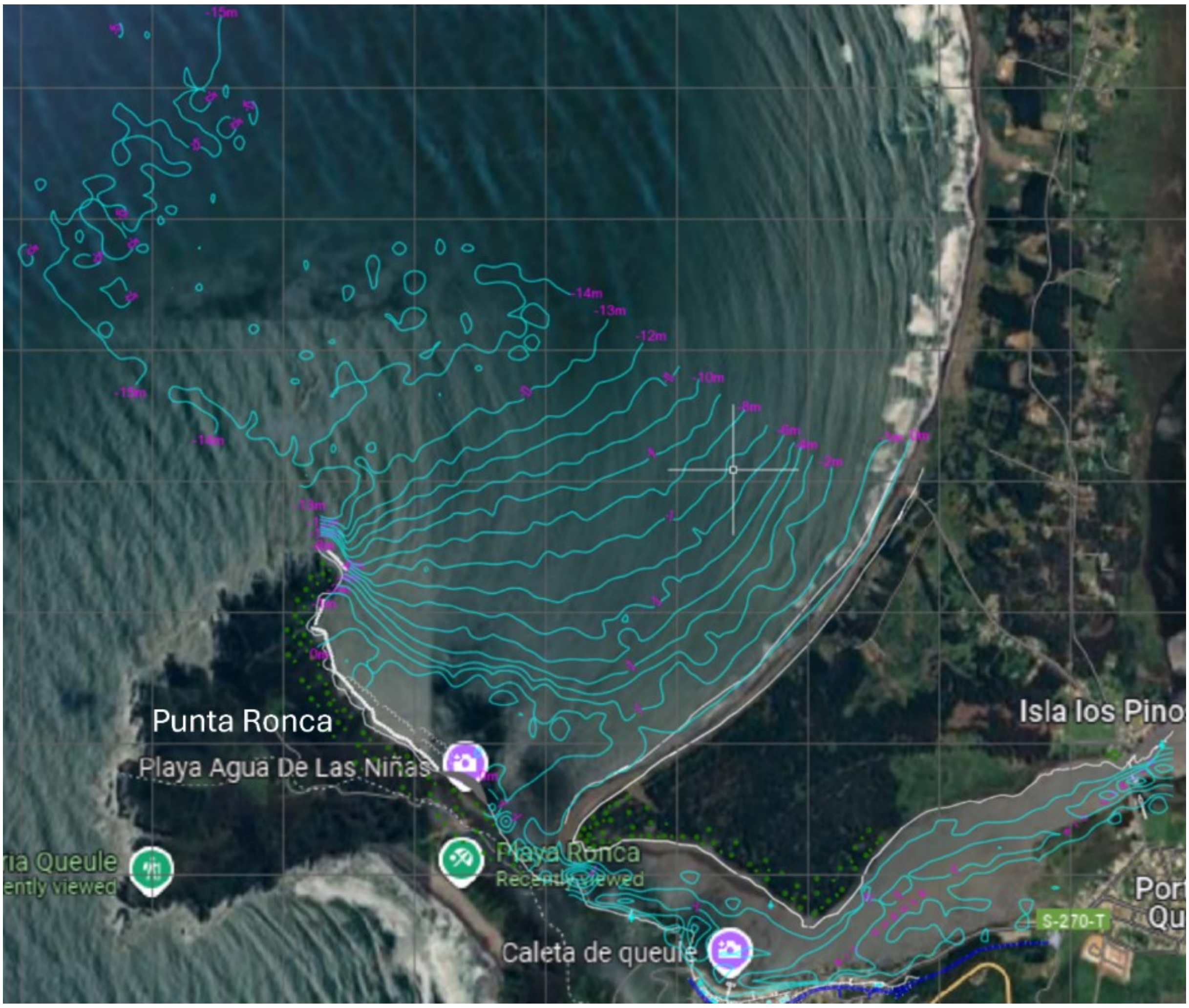


Figure 13: The bathymetry obtained from a survey in 2014 mapped on satellite imagery (Qproject S.A., 2014)

Tide

The tides at the coast of Queule are mixed, meaning they have characteristics of both daily (diurnal) and twice-daily (semi-diurnal) tides (Qproject S.A., 2014). The water level difference between the mean of the lowest high tide and the mean lowest low tide is 0.66 meter (0.71 in winter) and 0.90 meter (1.09 in winter) respectively at the river and at the coast (Figure 14). The water level near the river mouth is generally related to the tide and therefore well-predictable: the correlation between in situ records and the forecast reached 87 % (93 % in winter) at the river and 97 % (89 % in winter) at the coast.

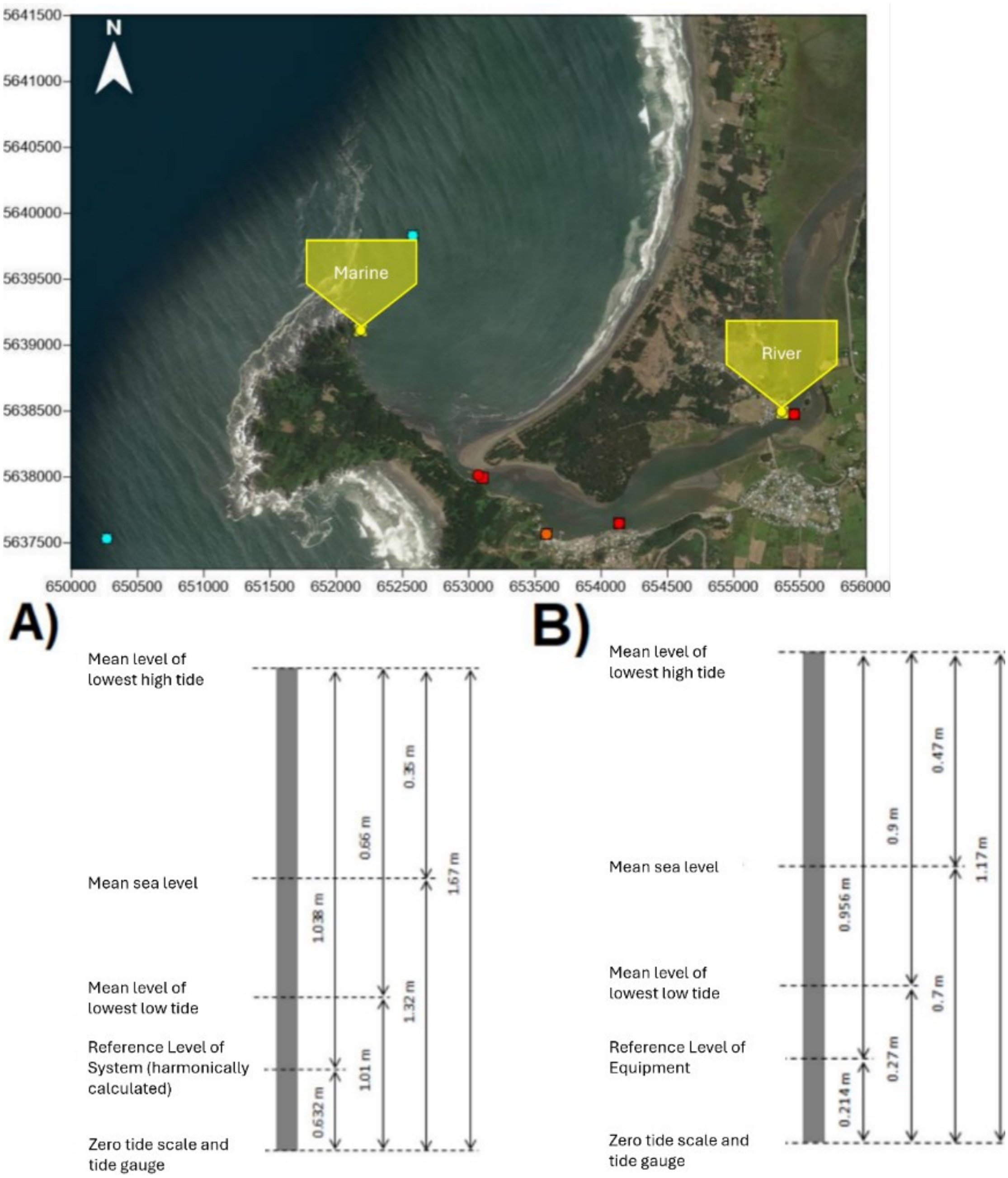


Figure 14: Above: Location of marine and river measurement points. Below: water levels obtained in summer of 2014 at the river (a) and marine (b) (Qproject S.A., 2014)

Waves

The waves offshore of the coast of Queule are generally unidirectional and come from the west-southwest direction during both summer (Figure 15) and winter. In the winter, in addition waves from the west are observed.

The wave heights in winter mostly range from 1.25 to 2.5 meters. Heights greater than 2.5 meters occur about 13 % of the time. In summer, wave heights are slightly higher and mostly range from 1.75 to 3.50 meters. Peak periods are between 6 and 16 seconds.

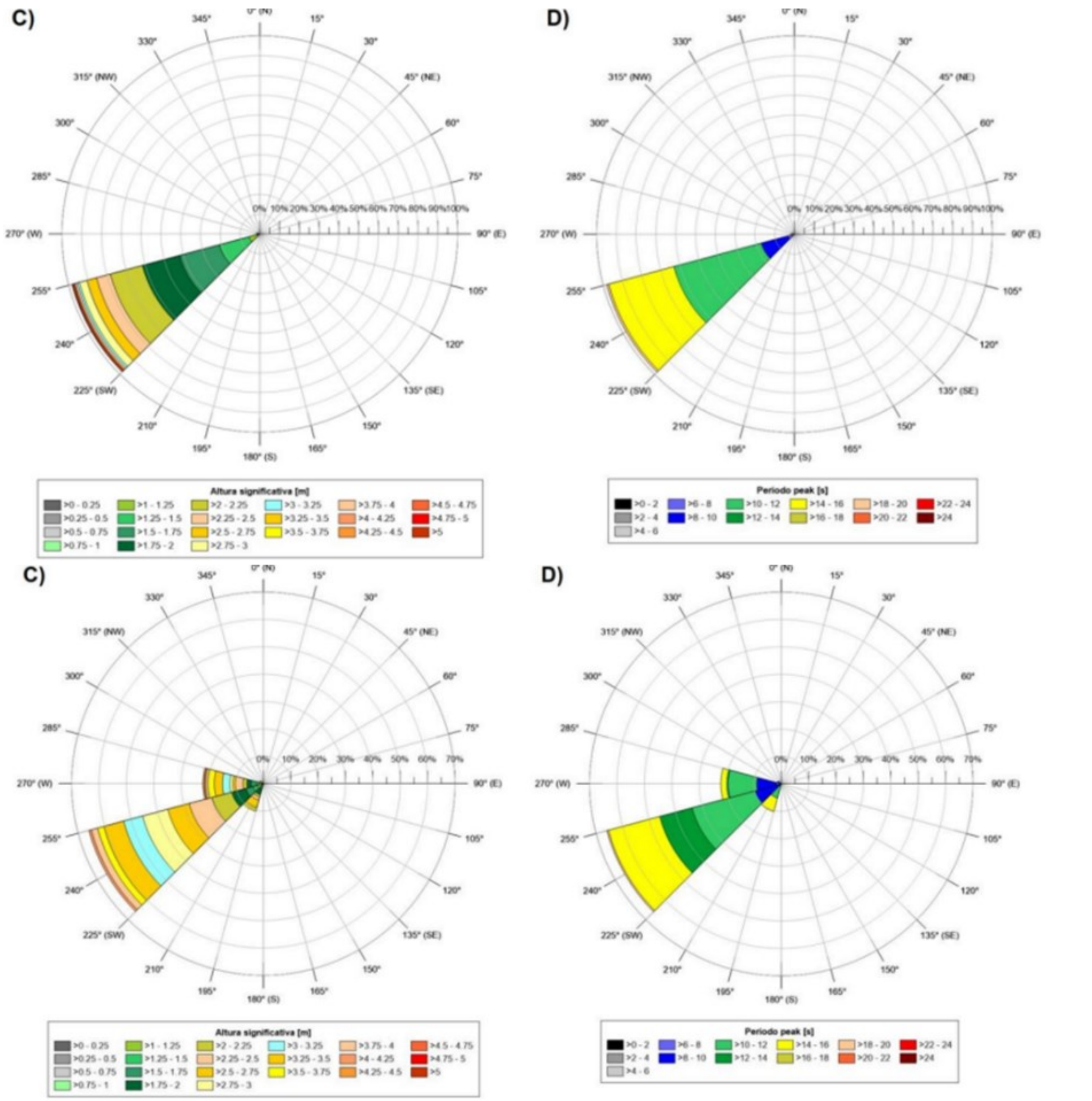


Figure 15: Significant wave height (left) and peak period (right) for Coasta during summer (upper figures) and winter (lower figures) (Portuarias, Ministerio de Obras Públicas/Dirección de Obras, 2022)

Sediment Composition

The marine sediments analysis indicates that the coast predominantly contains (fine) sand (Aguas Consultores SpA, 2022). The sediment distribution of the marine measurement points (see Figure 11) can be seen in Table 2.

Table 2: Sediment distribution at coastal measurement points

Station		Decreasing size of sediments					
		Gravel		Sand		Mud	
		Summer	Winter	Summer	Winter	Summer	Winter
← Distance from coast	E1	0.76	0.09	98.65	99.81	0.59	0.1
	E2	1.40	0.06	98.49	99.3	0.11	0.64
	E3	0.91	0.01	97.67	99.99	1.42	0
	E4	0.66	0.01	99.15	98.87	0.19	1.12
	E5	0.03	0	99.95	99.56	0.02	0.44
	E6	0.09	0	99.86	99.96	0.05	0.04
	E7	0.79	0.02	98.92	99.94	0.29	0.04
	E8	0.10	0	99.89	99.31	0.01	0.69
	E9	0.14	0	99.84	99.97	0.02	0.03
	E10	0.60	0	99.39	99.98	0.01	0.02
	E11	0.71	0	99.26	100	0.03	0
	E12	0.53	0	99.5	100	0.02	0

0% 100%

Morphology

The waves offshore of the coast of Queule are generally unidirectional and come from the west-southwest in the summer and west during the winter (see Figure 16). In general, these waves create longshore sediment transport in northern direction along the Chilean coastline. However, due to the presence of Punta Ronca, the waves undergo diffraction as they pass the peninsula. This causes waves to bend around the peninsula. Therefore, in the most southern part the net longshore sediment transport is directed southward resulting in the formation of the spit (Figure 16).

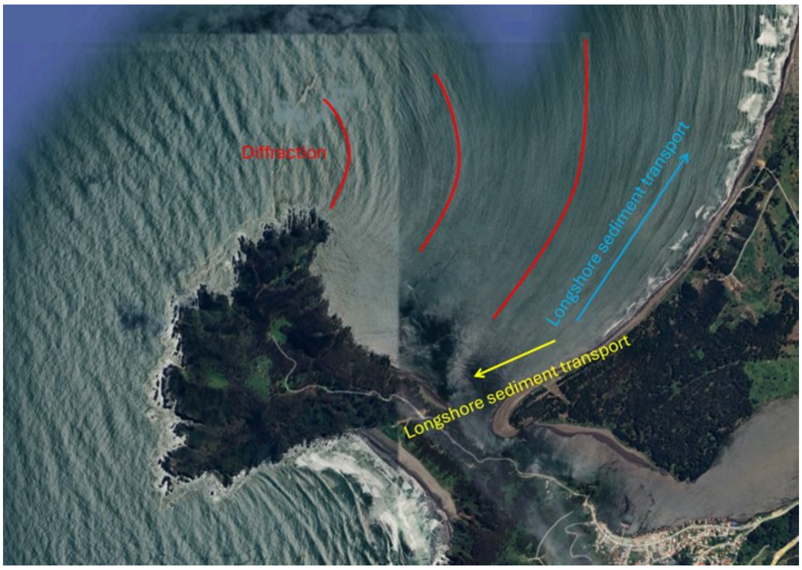


Figure 16: Schematization of wave and net sediment transport directions near Queule

Salinity
The salinity in the estuary exhibits seasonal variation, being lowest (0.5-2.0%) from June to September, which coincides with the period with the highest rainfall (EDUARDO JARAMILLO, 1992). Low salinities are primarily observed at the surface waters and during low tide, while salinities of up to 0.285% have been recorded in the lower part of the water column.

2.1.1.3 Tidal flat

The tidal flats and wetland area in the Rio Boldo O Queule River estuary are vital habitats for a diverse array of migratory and resident shorebirds and waterbirds (Smith, 2012). These intertidal flats were formed by water currents and sedimentation resulting from a massive earthquake (Mw 9.5) and tsunami in 1960. The intertidal flat system comprises of three types of microhabitats as shown in Figure 17:

A. Sandflat: This area has a sandy substrate, no vegetation, and a total exposed area of 3.6 hectares during lower spring tides.
B. Vegetated Sandy-Muddy Bottom: Adjacent to a grassland with low vegetation composed of *Sarcocornia fruticosa*, this area has a total exposed area of 1.4 hectares.
C. Mudflat: This area has a muddy bottom and adjacent high vegetation consisting of *Juncus* and *Scirpus*, with a total exposed area of 2.1 hectares during lower spring tides.

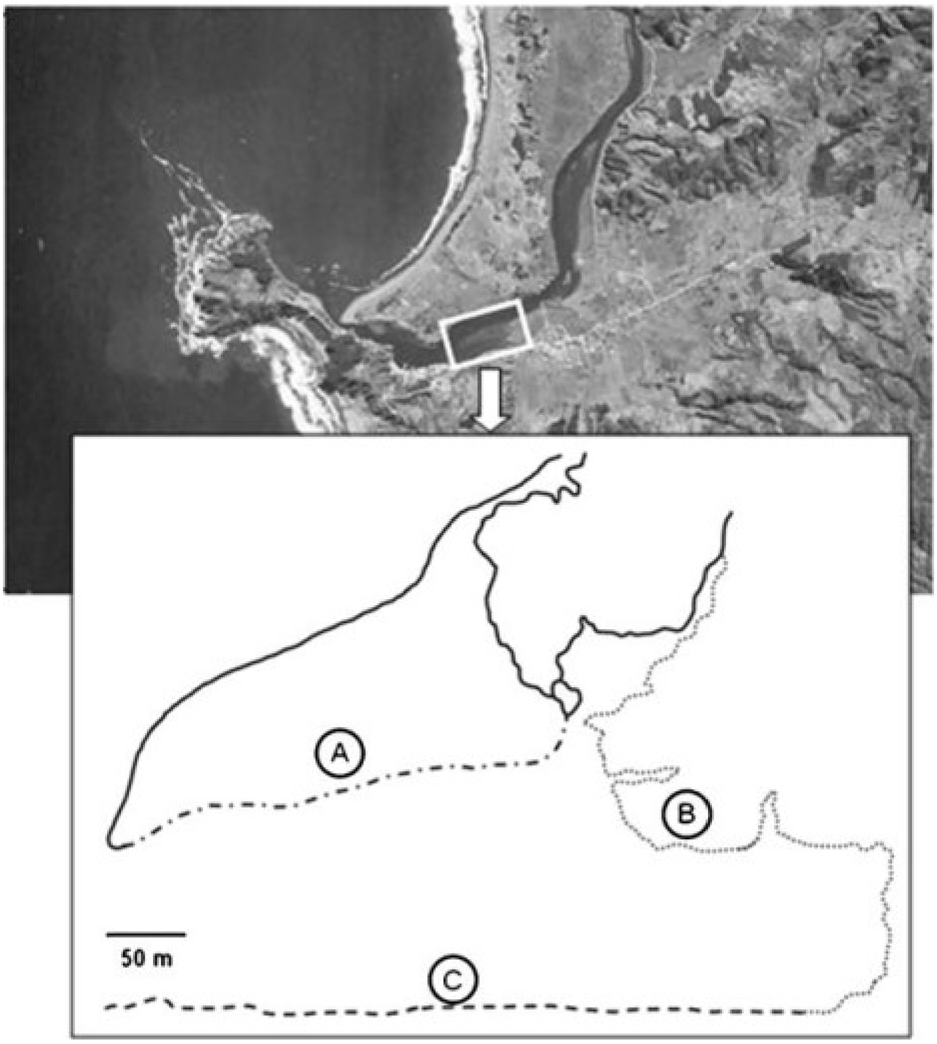


Figure 17: The intertidal flat system of the Queule river mouth with its microhabitats defined as A (Sandflat), B (Vegetated Sandy-Muddy Bottom, and C (Mudflat) (Smith, 2012).

2.1.1.4 Natural hazards

Earthquakes
The Queule River mouth has undergone significant changes due to seismic activity, particularly from tsunamis triggered by major earthquakes (earthquaketrack, 2025). The first notable alteration occurred during the 1960 tsunami, caused by the Valdivia earthquake (Mw 9.5) on May 22, 1960. The 1960 Valdivia earthquake caused the land to sink, creating depressions that were filled with sediment by the subsequent tsunami, forming the tidal flat in Queule, while narrowing the channel near the river mouth (González, 1999). The land subsided by approximately 1.5 meters, leading to a permanent change in the river's morphology.

Before the 1960 tsunami, historical images and orthophotos show the dynamic nature of the spit at the river mouth. After the tsunami, the river mouth became more stable, with a well-defined spit system that has shown variations in size.

The area was again impacted by a tsunami on February 27, 2010, following the Cobquecura earthquake (Mw 8.8). This earthquake occurred at the boundary between the Nazca and South American tectonic plates, causing significant changes to the river's mouth and further influencing its morphology. Despite this event, the tidal flats remained intact and visible on satellite imagery.

To investigate potential changes caused by the earthquake in 2010, a DEM of the year 2023 was compared with SRTM data from the year 2000. Both increases and decreases in elevation were observed but based on the pattern this is most likely related to differences in measuring method. There was probably no significant change in the watershed.

Extreme flood events
Extreme river discharges could substantially alter the morphology of the coastal spit. A model study indicated retreat of up to 120 meters for flood events with a 50-year return period in a situation with a dam in the river mouth (Figure 18, structure not shown).

Figure 18: Scenarios of spit retreat due to extreme flood events (QProject S.A., 2014)

2.1.1.5 Climate change

Climate change is expected to significantly alter the frequency, intensity, exposure, and magnitude of various hazards in Chile, including wildfires, floods, landslides, droughts, and sea level rise. These changes pose substantial risks to economic growth and development, particularly affecting sectors such as electricity generation, agriculture, and public health (World Bank Group, 2021).

Table 3 shows the historic and projected future yearly rainfall in Queule region obtained from NASA NEX-GDDP-CMIP6 data. The total yearly rainfall is projected to decrease by more than 20% in 2070 for the SSP5-8.5 climate scenario. This reduction, combined with rising temperatures (1.4 °C by 2050 and by 3.1°C by 2090 for the SSP5-8.5 climate scenario) and increased wind intensity that could lead to higher evapotranspiration pressures, is expected to surface water bodies, runoff and river flow.

Table 3: Historic and projected future yearly rainfall in Queule obtained from NASA NEX-GDDP-CMIP6 data

Historic	SSP2-4.5		SSP5-8.5	
	2050	2070	2050	2070
1,439 mm/year	1,334 mm/year	1,236 mm/year	1,267 mm/year	1,121 mm/year

The coastal system is also expected to be affected by climate change. Research conducted by Winckler Grez et al. (2020) reveals significant trends in wave height and direction driven by climate change. Notably, there is an observed increase in wave heights and a southward shift in wave direction along the Chilean coast. These expected changes are the result of the intensification of the Southeast Pacific Subtropical Anticyclone, which influences wind patterns and coastal surges. It is unclear how this will affect Queule as there will be more wave dissipation by Punta Ronca from incoming waves from southern direction, but the incoming wave heights themselves are higher.

Climate change is also expected to cause an increase in sea level. The local sea level is expected to rise by 0.26 m in 2070 and 0.54 m in 2100 under climate scenario SSP5-8.5 (NASA, s.f.).

It is not expected that the increase in sea level will lead to an increase in channel depth for navigation. In case of a higher sea level, waves will initially experience less bottom friction. Hence, wave dissipation will decrease, resulting in larger waves, which will still transport sediment towards the river mouth. The exact coastal changes are difficult to predict, but overall existing problems are expected to be further exacerbated by climate change mainly due to the expected decrease in river discharge.

2.1.2 Biological aspects (biotic)

This section aims to describe available biological (biotic) elements. The biological elements encompass the living components, including bird populations and mussels, which contribute to the ecological balance and health of the system.

2.1.2.1 Birds

During the summer, the intertidal flats (for location see Figure 17) become temporary homes for various bird species, creating a short but significant bird assemblage. Migratory species such as the Whimbrel (Numenius phaeopus) and Greater Yellowlegs (Tringa melanoleuca) travel from the Northern Hemisphere to utilize these flats, primarily selecting sandy substrates for feeding. Resident species, including the Southern Lapwing (Vanellus chilensis) and Yellow-billed Pintail (Anas georgica), also rely on these tidal flats. The Southern Lapwing prefers sandy substrates, while the Yellow-billed Pintail selects muddy-sandy bottoms, especially during spring tides. These resident birds engage in feeding activities during both tidal conditions, with the Yellow-billed Pintail resting during neap tides. The intertidal flats provide essential feeding and resting areas for these birds, supporting their survival and migration. The availability of different microhabitats within the flats allows various species to thrive, depending on their substrate preferences and tidal conditions.

The ecological importance of the tidal flats cannot be overstated. They support a wide range of bird species by providing critical resources during different tidal conditions. However, the study by Smith et al. (2012) also highlights the need for conservation efforts to protect these habitats. The intertidal flats are susceptible to natural disturbances such as mega-earthquakes and tsunamis, which can significantly alter or destroy these environments. Protecting these habitats is essential for the continued support of both migratory and resident bird species.

2.1.2.2 Mussels

In addition to birds, mussels also inhabit the tidal flats. The mussels Choromytilus chorus (MOLINA) and Mytilus chilensis (HUPE) are the most distinctive bivalves of the subtidal bottoms of the Queule River estuary (EDUARDO JARAMILLO, 1992). Part of these tidal flats have been used for artificial farming since 1992. In some of the artificially farmed areas of the estuary, the semi-buried mussels reach densities as high as 250-300 adult individuals per square meter. This high density may limit space for other infaunal organisms compared to areas without such densely packed bivalves. The soft substratum in these mussel beds is also expected to have different physical and chemical characteristics than bare areas due to a higher content of mussel bio deposits. Consequently, these contrasting microhabitats are likely to accommodate differently structured infaunal communities.

Overall, the Queule River Estuary's tidal flats play a crucial role in maintaining bird biodiversity, mussel health, and ecological balance in the region. The conservation of these habitats is vital to ensure that they continue to provide essential resources for the diverse bird populations that depend on them.

2.2 Socio-economic context

This section addresses the socio-economic dimensions of the system. It presents the various stakeholders involved, and social and economic characteristics of the system.

2.1.2 Social and economic characteristics

Queule had a total of 2129 inhabitants in 2017, according to the census of that year, with an almost even distribution between men and women. The urban population was 40 %, which is below the average of the Araucanía Region being 71 %. The people that consider themselves belonging to an indigenous community was 43 %.

Around 60 % of the population do not have basic services in their homes. Poverty levels in terms of economic income is 35 % whereas the multidimensional poverty surrounds 45 %. Table 4 shows that number of workers per economic sector in Queule.

Table 4: Number of workers per economic sector in 2019 (Aguas Consultores SpA, 2022)

Economic sector	Number of workers	Workers in %
Agriculture, livestock, forestry and fishing	74	13 %
Manufacturing	25	5 %
Trade (large and small), workshops	288	52 %
Public administration, defense	124	22 %
Education	43	8 %

In 2015, there were 744 registered fishermen[1] in Queule, who are organized into unions, one association, and one cooperative (see Stakeholders below). The number of people directly involved in fishing, and as a percentage within other economic activities (Table 4), indicates fishing as one of the main drivers of Queule's economy.

Queule cove (Caleta) is the only among the three in Toltén commune (Figure 19) having fishing boats for sailing on the high seas with a stationary engine, a hold and a cabin. The other two coves (Caletas), *La barra del Toltén* and *Los Pinos*, have wooden fishing boats that can use one or two pairs of oars. Queule cove (Caleta), located in an urban area, has a pier or dock, shed, warehouses, bathrooms, defense wall, headquarters, processing room and cold storage. Los Pinos cove (Caleta)is located in a rural area and has a ramp, shed and winch.

[1] https://caletaenlinea.sernapesca.cl/

Figure 19: Fishing coves in Toltén commune

The main fishing extraction is of benthic and demersal resources belonging to the groups of mollusks, fish, crustaceans and echinoderms (QProject S.A., 2014). The resources mainly come from open access areas and areas for the management and exploitation of benthic resources (AMERB). The products are generally commercialized through industrial plants in the case of AMERB, or sold to intermediaries for later sale in places such as Temuco, Santiago and abroad (e.g., Perú). The products are usually collected after arrival in Queule by intermediary traders. Small quantities (0.2 %) are delivered to local restaurants. The product is sold fresh in wooden and plastic boxes.

In 2013, the characteristics of the fishing boats were a length range between 7.7 m and 15 m, wooden made, with a hold capacity between 4 m³ and 27.2 m³, and registered gross tons of the fishing boats ranging from 5 to 45.7 (QProject S.A., 2014). The fishing boat power was between 12 and 400 hp.

Tourist operators and diving schools are also actors that require sailing for their business. There is no information on the size of the sector or on the type of fishing boats they deploy. About the farmers or collectors of mussels no information is currently available.

2.1.3 Stakeholders

The main stakeholders in Quelue identified by DOP are:

Table 5: Main stakeholders and caletas in Queule. Source: DOP and SERNAPESCA

	Organization (Spanish original name)	Organization (English translation)
1	Asociación Gremial de Armadores de Embarcaciones Pesqueras Artesanales de Queule	Association of Owners of Artisanal Fishing Boats of Queule
2	STI de Pescadores y Buzos Artesanales Queule	STI of Artisanal Fishermen and Divers Queule
3	STI Armadores Pelágicos y Pescadores Artesanales de Queule	STI Pelagic Owners and Artisanal Fishermen of Queule
4	Sindicato de Armadores, Pescadores Pelágicos y Actividades Conexas de Caleta Queule	Union of Shipowners, Pelagic Fishermen and Related Activities of Caleta Queule
5	Cooperativa de Pescadores Artesanales Caleta Queule	Cooperative of Artisanal Fishermen Caleta Queule
6	Sindicato de Pescadores, Tripulantes, Buzos y Turismo	Union of Fishermen, Crew, Divers and Tourism
7	STI Armadores Pelágicos y Cerqueros Caleta Queule	STI Pelagic Owners and Purse Seiners Caleta Queule
8	Asociación Gremial de Armadores y Pescadores Artesanales Pelágicos de la Araucanía	Association of Owners and Artisanal Pelagic Fishermen of Araucanía
9	STI de Pescadores Artesanales y Turismo Queule	STI of Artisanal Fishermen and Tourism Queule
10	JJVV Caleta Queule	JJVV Caleta Queule
11	JJVV Portal Queule	JJVV Portal Queule

12	Caleta Los Pinos Queule	Caleta Los Pinos Queule
13	Comité de Agua Potable	Drinking Water Committee
14	Sindicato De Pescadores Artesanales Recolectores Orilla, Buzo Y Turismo "Lafquen Mapu"	Union of Artisanal Fishermen, Shore Collectors, Divers, and Tourism "Lafquen Mapu"
15	Cooperativa De Armadores Pesqueros Artesanales De Queule	Queule Artisanal Fishing Boat Owners' Cooperative
16	Sindicato De Trabajadores Independientes De Pescadores Artesanales Y Turismo Queule	Union of Independent Workers of Artisanal Fishermen and Tourism Queule
17	Sindicato De Trabajadores Independientes Armadores, Pescadores Artesanales Y Actividades Conexas De Las Caletas Queule Toltem	Union of Independent Shipowners, Artisanal Fishermen and Related Activities of the Queule Toltem Coves (Caletas)
18	Sindicato De Trabajadores Independientes De Pescadores Artesanales Y Mariscadores De Ribera "Los Pinos De Queule"	
19	A.g.de Armadores Cerqueros Y Tripulantes De Queule Acertriq A.g.	
20	Cooperativa Pesquera Artesanal Y De Turismo Limitada	

The following indigenous communities near Queule are identified by DOP:

Table 6: Indigenous communities near Queule. Source: DOP

	Nearby indigenous communities
1	Francisco Huaiquin
2	Francisco Trecan
3	Juan Liempi
4	Juana Aguila de Flores
5	Juana Pichi Pillan V. de
6	Manuel Penchulef

2.1.4 Public participation

Public participation meetings took place in June 2021 and show the following perspectives:

- Fishermen have long wanted a solution to improve the navigability to and from the sea. They now depend on the tides to do so. The consequences of that are that the fishing boats deteriorate when stranded, the crew faces risks to cross, accidents may happen, and any delay to return with the catch affects its price and thus the economy of the families. They would like to always be able to navigate in and out, also considering cases of emergency or disease among the inhabitants of Queule, when people would go by boat to a hospital. Fishermen manifest the willingness to find a joint (technical) solution in a workshop.
- The local community supports in general a solution, because of the economic benefits for local people and tourism. The indigenous communities near the project area are aware of the need to improve the navigability and safety of the fishermen, but they are concerned about the ecological impacts on the wetland.

2.3 Governance

The section describes institutional aspects of the system. It examines the policies, regulations, and organizational structures that govern and influence the system's operation and management.

2.1.5 Institutional stakeholders

The following are relevant institutions indicated by DOP:

Table 7: Relevant institutions (source: DOP)

	Institution (Spanish original name)	Institution (English translation)	Reference person	Jurisdiction
1	Gobierno Regional de La Araucanía	Regional Government of La Araucanía	Governor of the Araucanía Region	Regional
2	Delegación Presidencial de La Araucanía	Presidential Delegation of La Araucanía	Presidential delegate of La Araucanía	Regional
3	Dirección de Obras Portuarias, Ministerio de Obras Públicas	Port Works Directorate, Ministry of Public Works	Regional Director of Maule, Ñuble, Biobío and La Araucanía	Regional
4	SEREMI, Ministerio de Obras Públicas	SEREMI, Ministry of Public Works	Regional Ministerial Secretary of Public Works, La Araucanía Region	Regional
5	Directemar, Comuna de Valdivia	Directemar, Municipality of Valdivia	Port Captain	Communal
6	Alcaldía de Mar, Queule	Water Bailiff, Queule	Water Bailiff	Local
7	Servicio de Evaluación Ambiental, La Araucanía	Environmental Assessment Service, La Araucanía	Regional Director	Regional
8	Comisión Regional del Uso del Borde Costero (CRUBC)	Regional Commission for the Use of the Coastal Border (CRUBC)	President CRUBC	Regional
9	Oficina Técnica Región de La Araucanía, CMN	Technical Office of the La Araucanía Region, CMN	Office Manager	Regional
10	SERNAPESCA La Araucanía	SERNAPESCA La Araucanía	Regional Director (S)	Regional
11	SERNAPESCA Queule	SERNAPESCA Queule	Office Manager	Local
12	Ilustre Municipalidad de Toltén	Illustrious Municipality of Toltén	Mayor	Communal
13	Ilustre Municipalidad de Toltén	Illustrious Municipality of Toltén	Fishing Office Manager	Communal
14	Municipalidad Toltén	Toltén Municipality	SECPLAN	Communal
15	Oficina CONADI Toltén	CONADI Toltén Office	Office Manager	Communal

2.1.6 Environmental law

Queule estuary has a high environmental value and rich biodiversity. Several environmental laws and norms apply here, which have been indicated by DOP. Below a number of relevant laws are briefly described.

Environmental law N° 19.300/1994, updated through law N° 20.417/2010, regulates the activities and projects allowed in officially protected areas, national parks, and other natural environments. Article 10 indicates the kind of projects subject to an Environmental Impact Assessment System (SEIA in Spanish). The projects subject to a SEIA include:

- dredging sediments above 50,000 m³ in either inland or maritime waters;
- protection or modification of an inland water course which involves moving above 50,000 m³ of material;
- works that may physically or chemically alter the flow or biotic components in wetlands within urban limits, including the modification of a final spit and riparian vegetation.

The projects and activities subject to a SEIA are specified in more detail in Article 3 of decree DS Nº 40/2012.

Law N°21.202 sets the minimum requirements for the sustainability of urban wetlands. This is to ensure their rational use and preserve the hydrological regime, functioning, and ecological characteristics. There are abundant online guidelines containing methodologies and criteria to perform environmental impact assessments. For instance, a relevant criterion for Queule regards the alteration of the sediment regime in rivers, which might affect potential dredging activities.

Law 21.600 created the National System of Protected Areas and the service for Biodiversity and Protected Areas. This law has the purpose of conserving biological diversity and protecting the country's natural heritage through the preservation, restoration, and sustainable use of genes, species, and ecosystems. The National System of Protected Areas includes the following protection categories: a) Virgin Region Reserve; b) National Park; c) Natural Monument; d) National Reserve; e) Multiple Use Conservation Area; f) Indigenous Peoples Conservation Area. In the following section, the current status regarding protected areas in Queule is presented.

2.1.7 Protected areas

The latest available study (Aguas Consultores SpA, 2022) shows that:

- There are no Officially Protected Areas as defined by the Ministry of Environment in Toltén municipality, to which Queule belongs.
- Queule wetlands are a Priority Site within the Regional Biodiversity Strategy.
- No National Monuments have been identified in Toltén municipality.
- There are no designated Zones of Interest for tourism by SERNATUR.

2.1.8 Maritime concessions

Three maritime concessions are located in Queule and surroundings (Figure 20, left), including one in process, and one maritime destination (Figure 20, right).

Figure 20: Maritime concessions (top left) and maritime destinations (top right) (Aguas Consultores SpA, 2022). The bottom panel shows the location of the above panels in Queule estuary

There are three Management Areas of Benthic Resources (AMERB) in the study area (Figure 21, left), two active (green) and one in process (orange). Furthermore, there are seven permanent aquaculture concessions which are used for artisanal fishing (red). All these areas are sensitive due to their economic relevance to the local people. Interventions such as dredging could imply the loss or contamination of their production.

Figure 21: Management areas of benthic resources (left) and aquaculture concessions (right) (Aguas Consultores SpA, 2022)

There are two coastal areas for native people in the surroundings of the study area (Figure 22), but none lies inside the study area (red line in Figure 2222).

Figure 22: Coastal areas for native people: active (left) and in process (right). Red line indicates study area. (Aguas Consultores SpA, 2022)

2.1.9 Involvement of indigenous communities

Article 6 of Convention No. 169 on Indigenous and Tribal Peoples establishes the obligation to consult indigenous peoples whenever legislative or administrative measures are planned, which may directly affect them. Consultation must be carried out in good faith and with the aim of reaching an agreement or consent. If no agreement is reached, indigenous communities decide whether a project can be executed or not.

A consultation must be carried out also when the State carries out activities of exploration or exploitation of natural resources that lie in the territories where indigenous peoples live or use. Indigenous peoples have the right to participate in the benefits that such activities may generate.

Indigenous communities have the right to participate in the making, implementation and evaluation of development plans and programmes that affect them. They can define their own development priorities and participate in decisions that may affect their lives, lands or territories.

Decree DS Nº 66/2013 specifies that administrative measures, such as investment projects or resource exploitation concessions must be consulted, since they may generate significant impacts on indigenous peoples, their territories, or their traditional ways of life.

The consultation process must include the following phases, each with a maximum duration of 20 days:

- Planning the consultation process, with at least three meetings.
- Providing information and disseminating the consultation process.
- Internal deliberation of indigenous peoples.

- Dialogue between the parties.
- Systematization, communication of results and completion of the consultation process.

2.4 Financing

Nature-Based Solutions (NBS) are a cost-effective and promising adaptation approach, increasing climate change resilience, ensuring the delivery of sustainable infrastructure services and contributing to flexible planning in line with transformations and changes.

The Financing of a Nature-Based Solutions (NBS) initiative is one of the critical components to ensure its implementation in a project. Financial Institutions (multilateral development banks, public financial institutions, and international lending facilities) are already playing a role in supporting NBS regionally. They provide grant funding and technical assistance for project preparation, lending ordinary and concessionary capital to bankable green-gray projects, and managing external donor funds toward NBS projects.

Financial Institutions and private sector investment can help to provide natural capital solutions and implement financing strategies. Financial Institutions can increase the visibility, applicability and dissemination of NBS within the financial and private/public sector.

There is growing interest among Financial Institutions in Latin America in mainstream environmental, social, and governance considerations in their credit and investment decision-making cycles. Many Financial Institutions have established targets yet for promoting green financing, or developing green investment and lending mechanisms, such as green bonds or green credit lines. At present, most financial entities in the region do not promote green investments or disclose how they are taking measures to reduce environmental, social, and climate risks in their economic transactions.

Financial Institutions as the Corporacion Andina de Fomento (CAF), World Bank and Inter-American Development Bank (IDB) are currently providing fundings to implement NBS in Latin America. During March 2025, CAF met with representatives from EcoShape where the Building with Nature approach in Latin America and CAF potential interest in collaboration was discussed.

The United Nations Development Programme (UNDP) recommends eight action tracks and a stepwise process to capitalize on opportunities to finance NBS[2]:

1. Integrate NBS into climate and development policy and budgeting frameworks.
2. Foster the development of intersectoral collaboration for scaling up NBS.
3. Strengthen and share the evidence base for NBS.
4. Convene and mobilize inclusive multi-stakeholder coalitions and platforms to bring investors and NBS practitioners together.
5. Mobilize domestic public finance.
6. Catalyze international public finance.
7. Encourage domestic and international private sectors to invest.
8. Promote transparency and information sharing.

Projects developed by the DOP follow the project life cycle established by the MSDF, and its funding can be done in two ways: Sectoral (from the Ministry of Public Works) and Regional (from the regional government).
In Chile, Financial Institutions have provided financing and funding for the development of studies (climate, environmental, social) that complement project scopes, but not to finance its execution.

The creation of pilot projects in Chile (that can be replicated and implemented by DOP) can be low-risk opportunities to engage in NBS financing as this type of initiative provides a clear picture on what NBS are, the expectations around results, timing, methodologies and partnerships involved.

[2] https://www.undp.org/sites/g/files/zskgke326/files/2022-11/Nature-based%20Solutions%20Finance%20for%20NDCs-2022.pdf

Carrying out coordinated initiatives among stakeholders also can help to encourage more members of the private/public sector to join and invest in NBS.

3 Synthesis of Problem Causes

This chapter aims to analyse and synthesize the likely causes of the problem statement outlined in Chapter 1, based on the examination of potential factors contributing to the problem described in Chapter 2. The synthesis is divided into two sections: a description of the conclusions so far by MOD/DOP and the synthesis from this work.

3.1 Summary of previous studies and DOP

Previous design studies of DOP analysed the physical system and concluded that the problem consists of the sedimentation of the river mouth induced by marine currents from the beach towards the estuary. Three previous studies mostly focused on a technical solution consisting of a breakwater across the spit with the aim to block the longshore coastal sediment transport and increase the flow velocities and sediment transport capacity through the estuary towards the sea. The latest study (Aguas Consultores SpA, 2022) also includes dredging as a softer approach with limited structural measures (shorter than 100 m). The previous studies, besides describing the physical system in detail, also included a description of the economic system, land-use planning, applicable laws and regulations, and incorporated public participation sessions.

DOP commented that the sedimentation problem, and the associated navigation problem through the river mouth, has increased in the approximately last 10 years, especially after the 2010 earthquake. They also manifested the lack of support for the proposed structural solutions (longitudinal breakwaters) and maintenance dredging by the indigenous communities. Finally, DOP considers that the structural solutions proposed so far have a probability of not being approved by an environmental impact assessment, which is mandatory for those measures.

3.2 Synthesis

3.2.1 Hypothesis

Based on the information presented in Chapter 2, the system is clearly complex. It comprises a combination of factors that led to increased sedimentation in the past and can influence sedimentation in the future. The sedimentation problem has been described as worsening after the 2010 earthquake and tsunami. However, there is no evidence from the analysed data to support that 2010 worsened the problem. The direct impact of these events was assessed using satellite imagery, but no significant changes were observed. Additionally, the catchment size of the Queule River likely remained unchanged, as there are no visible changes in the Digital Elevation Model (DEM) to suggest otherwise.

The coastal spit dynamics can be explained by the interaction of waves, tides and river flow on the transport of sediments. Waves from the southwestern direction generally transport sediments in a northern direction across the coast in front of Queule. However, due to diffraction around Punta Ronca, locally the net longshore sediment transport direction along the coast is southward resulting in the formation of the spit. These sediments are transported towards the river mouth, but are flushed out during high-discharge events, as indicated by the channel's greater depth and different sediment composition.

Although the catchment size likely remained the same, the river's discharge has decreased in recent years due to a lower mean annual precipitation and increased temperatures. A decreased discharge could explain the increased sedimentation at the river mouth in recent years, as flushing of the channel decreases.

Simultaneously, the sediment flux towards the river could have increased because of a decrease in tree cover in the basin (Yadav, 2025), although the reduced rainfall may have also resulted in less erosion in the higher areas in general. As the river slope is around zero in the last 2 km of its course it is expected that an increase in sediment load of the river would result in more deposition in the floodplains rather than a large increase in sedimentation near the river mouth.

Climate change is expected to exacerbate the problem. Climate projections for SSP5-8.5 indicate that the annual precipitation can reduce by more than 20 % in 2070. This reduction, combined with rising temperatures (1.4 °C by 2050 and by 3.1°C by 2090 for the SSP5-8.5 climate scenario) and increased wind intensity that could lead to higher evapotranspiration pressures, is expected to further decrease the river discharge. It is important to note that the current dynamics can be changed by natural hazards such as earthquakes and tsunamis.

Although specific data is lacking, fishing appears to be one of the most important economic drivers in Queule, which involves diverse social groups and associations. The groups who engaged in public-participation sessions manifested general support to finding a solution to the sea connection for Queule, which would benefit fishing and other activities. The current legislation requires the mandatory involvement of indigenous communities if their environment should be altered.

The current environmental law also frames the actionable potential solutions in Queule as it requires performing an environmental impact assessment (SEIA) that regulates the type and way wetlands can be modified from their current state. These assessments contain elaborate methodologies and criteria.

3.2.2 Scale (time, space)

The larger system will be considered for alternative solutions rather than just the river mouth. This broader perspective enables us to include aspects such as ecology and education while evaluating the needs of different stakeholders. Additionally, not only past changes but also factors like climate change will be considered to develop sustainable solutions.

4 From potential measures to recommended solutions

This chapter presents the process from a long list of potential measures for the Queule river mouth towards selection of the preferred measures.

4.1 Methodology

Based on the synthesis of problem causes for the navigation challenges in Queule (chapter 3) a longlist is created with potential measures. A high-level assessment was performed to create a shortlist of promising measures. These measures are assessed in more detail to come up with a final selection of preferred measures.

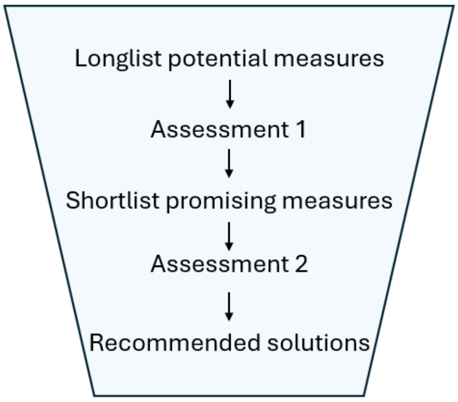


Figure 23 Process from the longlist of potential measures to recommended solutions

Table 8 presents the different selection criteria used to evaluate the longlist of measures. These criteria are divided into four categories: Goal Achievement (G), Feasibility (F), Additional Benefits (B), and Costs (C). The measures to be implemented in the Queule region are evaluated in two steps.

In assessment 1 all measures in the longlist are scored at a high level. They are evaluated based on Goal Achievement, Feasibility and Additional benefits using a system of -, 0 and +. The costs are not considered in this step. Table 9 indicates how scores are determined for each criterium.

The assessment of potential measures (assessment 1) and assessment of promising measures (assessment 2) shown in Table 14 and Table 19 respectively, do not included a weighting as it depends on the importance to be given to the categories and individual criteria.

In assessment 2, the promising measures are scored for all aspects shown in **Fout! Verwijzingsbron niet gevonden.** in more detail using a scale of --, -, 0, +, ++. Table 11 indicates how scores are determined for each criterium.

Table 8 Selection criteria used for assessment of the measures with their explanation

G	Goal achievement	
G1	Short term effectiveness (0-5 years)	Increase in channel navigability
G2	Long term effectiveness (>10 years)	Increase in channel navigability

G3	Ecological benefits	Impact of the measure on habitats and species
F	**Feasibility**	
F1	Technical feasibility	- Technical complexity of the measure - Constructability - Safety - Fits within local design and construction methods
F2	Maintenance effort	- Is few or much maintenance required. - Is the maintenance complex or easy
F3	Permittability	Is measure permittable (e.g. in respect to local nature laws and policies)
F4	Institutional complexity	- Fits within goals of institutions - Few or multiple institutions required for decision making
B	**Additional benefits**	
B1	Economy	Benefits for local economy, e.g. increase/decrease in opportunities for fishing and recreation
B2	Social/engagement	Engagement with indigenous communities, different genders, younger people
C	**Costs**	
C1	CAPEX	Construction costs
C2	OPEX	Maintenance costs

Table 9 General explanation of scores for assessment 1

Criteria	Score	Explanation
Goal achievement – Short term effectiveness (0-5 years)	+	Measure is expected to significantly increase channel navigability in the first 5 years after implementation
	0	Measure has no significant effect on channel navigability in the first 5 years after implementation
	-	Measure is expected to significantly decrease channel navigability in the first 5 years after implementation
Goal achievement – Long term effectiveness (>10 years)	+	Measure is expected to increase channel navigability still significantly 10 years after implementation
	0	Measure has no significant effect on channel navigability 10 years after implementation
	-	Measure is expected to significantly decrease channel navigability 10 years after implementation
Goal achievement – Ecological benefits	+	The measure has a significant net positive impact on ecology
	0	The measure has no significant impact on ecology or there is a balance between positive and negative effects
	-	The measure has a net negative impact on ecology
Feasibility (technical, maintenance effort, permittability, institutional complexity)	+	The measure is easy to implement regarding technical feasibility, maintenance effort, permittability and institutional complexity.
	0	There are some bottlenecks regarding technical feasibility, maintenance effort, permittability or institutional complexity, but the measure may be feasible.
	-	The measure seems not feasible due to large bottlenecks related to technical feasibility, maintenance effort, permittability or institutional complexity.
Additional benefits (economy, social, engagement)	+	The measure has many additional benefits
	0	The measure has limited additional benefits
	-	The measure has significant negative impact on ecology, social aspects, or engagement.

Table 10 General explanation of colour coding for assessment 1

Code	Colour	Explanation
Green		- Associated to ''+''score - Positive impact/effects - Easy to implement or have additional benefits
Yellow		- Associated to ''0'' score - Negative (large) impact/effect - Limited additional benefits
Red		- Associated to ''-'' score - Negative impact/effects - No additional benefits

Table 11 General explanation of scores for assessment 2

Criteria	Score	Explanation
Goal achievement		
Short term effectiveness (0-5 years)	++	Measure strongly increases channel navigability in the first 5 years after implementation
	+	Measure increases channel navigability in the first 5 years after implementation
	0	Measure has no significant effect on channel navigability in the first 5 years after implementation
	-	Measure decreases channel navigability in the first 5 years after implementation
	--	Measure strongly decreases channel navigability in the first 5 years after implementation
Long term effectiveness (>10 years)	++	Measure strongly increases channel navigability 10 years after implementation
	+	Measure increases channel navigability 10 years after implementation
	0	Measure has no significant effect on channel navigability 10 years after implementation
	-	Measure decreases channel navigability 10 years after implementation
	--	Measure strongly decreases channel navigability 10 years after implementation
Ecological benefits	++	The measure has a large (net) positive impact on ecology
	+	The measure has a small (net) positive impact on ecology
	0	The measure has no significant impact on ecology or there is a balance between positive and negative effects
	-	The measure has a small (net) negative impact on ecology
	--	The measure has a large (net) negative impact on ecology
Feasibility		
Technical feasibility	++	The measure's technical feasibility is very good, the measure is easy to construct, safe and fits within local design and construction methods
	+	The measure's technical feasibility is good. The measure is easy to construct, safe and fits within local design and construction methods, but there are some points of attention
	0	The measure is expected to be technically feasible, but there are points of attention
	-	The measure may not be technically feasible due to bottlenecks regarding construction complexity and safety

	--	The measure is technically not feasible due to large bottlenecks regarding construction complexity and safety
Maintenance effort	++	Measure requires relatively very low maintenance effort
	+	Measure requires a relatively low maintenance effort
	0	Measure requires intermediate maintenance effort
	-	Measure requires a high maintenance effort
	--	Measure requires a relatively very high maintenance effort
Permittability	++	No bottlenecks for permittability
	+	Minor bottlenecks for permittability
	0	Some bottlenecks for permittability
	-	Permittability of the measure is difficult
	--	Measure is not permittable
Institutional complexity	++	Very low institutional complexity for implementation
	+	Low institutional complexity for implementation
	0	Intermediate institutional complexity for implementation
	-	High institutional complexity for implementation
	--	Very high institutional complexity for implementation
Additional benefits		
Economic benefits	++	The measure has large economic benefits
	+	The measure has small economic benefits
	0	The measure has no significant effect on economy
	-	The measure has a small negative effect on economy
	--	The measure has large negative effects on economy
Social benefits and engagement	++	The measure has large social/engagement benefits
	+	The measure has small social/engagement benefits
	0	The measure has no significant effect in terms of social benefits/engagement
	-	The measure has a small negative effect in terms of social benefits/engagement
	--	The measure has large negative effects in terms of social benefits/engagement
Costs		
CAPEX (construction)	++	Construction costs are much higher than for the other measures
	+	Construction costs are relatively high compared to the other measures
	0	Construction costs are intermediate compared to the other measures
	-	Construction costs are low compared to the other measures
	--	Construction costs are much lower than for the other measures
OPEX (maintenance)	++	Maintenance costs are much higher than for the other measures
	+	Maintenance costs are high compared to the other measures
	0	Maintenance costs are intermediate compared to the other measures
	-	Maintenance costs are low compared to the other measures
	--	Maintenance costs are much lower than for the other measures

Table 12 General explanation of colour coding for assessment 2

Code	Colour	Explanation
Green		- Associated to ‘’++’’ or ‘’+’’score - Positive impact/effect - Easy to implement or have additional benefits
Yellow		- Associated to ‘’0’’ score - No significant (or Neutral) impact/effect - Limited additional benefits
Red		- Associated to ‘’-‘’ score - Negative (small) impact/effect - No additional benefits
Pink		- Associated to ‘’--’’ score - Negative (large) impact/effect - No additional benefits

4.2 Longlist of potential measures

Table 13 shows a longlist of measures that can provide safe navigation of the river mouth. This could be through reducing sediment input, increasing the flow of velocities at the river mouth or adaptive measures (see chapter 3).

The list includes both structural and non-structural measures. Nature-Based Solutions (NbS) have emerged as a vital approach to tackling environmental challenges by harnessing the power of natural ecosystems. These solutions involve protecting, managing, and restoring natural or modified ecosystems to address societal issues while benefiting both people and nature. NbS can offer essential services such as climate change mitigation, disaster risk reduction, and biodiversity conservation. Complementing NbS, non-structural interventions focus on management practices and operational changes that enhance the effectiveness of natural systems without relying on physical infrastructure. By integrating NbS with these non-structural interventions, a comprehensive approach can be developed that addresses the environmental concerns and promotes long-term sustainability and resilience.

The longlist is also included in chapter Appendix 9 **Fout! Verwijzingsbron niet gevonden.**where links to projects with similar adaptation measures are included.

Table 13: Longlist of adaptation measures

Possible NBS measures in coastal areas	Type of interventie	Measure
MOP/DOP measure	Retain sediment along the beach	Longitudinal breakwater
Reduce sediment input	Retain sediment along the beach	Offshore parallel breakwater
		Small-scale sediment capture structures
		Perpendicular beach groynes
		Sea grass restoration/implementation
		Creating sedimentation basins
	Reduce river sediment input	Dam upstream
		Reforestation
		Terracing/contour cropping
Increase channel flow velocities	Changing channel dimensions	Channel narrowing
	Increasing upstream discharge	River diversion

		Wetland restoration/land use change
Management and adaptation measures	Dredging	Dredging
		Optimized dredging
		Seabed biodiversity (landscaping dredging)
	Queue cove (Caleta) location	Change harbor location
	Fishing boat alteration	Shallow draft fishing boats
	Navigation	Time schedule for fishing boats/information system
		Signalling system
		Frequent bathymetry survey

4.3 Assessment potential measures (assessment 1)

Gives an overview of the results of the high-level assessment of the longlist of measures (assessment 1). A general explanation of the scores was already presented in Table 9. Further explanation of the scores for the different groups of measures (measures that reduce sediment input, increase channel flow and adaptive measures) is given in the sections that follow. In general, there is little distinction between effectiveness of measures in the short or long-term: the measures are expected to be either effective or not. Some of the measures that are expected to be effective have low feasibility.

Table 14 Overview of results of assessment 1, scoring of the longlist of potential measures

Category	Subcategory	Measure	Goal achievement	Goal achievement	Goal achievement	Feasibility	Additional benefits
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility, maintenance effort, Permittability, institutional complexity	economy, social/ engagement
MOP/DOP measure		**Longitudinal breakwater**	+	+	-	**0**	**0**
Reduce sediment input	Retain sediment along the beach	Offshore parallel breakwater	0	0	-	0	0
		Small-scale sediment capture structures	0	0	+	0	+
		Perpendicular beach groynes	+	+	-	0	0
		Sea grass restoration/ implementation	0	0	+	-	+
		Creating sedimentation basins	+	0	-	-	+
	Reduce river sediment input	Dam upstream	-	-	-	-	0
		Reforestation	0	0	+	-	+
		Terracing/contour cropping	0	0	+	0	+
Increase channel flow	Changing channel dimensions	Channel narrowing	0/+	0/+	+	0	+
	Increasing upstream discharge	River diversion	+	+	-	-	-
		Wetland restoration/ land use change	0	0	+	0	+

Management and adaptation measures	Dredging	Dredging	+	+	-	0	0
		Optimized dredging	0/+	0/+	0/-	0	0
		Seabed biodiversity (landscaping dredging)	0	0	0/+	0	+
	Harbor location	Change Queule cove (Caleta)	+	+	-	-	-
	Fishing boats alteration	Shallow draft of fishing vessels	+	+	0	-	-
	Navigation	Time schedule for boats/information system	+	+	0	+	0
		Signalling system	+	+	0	+	0
		Frequent bathymetry survey	0	0	0	+	0

Assessment of measures that reduce sediment input

Table 15 gives an overview of the results of assessment 1 for the category measures that reduce sediment input. The scores are explained below.

Table 15 Overview of the scores of assessments 1 for the measures on the longlist that reduce sediment input

Category	Subcategory	Measure	Goal achievement	Goal achievement	Goal achievement	Feasibility	Additional benefits
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility, maintenance effort, Permittability, institutional complexity	economy, social / engagement
MOP/DOP measure		**Longitudinal breakwater**	**+**	**+**	**-**	**0**	**0**
Reduce sediment input	Retain sediment along the beach	Offshore parallel breakwater	0	0	-	0	0
		Small-scale sediment capture structures	0	0	+	0	+
		Perpendicular beach groynes	+	+	-	0	0
		Sea grass restoration/ implementation	0	0	+	-	+
		Creating sedimentation basins	+	0	-	-	+
	Reduce river sediment input	Dam upstream	-	-	-	-	0
		Reforestation	0	0	+	-	+
		Terracing/contour cropping	0	0	+	0	+

Longitudinal breakwater (DOP measure)

A longitudinal breakwater is a coastal structure designed to protect shorelines, harbors, and ports from wave action and sedimentation. In this case, the structure also serves to guide vessels by creating an artificial channel that leads boats safely to deeper waters, where sedimentation poses less of a problem.

The effectiveness of this solution is considered positive in both the short term (0–5 years) and long term (over 10 years), as it reduces sedimentation in the channel and hence facilitates safer and more reliable navigation. However, its construction may have negative ecological impacts. Additionally, the overall feasibility is rated as intermediate, because the measure is technically feasible with limited maintenance effort and institutional complexity, but obtaining the necessary permits can be more complex than for smaller scale measures. The intervention does not offer large significant additional benefits, resulting in a neutral score in that regard.

Offshore Parallel Breakwaters:
Offshore parallel breakwaters reduce wave energy and promote sedimentation in the sheltered areas behind them. However, their effectiveness in both the short and long term is limited (0), as they likely do not fully prevent the longitudinal sediment transport occurring in Queule. While the structures block waves before they reach the beach, they can potentially reduce sediment transport toward the river mouth—their impact depends heavily on their location. In some cases, they may even cause erosion. Additionally, depending on the size and placement of the breakwaters, they could affect ecologically valuable areas.

Small-Scale Sediment Capture Structures
These structures create sheltered zones with reduced flow velocities and wave energy, promoting sediment accumulation. They are generally more suitable for wider coastlines with lower wave energy and finer sediments (such as mud or sand-mud mixtures), whereas Queule features a sandy coastline.

Perpendicular Beach Groynes
Perpendicular beach groynes interrupt the net longshore sediment transport, causing localized sediment accumulation. Because these structures reduce the sediment transport along the beach, towards the river mouth they are effective in improving navigation. However, they have a negative impact on ecology (-) both directly after construction (footprint) as well as disrupting the natural sediment transport processes along the beach.

Sea Grass Restoration
Seagrass restoration involves establishing meadows that reduce wave energy and promote the deposition of fine sediments. These meadows require a gently sloping seabed and a low-energy wave environment. The effectiveness of sea grass meadows is limited in both the short (0) and long (0) term. These meadows first need time to develop. Due to the local bathymetry, seagrass cannot be established in the critical areas where sediment needs to be trapped (resulting also in a low score on feasibility). On the long term it is therefore expected that no significant meadow can develop and even if the meadow matures it is unlikely that it will capture the full volume of sediment transported from the sea into the river mouth. Ecologically, seagrass meadows provide positive benefits (score: +).

Creating Sedimentation Basins
Creating sedimentation basins involves excavating underwater trenches or pits that form low-energy zones where sediments can settle. Their short-term effectiveness (0–5 years) is positive (score: +), as they can effectively trap sediment hence reducing sediment input towards the river mouth. However, in the long-term (>10 years) their effectiveness decreases (score: 0) because the basins gradually fill with sediment, reducing their capacity and effectiveness over time. While sedimentation basins may reduce the need for dredging within the channel itself, dredging would still be required—just relocated to the basin area.

Reduce River Sediment Input
Efforts to reduce sediment input near the river mouth from upstream include:

- Upstream dams.
- Reforestation.
- Terracing or contour cropping.

Dams regulate water flow by storing excess water during wet periods and releasing it during dry periods, helping to maintain steady flow but at the same time capturing sediment that is transported downstream. Reforestation involves planting trees to slow stormwater runoff, stabilize soil, and reduce erosion and landslides. Terracing and contour cropping help stabilize slopes and protect urban areas with steep, erosion-prone soils, while also benefiting agriculture.

These measures are all rated as having low effectiveness on improving the navigability (score: 0 or -), as the sedimentation issue at the Queule river mouth is likely driven more by the interaction between wave-induced sediment transport and the river's flushing capacity than by the sediment input from upstream (see Chapter 3). Additionally, the feasibility of upstream dams and reforestation is low, as they require coordination among multiple upstream stakeholders who may not support or prioritize these interventions.

Assessment of measures that increase channel flow

Table 16 gives an overview of the results of assessment 1 for the category measures that increase channel flow. The scores are further explained below.

Table 16 Overview of the scores of assessments 1 for the measures on the longlist that increase channel flow

Category	**Subcategory**	**Measure**	**Goal achievement**	**Goal achievement**	**Goal achievement**	**Feasibility**	**Additional benefits**
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility, maintenance effort, Permittability, institutional complexity	Economy, social/ engagement
Increase channel flow	Changing channel dimensions	Channel narrowing	0/+	0/+	+	0	+
	Increasing upstream discharge	River diversion	+	+	-	-	-
		Wetland restoration/ land use change	0	0	+	0	+

Channel Narrowing

Channel narrowing can be performed in multiple ways, for example with large heavy constructions (e.g. concrete dams) or by stimulating sedimentation and growth of vegetation along the side of the channel. By narrowing the channel flow velocities can increase so that sediment is flushed out towards the sea.

The effectiveness of channel narrowing is uncertain (score 0/+). The success of this measure depends on both the design and the materials used, as well as the specific location, which can influence ecological outcomes. Also, based on the outcomes of chapter 3 it is expected that channel narrowing alone will not be enough to improve the navigability at Queule, but measures that reduce sediment input towards the river mouth are needed as well. In case channel narrowing is done with stimulating sedimentation and vegetation growth it can have a positive effect on ecology. The feasibility is considered neutral (score: 0).

River Diversion

This approach involves permanently increasing the river discharge near the mouth by connecting the downstream part of the river to another river. In this case, it would mean diverting part of the downstream Tolten River to the Queule River. This method is expected to be effective in both the short and long term (score: +) for improving navigability at the river mouth as the increased discharge will help in flushing sediment out towards the sea. However, it is expected to have large negative ecological impacts due to the disruption of the natural river system (score: -) and poses significant feasibility challenges (score: -), due to the complexity and scale of the intervention.

Wetland Restoration/Land Use Change

This measure involves the creation or restoration of upstream natural wetlands. These wetlands can retain water upstream, creating a buffer for dry periods. Water may be released from these wetlands during dry periods to flush out sediments from the river mouth towards the sea.

The effectiveness of this measure is uncertain and expected to be limited in both the short and long term (score 0). To flush out the sediments from the river mouth a large volume of water is needed and it is expected that wetland restoration alone will not result in large increases in the river discharge. The restoration of wetlands does offer ecological benefits (score: +), economic value, and social engagement.

Assessment of management and adaptation measures

Table 17 gives an overview of the results of assessment 1 for the category adaptive and management measures. The scores are further explained below.

Table 17 Overview of the scores of assessments 1 for the measures on the longlist in the category management or adaptation measures

Category	Subcategory	Measure	Goal achievement	Goal achievement	Goal achievement	Feasibility	Additional benefits
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility, maintenance effort, Permittability, institutional complexity	economy, social/ engagement
Management and adaptation measures	Dredging	Dredging	+	+	-	0	0
		Optimized dredging	0/+	0/+	0/-	0	0
		Seabed biodiversity (landscaping dredging)	0	0	0/+	0	+
	Harbor location	Change Queule cove (Caleta)	+	+	-	-	-
	Fishing boats alteration	Shallow draft of fishing vessels	+	+	0	-	-
	Navigation	Time schedule for boats/information system	+	+	0	+	0
		Signalling system	+	+	0	+	0
		Frequent bathymetry survey	0	0	0	+	0

Dredging

Dredging involves the removal of sediment, debris, and other materials from the bottom of water bodies using specialized equipment. This process helps maintain adequate water depth for navigation and reduces flood risk by keeping channels clear.

Dredging is considered very effective in both the short term (0–5 years) and long term (>10 years), take that dredging needs to take place repeatedly. However, due to restrictions on the volume of sediment that can be dredged in the Queule area (see Section 2.1.6), the permittability may be difficult. Dredging has a negative impact on ecology by disrupting the river- or seabed.

Optimized Dredging Techniques

Optimized dredging techniques that are considered here include water injection dredging, natural sediment bypassing, and the use of silt curtains. These methods aim to enhance sediment management while minimizing environmental impact:

- **Water Injection Dredging:** Water injection dredging involves pumping large volumes of water at low pressure through nozzles on a horizontal jet bar to fluidize bottom sediments. This process reduces sediment cohesion or internal friction, allowing the material to flow naturally to deeper areas, forming a density current. This technique minimizes ecological disturbance and supports natural sediment transport (International Association of Dredging Companies, 2013). It is most effective during the rainy season, when river discharge is highest, helping to flush out resuspended sediment. Tidal dynamics at the river mouth also influence sediment transport; implementing this method during low tide can enhance effectiveness as water retreats. However, current river discharge levels may not be sufficient to remove all sediment, meaning regular dredging may still be required.

- **Natural Sediment Bypassing:** This technique leverages natural water currents—such as tidal or river flows—to transport sediment in a controlled manner. It is particularly effective in areas with strong hydrodynamic forces that can carry sediment away efficiently. By reducing reliance on mechanical dredging, this method lowers operational costs and environmental impact (FitzGerald, 2000).
- **Silt Curtain Techniques:** Silt curtains are vertical barriers that extend from the water surface to the seabed, designed to contain fine suspended sediments within a work area and prevent their spread into the surrounding environment. (JC Ogilvie, 2012). While not a dredging method on their own, they serve as a complementary measure to reduce environmental disturbance during dredging operations. However, in dynamic environments like river mouths—where water flow is constant and natural turbidity is already high, the effectiveness of silt curtains may be limited.

The effectiveness of optimized dredging techniques depends on the chosen method (score 0/+). For Queule silt curtain techniques seem not suitable as the river mouth is a dynamic environment and the natural turbidity is high. Water injection dredging and natural sediment bypassing may be more effective. Optimized dredging offers limited additional benefits compared to regular dredging but may have a bit less negative impact on the environment.

Seabed Biodiversity (Landscaping Dredging)
This approach involves shaping the seabed during dredging activities to create varied textures (e.g., gravel sowing) and depth gradients (e.g., variable-depth extraction). These modifications promote habitat diversity, enhance biodiversity, and support faster recolonization by marine organisms.

While not a standalone solution, landscaping dredging can be used as a complementary measure to make dredging more environmentally friendly. However, in the case of the Queule river mouth, the effectiveness of this approach is limited. The strong flushing action of the river and the high sedimentation rate would quickly alter or erase the created patterns. As a result, the ecological benefits of seabed landscaping in this location are likely to be minimal (score 0/+).

Changing Queule cove (Caleta) Location
This measure involves relocating the Queule Cove (Caleta) outside the river mouth to bypass navigation challenges within the channel, while still maintaining access to the open sea. It could be effective in both the short and long term, as fishing vessels would no longer need to navigate through the problematic river mouth. However, relocating the cove could negatively impact the ecology of the new site, potentially disrupting local habitats. Additionally, the feasibility of constructing a new cove in a suitable location is low as this brings its own challenges related to accessibility to the hinterland, potential negative impacts on the natural area at the new location, and obtaining permits, resulting in a negative feasibility score.

Fishing boat alteration
This measure involves redesigning fishing boats with a shallower draft to better suit the altered conditions of the river channel. Depending on the size of the vessels, this would require a reduction in draft to ensure safe navigation through shallow waters. While this adaptation could improve access through the river mouth, it may also increase travel time due to reduced speed or maneuverability. The feasibility of this measure is expected to be low as it is expected that stakeholders will not support this measure, because it is difficult and very expensive for all the boat / ship owners and because it does not improve the navigability towards the harbor to new vessels (which can be important for the functioning of the harbor in the future).

Navigation
Navigation through the Queule river mouth can also be enhanced through the following management/adaptation measures:

- **Time schedule for boats/information system**: Develop a scheduling system that allows fishing boats to navigate during high tide, when water depth is greatest and passage is safest. This system could be digital, providing real-time notifications to inform boat operators of optimal crossing times.

- **Signalling System**: Install navigational aids such as buoys or markers to indicate the safest and deepest parts of the channel. These visual cues would help guide vessels and reduce the risk of grounding.
- **Bathymetric Surveys**: Conduct regular bathymetric surveys to monitor changes in channel depth and sediment distribution. Updated depth data can be used to inform navigation routes and support the scheduling and signalling systems.

Depending on the scale of the sedimentation problem, a time schedule (tide-based) and signaling system can improve the channel navigability towards the harbor. These measures will however not be effective in limiting sedimentation in the channel itself. Bathymetric surveys will not improve navigability directly (score 0 on effectiveness) but are required to monitor the situation and with that improve the effectiveness of other measures. These navigation measures have no significant negative effects on ecology and are relatively easy to implement (+ score on feasibility).

4.4 Shortlist of promising measures

Measures are shortlisted based on assessment 1 if they score positive on goal achievement regarding improving navigability and positive or neutral on feasibility. The channel narrowing measure is included as well, because its effectiveness depends on the design and needs further assessment. In addition, the measure bathymetry survey is included. Even though this measure itself does not improve navigability, it can be useful to support other measures.

Based on this line of reasoning, Table 18 indicates the measures that are shortlisted as promising measures.

Table 18: Indication of shortlisted promising measures

Possible NBS measures in coastal areas	Type of intervention	Measure	Shortlisted?
MOP/DOP measure	Retain sediment along the beach	Longitudinal breakwater	Yes
Reduce sediment input	Retain sediment along the beach	Offshore parallel breakwater	No
		Small-scale sediment capture structures	No
		Perpendicular beach groynes	Yes
		Sea grass restoration/implementation	No
		Creating sedimentation basins	No
	Reduce river sediment input	Dam upstream	No
		Reforestation	No
		Terracing / contour cropping	No
Increase channel flow velocities	Changing channel dimensions	Channel narrowing	Yes
	Increasing upstream discharge	River diversion	No
		Wetland restoration/land use change	No
Management and adaptation measures	Dredging	Dredging	Yes
		Optimized dredging	Yes
		Seabed biodiversity (landscaping dredging)	No
	Queue cove (Caleta) location	Change harbour location	No
	Fishing boat alteration	Shallow draft fishing boats	No
	Navigation	Time schedule for fishing boats/information system	Yes
		Signalling system	Yes

		Frequent bathymetry survey	Yes

4.5 Assessment promising measures (assessment 2)

This section describes assessment 2 of the shortlisted promising measures.

Overview scoring phase two

The measures presented in chapter 4.4 are evaluated below and result in three recommended solutions.

Table 19 Overview results assessment 2, scoring of the shortlist of promising measures

Category	**Subcategory**	**Measure**	**Goal achievement**	**Goal achievement**	**Goal achievement**	**Feasibility**	**Feasibility**	**Feasibility**	**Feasibility**	**Additional benefits**	**Additional benefits**	**Cost**	**Cost**
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility	Maintenance effort	Permittability	institutional complexity	Economy	Social/ engagement	CAPEX (construction)	OPEX (maintenance)
MOP/ DOP measure	Retain sediment along the beach	Longitudinal breakwater	++	++	-	+	+	-	+	+	0	-	0
Reduce sediment input	Retain sediment along the beach	Perpendicular beach groynes	++	++	--	+	+	-	+	+	0	-	0
Increase channel flow	Changing channel dimensions	Channel narrowing	0/+	0/+	+	+	0	0	0	+	+	0	0
Management and adaptation measures	Dredging	Dredging	++	++	-	++	-	-	+	0	0	-	-
		Optimized dredging	+	+	-	+	-	-	+	0	0	-	-
	Navigation	Time schedule for boats/ information system	+	+	0	++	+	0	0	0	-	+	++
		Signalling system	+	+	0	++	+	++	++	0	0	++	0
		Frequent bathymetry survey	0	0	0	+	-	++	++	0	0	0	0

Assessment of promising measures that reduce sediment input

Longitudinal Breakwater

The longitudinal breakwater is a structural measure proposed by DOP to prevent further siltation in the channel, without aiming to improve or deepen it. In the short term, the structure helps ensure that existing sedimentation issues do not worsen. Over both the short and long term, it is expected to prevent sediment transport from the beach towards the river mouth and aid in flushing out accumulated sediments during periods of high river discharge, thereby maintaining the channel's functionality.

However, this measure has ecological drawbacks. The construction of the structure disrupts the local ecosystem, and the breakwater itself is a structural solution that lacks integration with natural elements. As a result, it receives a negative ecological score (G3).

The design uses standard materials and construction methods, but transporting heavy equipment to the site can be challenging. A preliminary design study has already been conducted (Aguas Consultores SpA, 2022), which advances its technical feasibility and earns a positive score (F1). These structures are durable and require minimal maintenance, although repairs do necessitate heavy machinery—contributing to another positive score (F2).

Obtaining construction permits may be difficult due to regulatory constraints. It is therefore essential to review local laws and regulations to understand the necessary requirements for implementation (F3). Environmental disruption during construction could lead to opposition from nature organizations; involving these stakeholders early in the process may help mitigate resistance.

Institutionally, the complexity is low, as the site falls under DOP's jurisdiction. From an economic perspective, construction could generate short-term employment for local workers, without significant long-term economic impact—resulting in a positive score (B1). While initial construction costs are high, operational expenses remain low due to minimal maintenance needs (C1 & C2). The maintenance is low because the longitudinal breakwater is expected to be designed to with international standards and hydraulic modeling based on local conditions. This would result in a breakwater which would be designed for a lifetime of 50 years. This would mean there is a need for monitoring after storms, but low maintenance efforts in general.

The proposed design for this measure is illustrated in Figure 24 (Aguas Consultores SpA, 2022).

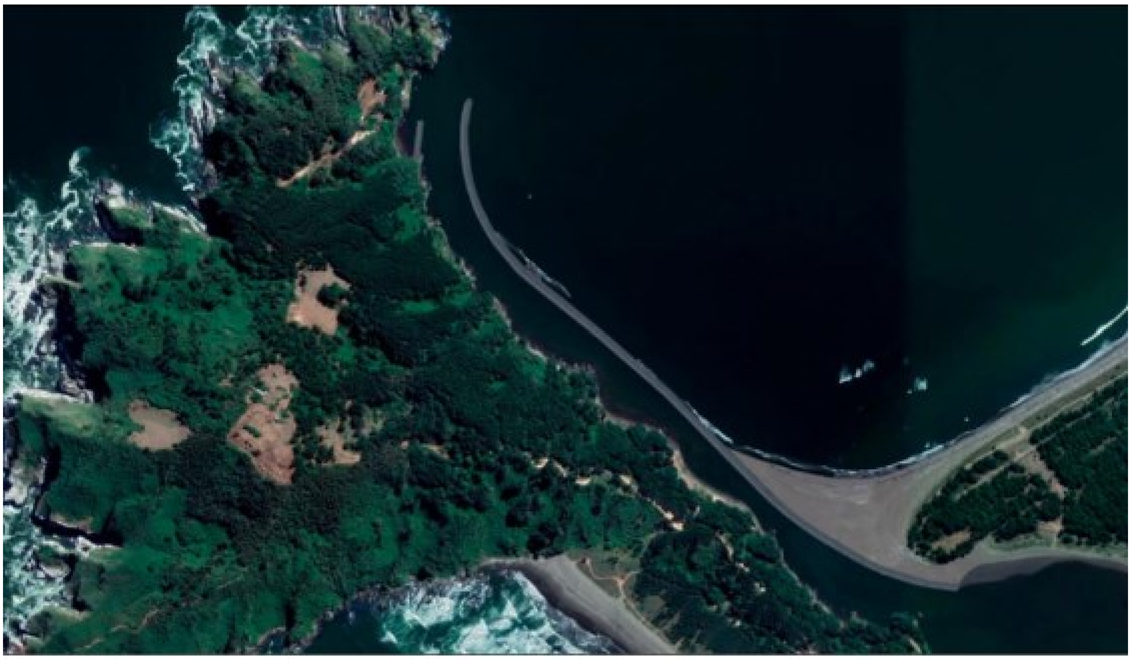


Figure 24 Longitudinal breakwater (Aguas Consultores SpA, 2022)

Perpendicular Beach Groynes

An example of Perpendicular Beach Groyne is shown in Figure 25. These structures are designed to reduce longitudinal sediment transport and, consequently, sedimentation at the river mouth. The performance scores for

perpendicular beach groynes are like those of longitudinal breakwaters. They are expected to be effective in both the short and long term.
Like longitudinal breakwaters, perpendicular groynes disrupt the local ecosystem during construction (G3). Construction can be carried out using standard materials, making it technically feasible for local workers and eliminating the need for imported materials. This results in a positive score for technical feasibility.
Transporting heavy equipment to the site remains a challenge, which limits the score to + rather than ++ (F1). These structures are durable and require minimal maintenance, but repairs do necessitate heavy machinery. Therefore, the maintenance effort score is also + instead of ++ (F2).
Licensing can be difficult due to regulations concerning protected natural areas, resulting in a negative score (F3). During construction, only a few parties are involved, and since the location falls under the jurisdiction of DOP, the overall institutional complexity is low (F4).
Economically, construction provides short-term employment for local workers but offers no long-term economic benefits or drawbacks. While initial construction costs are high, operating expenses are low due to minimal maintenance requirements.

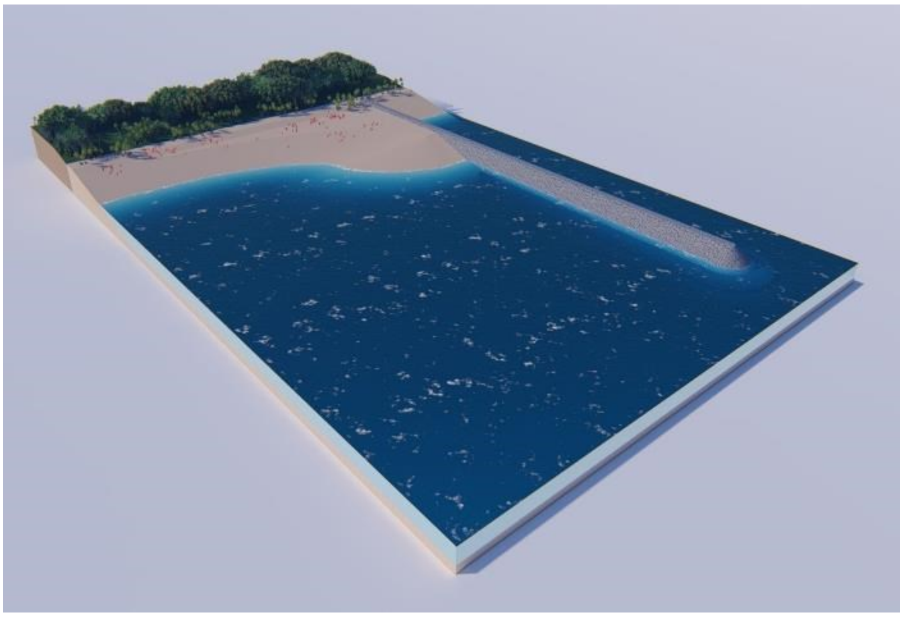


Figure 25: Perpendicular Beach Groynes

Assessment of promising measures that increase channel flow

Channel Narrowing

Channel narrowing can be achieved using a variety of materials, ranging from concrete or rock structures to bamboo, wood, or even vegetation. These interventions aim to direct the flow and increase the velocity of water in the channel, helping to flush sediment out to sea. For scoring, we assume channel narrowing by stimulating vegetation growth.

The effectiveness of channel narrowing as a standalone measure is uncertain and depends strongly on the chosen method. Channel narrowing is expected to increase river flow velocities and will help to flush out more sediments from the channel. However, based on the outcomes of chapter 3, it is expected that channel narrowing alone will not be enough to significantly improve the navigability at Queule (score 0/+, G1, G2). Measures that reduce sediment input from the beach towards the river mouth are needed as well. When stimulating vegetation growth for channel narrowing, the measure is expected to be less effective at the beginning and more effective over time, as the vegetation needs time to establish.

Ecologically, the intervention can be beneficial (score: +, G3), as it promotes riparian vegetation and attracts biodiversity. However, care must be taken to avoid disrupting sensitive intertidal habitats.

Channel narrowing by stimulating vegetation growth is technically feasible, but careful planning is needed to ensure the structure is stable. Maintenance is labour-intensive but does not require heavy machinery, resulting in a neutral score (score: 0, F2).

The permittability and institutional complexity depends on the scale and design of the intervention. For channel narrowing by stimulating vegetation growth the permittability is expected to be easier than for large concrete structures. The institutional complexity is intermediate, as coordination among stakeholders is necessary, particularly for long-term maintenance and ecological monitoring.

Economically, the measure offers some benefits (score: +), including potential for resource harvesting and land use. The measure offers opportunities for local employment and community involvement (score: +, B2).

Construction costs are moderate (score: 0, C1), depending on the materials used, while operational costs are intermediate (score: 0, C2), as minimal machinery is needed but ongoing manual labour is required.

The location of implementation is a critical factor for success, to ensure the measure is effective and does not have negative effects on the environment.

Figure 26: Channel narrowing example (Salix, 2014)

Assessment of promising management and adaptation measures

Dredging

Dredging directly improves channel navigability by removing accumulated sediments. However, it must be repeated periodically—often annually—as it does not address the root causes of sedimentation. Ecologically, dredging can degrade habitats such as mussel beds on tidal flats and may remobilize contaminants. It also increases suspended sediment in the water, which negatively affects filter feeders like mussels, reducing their growth and survival.

Technically, dredging is feasible as the area to dredge is relatively small. Maintenance involves regular dredging to maintain channel depth. Licensing can be challenging due to environmental concerns and restrictions on the maximum allowable dredged volume. The institutional complexity is low, typically involving an external contractor with minimal stakeholder involvement.

Economically, dredging offers limited benefits beyond potential short-term employment for local workers. Social engagement is minimal. The intervention is costly, both in terms of initial implementation and ongoing operational expenses. The estimated annual dredging volume is 38,600 m^3 (Aguas Consultores SpA, 2022), which is below the 50,000 m^3 threshold for which an Environmental and Social Impact Assessment (ESIA) is needed.

The proposed dredged channel would be 590 meters long, 3 meters deep, and 40 meters wide—sufficient for fishing boat passage (Aguas Consultores SpA, 2022). However, further research is needed to determine optimal dredging locations, assess annual volume variations, and evaluate potential ESIA requirements.

Optimized Dredging

The effectiveness of optimized dredging - such as water injection, natural sediment bypassing, and silt curtains - depends on the chosen technique. For Queule silt curtain techniques seem not suitable as the river mouth is a dynamic environment and the natural turbidity is high. Water injection dredging and natural sediment bypassing may be more effective. Like with regular dredging, the optimized dredging directly improves channel navigability by removing accumulated sediments but must be repeated periodically—often annually—as it does not address the root causes of sedimentation. Optimized dredging methods may reduce ecological impacts compared to conventional dredging but still pose risks to habitats and may remobilize contaminants. Technically, these methods are feasible but require specialized equipment. The intervention is costly, both in terms of initial implementation and ongoing operational expenses. Licensing remains difficult due to environmental concerns. Institutional complexity is low. Economically and socially, no additional benefits or engagement are expected. Optimized dredging is expensive initially and requires ongoing operational costs. The same annual dredging volume (38,600 m^3) applies as for regular dredging. Further investigation is needed to assess the suitability of these techniques for the site. For example, water injections may be ineffective if river discharge is insufficient to transport the loosened sediment.

Time schedule

Implementing a time schedule for navigation—based on favourable tidal conditions and river discharge—can mitigate access issues. It has moderate short-term (G1: +) and long-term (G2: +) effectiveness, though sedimentation may still pose challenges.

Ecologically (G3: 0), no impact is expected. Technically (F1: ++), a tide-based schedule is feasible and can be enhanced with bathymetric surveys and signalling systems. Maintenance effort (F2: +) is low, especially if automated. Licensing is straightforward, but making the schedule mandatory is more complex (F3: 0) also institutionally (F4: 0) due to potential resistance.

Economically (B1: 0), the schedule may restrict fishing activities. Social engagement (B2: -) is limited to daily communication. Construction costs (C1: +) are low, requiring expertise but minimal labour. Operational costs (C2: ++) are also low, especially with automation.

Signalling System

A signalling system improves navigation by marking safe routes but does not address sedimentation. It has moderate short- and long-term effectiveness (G1: +). Updating the signalling system is needed in case of bed level changes over time. Ecologically (G3: 0), no significant impact is expected. Technically (F1: ++), buoys are easy to install. Maintenance (F2: +) involves periodic buoy relocation. Licensing (F3: ++) is straightforward due to minimal environmental impact. Institutional complexity (F4: ++) is low, as the buoys can be managed by the local harbor authority. Economically (B1: 0), the system may reduce safety risks and associated costs but apart from that there a no large additional benefits. Social engagement (B2: 0) is minimal. Construction costs (C1: ++) are low, and operational costs (C2: 0) are limited to buoy maintenance.

Frequent Bathymetry Surveys

Frequent bathymetric surveys enhance navigation by providing up-to-date channel information but do not address sedimentation. Their short-term (G1: 0) and long-term (G2: 0) effectiveness is limited to improved safety.

Ecologically (G3: 0), there are no direct benefits, though sonar may disturb aquatic life. Technically (F1: +), the method is feasible with specialized equipment. Maintenance effort (F2: -) is higher due to the need for regular surveys. Licensing (F3: ++) is easy, with minimal environmental concerns. Institutional complexity (F4: ++) is low, typically managed by the harbor authority.

Economically (B1: 0), there are no direct benefits. Social engagement (B2: 0) is minimal. Construction and operational costs are moderate (C1 & C2: 0) due to equipment needs. This measure is best combined with a signalling system to maximize safety and cost-effectiveness.

4.6 Recommended solutions

According to the scoring shown below three measures are coming out best which are presented below.

Longitudinal Breakwater: Combines short-term and long-term effectiveness in enhancing flow and washing out sediments. It involves local workers and provides resources, making it economically and socially beneficial. The current design of the longitudinal breakwater can be adjusted with some nature friendly combinations like creating enriched revetments to enhance biodiversity or planting kelp forests to possibly trap sediments. (Jackson, 1983) (Graham, 2002). The location of planting vegetation should be considered as it will increase sedimentation on those locations.

(Optimized) Dredging combined with adaptive measures: Provides an expected direct improvement with the option of optimized dredging which could have less ecological harm than standard dredging. Different methods for optimized dredging are Water Injection Dredging, Natural Sediment Bypassing and Silt Curtain Techniques.

Dredging can be combined with a signalling system, frequent bathymetry surveys, and reuse of sediments beneficial for nature (examples are shoreline stabilization on eroded location, enhance recreational areas, habitat restoration of nature areas). Combining these measures ensures safe navigation with updated information and buoy placement, addressing short-term navigation issues effectively. This combination is expected to be technically feasible and has low institutional complexity and operational expenses.

Nature-based and non-structural interventions:

NBSs, which consider natural, socio-economic, and institutional systems, can address root causes and offer numerous benefits often at limited costs. These interventions may fall outside the DOP's jurisdiction and require coordination with other agencies or ministries. Examples from the longlist and shortlist include upstream reforestation, vegetation restoration, and terrace construction to limit erosion, as well as building dams to store rainwater or channel rivers. Restoring vegetation in river mouths and coastal zones, such as wetlands, seagrass, and kelp, can stabilize sediment and provide additional ecosystem services.

Non-structural measures, such as relocating the fishing cove (Caleta), adjusting to shallower draft fishing boats, using stronger engines, providing life vests, improving weather forecasting, conducting seabed surveys, and enhancing signalling systems, can also effectively address the problem.

The factsheets prepared for these recommended solutions are in appendix D. Two factsheets focus on measures near the river mouth, and one factsheet on Nature-based and non-structural interventions that can be implemented upstream. Combining upstream and downstream measures should be considered, as they can complement each other effectively. However, the overall impact on the system must be carefully evaluated.

Additional research, field studies and modelling are required to refine the design and assess the effectiveness of these measures. This additional work should focus on long-term discharge measures, local climate data, and long-term sediment flow patterns as well as local involvement. The long-term data can provide more background knowledge on the changes happening in the system. For all solutions also the indigenous communities need to be consulted and an EIA needs to be made.

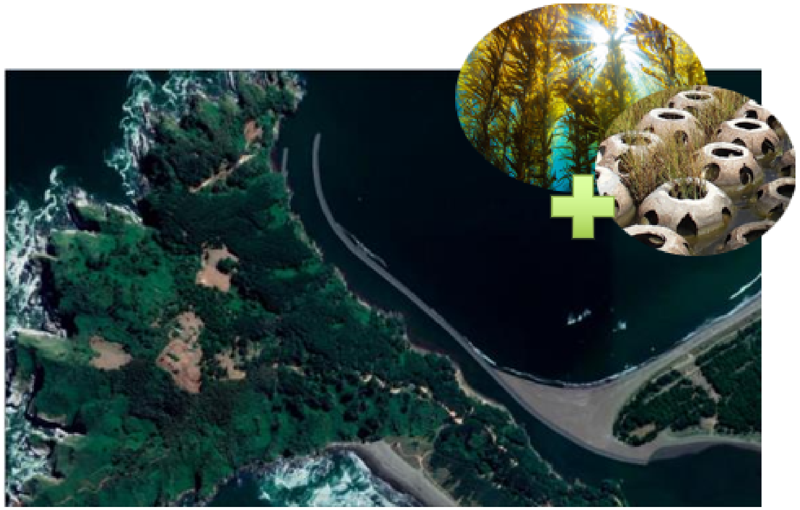
Longitudinal Breakwater

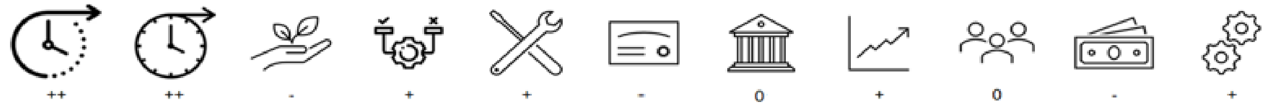
A longitudinal breakwater is a coastal structure designed to protect shorelines, harbors, and ports from wave action and sedimentation. They are also used for channel guidance, creating an artificial channel for boats to enter the sea. For Queule, this means creating an artificial channel that protects the river mouth from sedimentation. The current design can be adjusted with nature-friendly combinations, such as creating enriched revetments to enhance biodiversity or planting kelp forests to slow down longitudinal flow.

Hydraulic and Morphological Design Conditions: Understanding the hydraulic and morphological conditions is crucial. This includes wave and hydrodynamic modeling, subsoil strength information, existing bathymetry, and marine ecology. Integrating sediment transport modeling and seasonal drift patterns into breakwater design can give insight to minimize adverse environmental impacts. Breakwaters and other coastal structures can reduce tidal flushing, leading to increased residence time of water and altered salinity gradients. This can affect nutrient cycling, sediment transport, and the distribution of estuarine species (source 7).

Operational Needs: Monitoring and maintenance are essential. This includes monitoring erosion and sedimentation patterns behind the groynes, including scouring holes, and inspecting the structural integrity above and below water annually and after extreme events. Accretion is commonly observed on the north side of northern breakwaters, while temporary accretion followed by erosion occurs on the south side of southern breakwaters. This is only the case if the longitudinal transport comes from the north to the south, which is the case in Queule (source 6). Although limited maintenance is required, the underwater part can be complex to monitor. Ad hoc replacement or repairs of weakened or damaged rock or concrete elements may be necessary, as well as corrections to stability if needed.

Additions to the design: To make this measure is more nature-friendly and minimize disruption to the ecosystem, several additions can be implemented. or using natural materials can benefit local marine biodiversity. Another option is planting kelp forests which could slow down coastal currents, which reduces the energy of water movement and allows sediments to settle more easily (Source 4). Kelp forests provide complex structures that trap sediments and organic matter. The dense canopy and holdfasts of kelp create a physical barrier that helps in sediment accumulation (source 5). The exact location for planting kelp requires additional study to determine the optimal site.





Additional add-ons:

- Creating enriched revetments to enhance biodiversity
  - Planting kelp forest to possibly trap sediments

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EcoShape

building with nature

(Optimized) Dredging

This technique involves removing sediment and debris to maintain depth and prevent flooding. **Normal dredging** would be the most effective manner to remove sediments. However, there are methods like **Water Injection Dredging**, **Natural Sediment Bypassing**, and **Silt Curtain Techniques**, often combined with adaptive measures to enhance efficiency and reduce ecological impact.

Water Injection Dredging involves injecting large volumes of water at low pressure into the sediment using pumps with nozzles on a horizontal jet bar, which fluidizes the sediment by overcoming soil cohesion or internal friction. This fluidized sediment then flows down to deeper areas, creating a density current that minimizes ecosystem disturbance and allows natural sediment transport (Source 5). This dredging technique is most effective during the rainy season as discharge of the river is the highest. Resulting in higher discharge to wash out resuspended sediment. What also should be considered is the tidal in and out flux at the river mouth also influencing the sediment transport. Implementing this measure during low tide, helps as well as the water is retreating. However, the current river discharge may not be sufficient to remove the necessary amount of sediment, necessitating regular dredging.
Natural Sediment Bypassing harnesses natural water currents to transport sediment in a controlled manner. This method is particularly effective in areas with strong tidal or river currents, reducing the need for mechanical dredging. By utilizing natural forces, this technique decreases the ecological footprint of dredging operations (Source 6).
Silt Curtain Techniques is a barrier from the water's surface to the required depth, usually the seabed, designed to prevent fine-grained suspended material from spreading from the work site into the wider environment. (Source 7). This measure is more additionally to dredging to prevent further disturbance of the environment. However, because the project is in the river mouth there is a constant flow of water, and the water can already be quite turbid, is the effectiveness probably limited.

These dredging works can be combined with adaptive measures like signaling systems, frequent bathymetry surveys, and the beneficial reuse of sediments to further enhance navigation safety and environmental protection. Combining dredging with adaptive measures ensures direct improvement in navigability while reducing long-term operational expenses. Regular dredging intervals are necessary to maintain effectiveness, as sedimentation will reoccur over time. Understanding hydraulic design conditions, including wave and hydrodynamic modeling, is crucial for successful dredging projects. Geotechnical investigations provide essential data on soil properties, aiding in the selection of appropriate dredging equipment and methodologies. While at the same time give information about the dredged soil which can reused more accurately for different purposes. Accurate bathymetric surveys are vital for assessing existing seabed conditions and calculating dredging volumes. Additionally, monitoring and maintenance are essential to evaluate channel depth and ensure navigability. When implementing dredging, sediments will be in resuspension influencing the turbidity. This influence of the turbidity change on mussels and fish should be assessed.

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Additional add-ons:

- Signalling system
- Frequent bathymetry surveys
- Reuse of sediments beneficial

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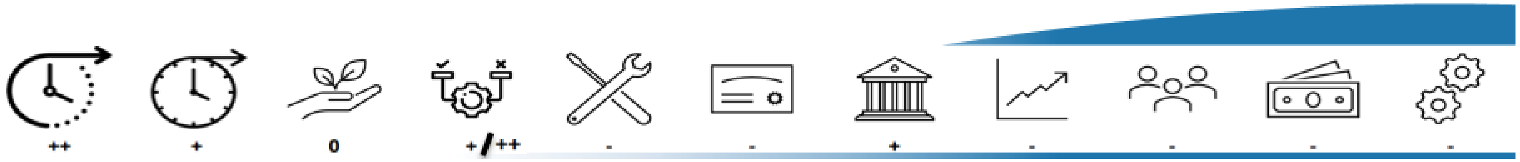


Nature-based and non-structural interventions

Nature-based solutions and non-structural interventions should be based on understanding the natural, socio-economic and institutional system and should address the root causes of the problem. Next to solving the problem they can also create multiple benefits for limited costs. As these interventions are based on system understanding they can be outside the jurisdiction of DOP and require alignment with other agencies or ministries.

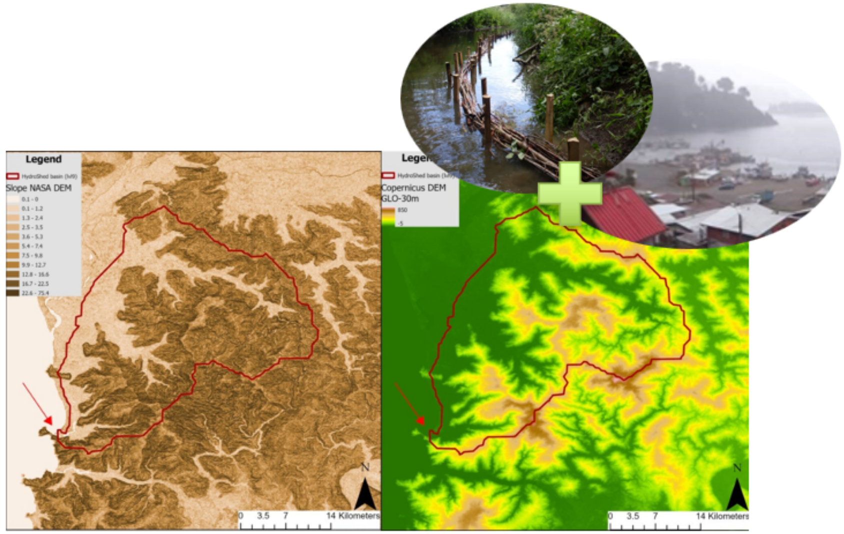
Examples of interventions to limit erosion are upstream reforestation, restoration of vegetation and terraces.

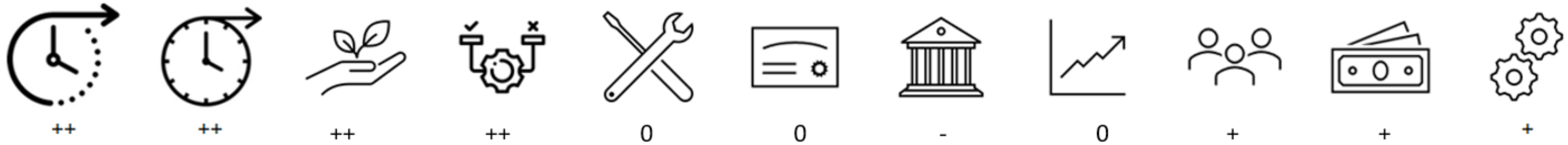
Other interventions can be construction of dams to store rainwater or to channel the river.

Restoration of vegetation in the river mouth and in the coastal zone, like wetlands, seagrass and kelp can stabilise the sediment and provide extra ecosystem services.

Non-structural measures that can improve the safety of navigation can be the relocation of the fishing cove, so the sandbar does need to be passed or changes to the fishing boats like reducing the draught, installing stronger engines and providing life vests.

The safety can also be increased by providing forecasting of the weather and tides, an and regularly surveying the seabed to know the location of the deeper channel(s) and moving the buoys (signalling system) to show the location of the channel.





EcoShape

building with nature

5 Project phases

This chapter consists of three parts. The first part describes the phases a project goes through in Chile. It is followed by the stage the Queule project is in and the steps to be taken.

5.1 Project phases

The project life cycle is a framework that outlines the stages a project goes through from start to finish. The Ministerio de Desarrollo Social y Familia (MDSF) is the Chilean authority responsible of overview the work methodology for the projects (including the environmental and social assessment components).
Projects are composed of three (3) main phases:

1. Pre investment.
2. Investment.
3. Operation.

Each of these phases includes project stages (seven in total) where the technical, financial, economic, social and environmental components are assessed/evaluated to determine project investment, beneficiaries and whether the project is profitable or not.

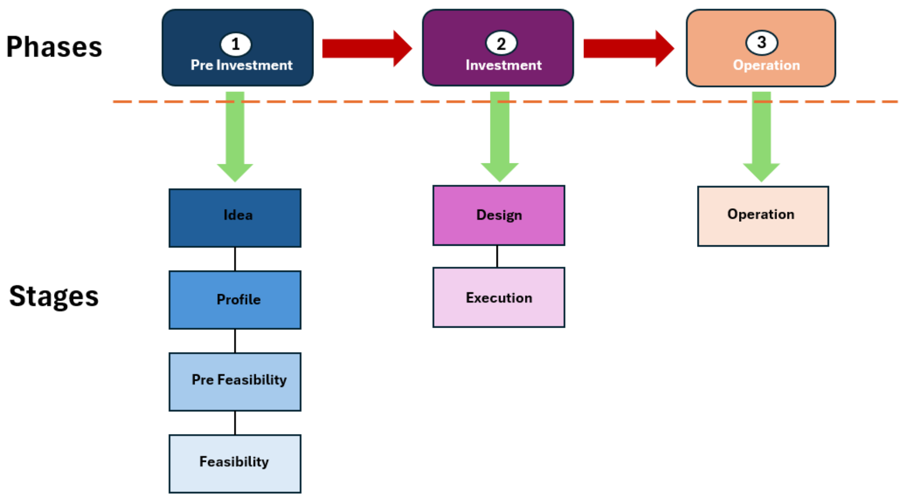


Figure 27 Project life cycle. Source: Ministerio de Desarrollo Social y la Familia (MDSF)

The Pre Investment and Investment phase is where the preparation and project assessment take place. This includes the execution and development of the studies, design and engineering (calculations, drawings, cost estimate of activities, technical specifications) and project feasibility certifications. During the Execution stage (Investment Phase), constructions activities take place and project management, project control and monitoring activities are carried out. Operation is the last phase of the project life cycle, where the testing and starting of operations of the project take place.

Pre - Investment

- During this phase, studies and assessments are conducted to formulate and evaluate the investment initiative.
- Main objective is to increase certainty by gathering sufficient and necessary information to make the best decision from a technical and economic perspective.
- The result is a decision on whether or not to pursue an investment project.

Idea

- A first approach to the problem (opportunity) is described and its initial solutions.
- Informal documental are developed.
- This stage starts the process of project development.

Profile

- A diagnosis is made that allows us to define possible alternatives based on information (mainly) secondary sources.
- The result allows for discarding non-feasible alternatives, selecting possibly feasible alternatives and moving to the next stage or selecting the best technical-economic alternative.
- Depending on the results, the project can go directly to the investment phase (design stage).

Pre-Feasibility

- Further study of the alternatives that are identified in the previous stage (technical and economic).
- The result of this stage enables us to discard non-feasible alternatives, select the best technical-economic alternative and move to the feasibility stage (if further study is necessary) or move to the investment phase (design stage).

Feasibility

- In this stage the best alternative (identified in pre-feasibility stage), is refined and specified.
- The result of this stage is to move to the investment phase (design stage).

Figure 28 Pre-Investment phase and stages definitions. Source: Ministerio de Desarrollo Social y la Familia (MDSF)

Investment

- This phase consists of actions that are required to formulate and evaluate the solution that has been defined as convenient.

Design

- In this stage the architectural and engineering design, and detailed budget of the required civil works are developed.
- It also considers the requirements for equipment and fittings, associated with the functionality of the solution.

Execution

- This stage consists of the execution of civil works, and acquisition of equipment and fittings.
- It includes purchasing or expropriation of land and vehicles.

Figure 29 Investment phase and stages definitions. Source: Ministerio de Desarrollo Social y la Familia (MDSF)

Operations

- Last phase of the project life cycle.

Operation

- This stage consists of testing and starting of operations of the project.

Figure 30 Operation phase. Source: Ministerio de Desarrollo Social y la Familia (MDSF)

5.2 Current status of the Queule River Mouth project

Currently, the Queule River Mouth project is in the Design stage, where the engineering documents (design, technical specifications, cost estimates) are completed. In 2022 DOP carried out a design study named *''Design improvement of the Queule River Mouth''*, where a design solution was proposed to improve the navigability conditions of the mouth of the Queule River. Prior to starting with the Execution stage, the following activities must be completed:

1. **Public and indigenous consultation**
   During social and public consultation, DOP will gather information and understand whether there is discontent, concern or approval of the existing solution by the communities. Indigenous consultation can be negative and result in the project not being implemented.
2. **Environmental and Social impact assessment (ESIA)**
   The potential environmental, social, and economic effects of the proposed Queule River Mouth project will be evaluated. ESIAs analyze a project's environmental and social impacts to identify risks and opportunities and plan mitigation measures. Essentially, ESIAs help ensure that projects are developed sustainably, minimizing harm to the environment and affected communities. The goal of environmental permitting is to balance economic growth with the preservation of the environment.
3. **MDSF approval**
   DOP submits all related documentation related to the public and indigenous consultation, ESIA and engineering design so MDSF can review and decide if the project is feasible and allocate investment for project execution.

Given that this design solution consists of structural measures with possible negative impacts to the environment, DOP asked support to the Dutch Embassy in Chile to find an NBS alternative to complement the fishermen access to sea on a preliminary level. This study provides alternative solutions for the Queule river mouth. In addition to that this study also provides a roadmap for projects like Queule that are early in the pre-investment phase where there are still possibilities to conclude on different types of solutions. Another aim of this study is to complement and suggest possible improvements to the existing project in Queule.

5.3 Next steps for the Queule River Mouth project

The results of the Public and indigenous consultations, obtaining the Environmental permit and MDSF approval during the design stage, will determine if the project proceeds to its Execution stage or if the project will be cancelled.

Table 20 provides a brief description of the activities that are needed to ensure the execution of Queule River Mouth project.

Table 20: Queule River mouth project next steps

Phase	Stage	Activities	Comments/Remarks
Investment	**Design**	**Indigenous consultation**	
		Discussion of proposed design solution with communities	
		Preparation of report	
		Submission for approval	It is expected that indigenous consultation, can take 1 up to 3 months (consultation) and up to 1 year to obtain approval from the communities. This is based on previous consultations for a dredging project in Queule.
Investment	**Design**	**Environmental and Social impact assessment (ESIA)**	
		Field studies and data gathering	
		Preparation of report	
		Submission for approval	Environmental and Social Impact Assessment (permit approval) can take up to 3 years from preparation of the environmental studies, submission, public consultation and approval from authorities.
Investment	**Design**	**NBS alternative**	
		Preparation of NBS alternative	DOP to evaluate proposed NbS recommendations. The proposed combined Nature-Based Solutions/Non-structural measures, needs to be study in more detail in a later stage to have a better understanding of their impact on the local natural system, both physical and environmental.
Investment	**Design**	**MDSF approval**	
		Submission, review, and approval of design project by MDSF	
Investment	**Design**	**Tender selection and contract award of construction activities**	
		Preparation of tender documents	
		Tender process	
		Review of proposals	
		Contract award	
Investment	**Design**	**Construction Activities**	
		Execution of construction activities	
Operations & maintenance	**Design**	**Project Close-Out**	
		Starting operations of project features	Factsheets #1, #2, #3 provide some recommendations on the expected operational needs include monitoring and maintenance
		Maintenance	

6 Stakeholder engagement plan

The objective of this project is to provide a roadmap to reach *a viable solution for the fishermen of Queule cove (Caleta), taking into account the system as a whole and existing stakeholders, interests, possibilities and restrictions.* Part of that roadmap is a technical approach to find new solutions (see previous chapter). But another major contribution in achieving the project's success is involving local stakeholders in the project, to gain their support.

This chapter outlines the important stakeholders (6.1), provides a general roadmap for stakeholder engagement, applicable for all projects (6.2) and advices on the steps that should be taken for the ongoing Queule project (already in stage 5, design) in order to ensure stakeholder support.

6.1 Stakeholder mapping - Queule

In this section, we provide an overview of the community groups and stakeholders involved in (measures in) Queule River mouth.

Figure 3125 shows a list of all stakeholder groups and a power-interest grid on which all groups have been plotted. The bottom right groups don't naturally have much power over the project, but do have a high interest in it, because their livelihood depends on the Queule River mouth. Therefore, it is important that they are enabled to participate in the project and to have influence on decisions that concern their lives and livelihoods. On the other hand, the upper right groups are powerful, they are the ones who need to support the project in order for it to continue. These four groups are presented in more detail in the tables below.

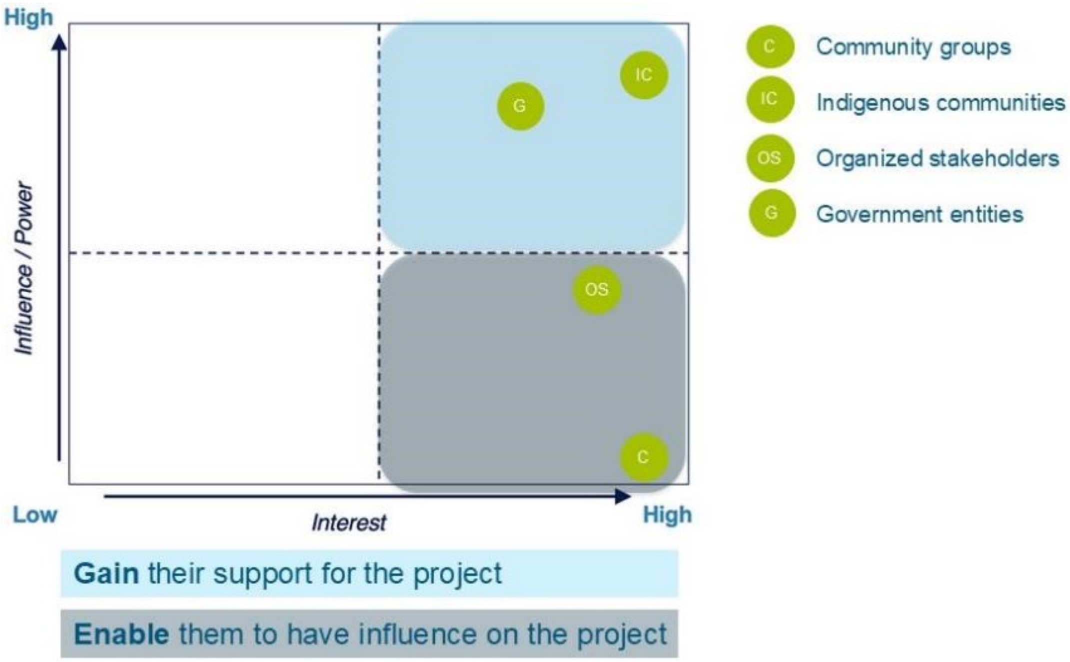


Figure 31 Power-Interest grid Queule River mouth

Community groups related to the project

Community group	Relations to Queule River and the project
Fishermen	The fishermen are the main problem owner in the current situation; they experience difficulties when going out to sea (or back) due to the sand bank. Solving this problem will be of a large benefit to them, as this will increase their safety, the safety of their assets (fishing boats), and their income.
Mussel farmers	In the current situation, the mussel farmers do not experience issues due to the sand bank. However, as some of the potential solutions involve dredging, the project could impact on the turbidity and sediment transport of the water, which in turn could impact the mussels. This should be studied in the EIA, and the resulting impact on the mussel farmers should be assessed.
Aquaculture practitioners	In the current situation, the aquaculture practitioners in the river do not experience issues due to the sand bank. However, as some of the potential solutions involve dredging, the project could impact the turbidity and sediment transport of the water, which in turn could impact the fish in the river. This should be studied in the EIA, and the resulting impact on the mussel farmers should be assessed.
Traders and people working in industry (related to fishing, mussels, and aquaculture)	If the solutions impact the fish catch and/or mussel harvest that is brought to shore in Queule, the traders and other people working in the fishing industry will be impacted as well.
Fishing boat owners	The organizational structure of the fishermen is unknown. If the fishing boats are owned by someone else or by a company, this is an additional stakeholder that will be impacted by the project.
Tourist operators	The tourist operators are a second problem owner in the current situation; they experience difficulties when going out to sea (or back) due to the sand bank. Solving this problem will be of a large benefit to them, as this will increase their safety, the safety of their clients, the safety of their assets (fishing boats), and their income.
Diving school owners	See tourist operators.
Other	To be determined.

Indigenous communities

Nearby indigenous communities	Relation to Queule River and the project
Francisco Huaiquin	As indigenous communities have been given the final say in a Go/No Go decision for projects that impact them, the Queule River project is highly dependent on their support. Next to their formal role in the Queule River project, members of the indigenous communities have a relation to the river and the project based on their livelihoods (see previous table).
Francisco Trecan	
Juan Liempi	
Juana Aguila de Flores	
Juana Pichi Pillan V. de	
Manuel Penchulef	
Simón Imihuala	

Organised stakeholders

Organization (Spanish original name)	Organization (English translation)
Asociación Gremial de Armadores de Embarcaciones Pesqueras Artesanales de Queule	Association of Owners of Artisanal Fishing Boats of Queule

STI de Pescadores y Buzos Artesanales Queule	STI of Artisanal Fishermen and Divers Queule (union)
STI Armadores Pelágicos y Pescadores Artesanales de Queule	STI Pelagic Owners and Artisanal Fishermen of Queule (union)
Sindicato de Armadores, Pescadores Pelágicos y Actividades Conexas de Caleta Queule	Union of Shipowners, Pelagic Fishermen and Related Activities of Caleta Queule
Cooperativa de Pescadores Artesanales Caleta Queule	Cooperative of Artisanal Fishermen Caleta Queule
Sindicato de Pescadores, Tripulantes, Buzos y Turismo	Union of Fishermen, Crew, Divers and Tourism
STI Armadores Pelágicos y Cerqueros Caleta Queule	STI Pelagic Owners and Purse Seiners Caleta Queule (union)
Asociación Gremial de Armadores y Pescadores Artesanales Pelágicos de la Araucanía	Association of Owners and Artisanal Pelagic Fishermen of Araucanía
STI de Pescadores Artesanales y Turismo Queule	STI of Artisanal Fishermen and Tourism Queule (union)
JJVV Caleta Queule	JJVV Caleta Queule (neighbourhood association)
JJVV Portal Queule	JJVV Portal Queule (neighbourhood association)
Caleta Los Pinos Queule	Caleta Los Pinos Queule
Comité de Agua Potable	Drinking Water Committee

Government entities

Institution (Spanish original name)	Institution (English translation)	Reference person	Jurisdiction
Gobierno Regional de La Araucanía	Regional Government of La Araucanía	Governor of the Araucanía Region	Regional
Delegación Presidencial de La Araucanía	Presidential Delegation of La Araucanía	Presidential delegate of La Araucanía	Regional
Dirección de Obras Portuarias, Ministerio de Obras Públicas	Port Works Directorate, Ministry of Public Works	Regional Director of Maule, Ñuble, Biobío and La Araucanía	Regional
SEREMI, Ministerio de Obras Públicas	SEREMI, Ministry of Public Works	Regional Ministerial Secretary of Public Works, La Araucanía Region	Regional
Directemar, Comuna de Valdivia	Directemar, Municipality of Valdivia	Port Captain	Communal
Alcaldía de Mar, Queule	Water Bailiff, Queule	Water Bailiff	Local
Servicio de Evaluación Ambiental, La Araucanía	Environmental Assessment Service, La Araucanía	Regional Director	Regional
Comisión Regional del Uso del Borde Costero (CRUBC)	Regional Commission for the Use of the Coastal Border (CRUBC)	President CRUBC	Regional
Oficina Técnica Región de La Araucanía, CMN	Technical Office of the La Araucanía Region, CMN	Office Manager	Regional
SERNAPESCA La Araucanía	SERNAPESCA La Araucanía	Regional Director (S)	Regional
SERNAPESCA Queule	SERNAPESCA Queule	Office Manager	Local
Ilustre Municipalidad de Toltén	Illustrious Municipality of Toltén	Mayor	Communal
Ilustre Municipalidad de Toltén	Illustrious Municipality of Toltén	Fishing Office Manager	Communal
Municipalidad Toltén	Toltén Municipality	SECPLAN	Communal
Oficina CONADI Toltén	CONADI Toltén Office	Office Manager	Communal

6.2 Stakeholder engagement plan - general roadmap

Engagement per stakeholder group

Within the practice of stakeholder engagement, different levels of engagement are defined, with increasing level of involvement (see Figure 32).

Although the stakeholders have been identified for Queule specifically, on a group level, they are universal for all projects. For each stakeholder group identified in paragraph 5.3.1, it is determined what their interest level in this project is, and what their level of engagement should be. This is shown in Table 21.

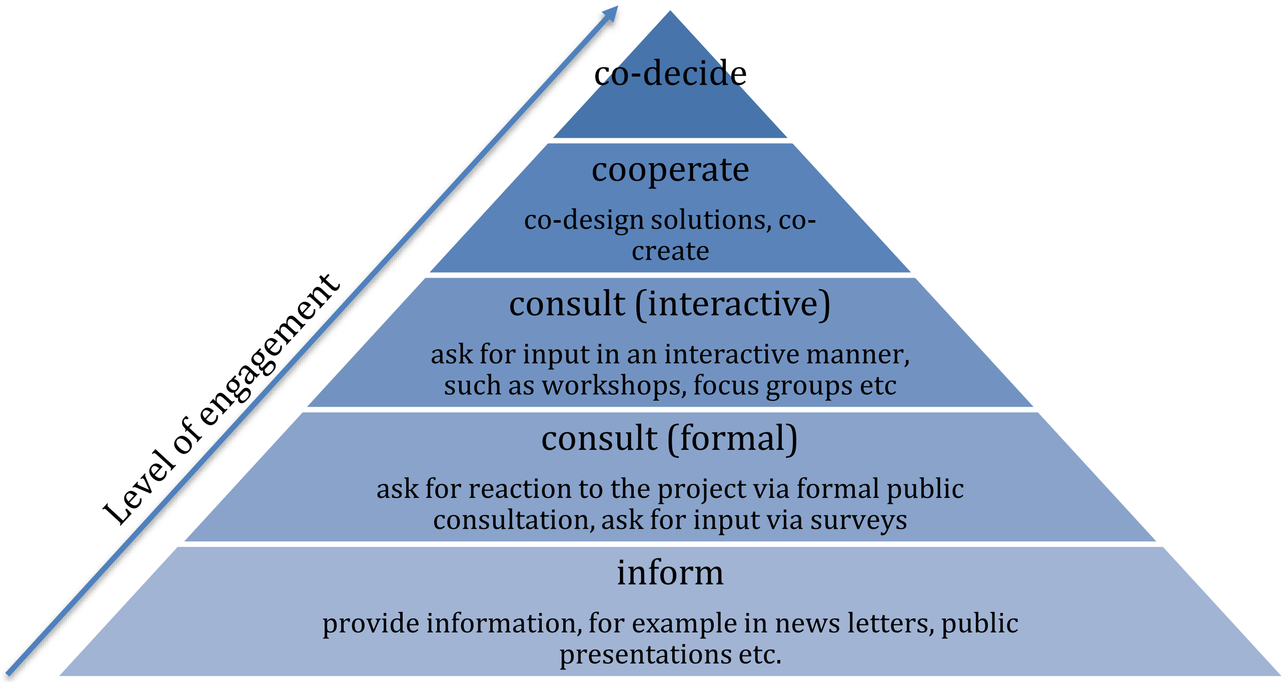


Figure 32 Levels of stakeholder engagement

Table 21 Stakeholder engagement overview

Stakeholder group	Interest level (very high, high, medium, low, very low)	Level of engagement
Community groups	very high	consult (interactive and formal)
Indigenous communities	very high	co-decide
Organised stakeholders	high	consult (interactive and formal)
Government entities	high	co-decide
Representatives from community groups and organised stakeholders	very high	cooperate (in the form of an advisory board)

Advisory board
As the community groups and organised stakeholders are not formally included in the decision-making process, it is important to ensure in a different way that their views are taken into account and that they feel engaged and taken seriously. This can be done by creating an advisory board, with representatives from the community groups and the organised stakeholders. The representatives should be appointed by their group, in order to ensure that they have a mandate to speak on behalf of their group.

The advisory board will meet before every decision. In the meeting, the designs, study results, etcetera will be explained by the project team, and the advisory board will be given the opportunity to ask clarifying questions. Based on this information, the advisory board will draft an advice on the decision at hand for the decision-makers. This is non-binding advice, but the decision-makers do need to provide an explanation if their decision deviates from the advice given.

Engagement per project stage
The stakeholder engagement stages are linked to the general project stages as described in paragraph 5.1. These stages require different levels and forms of engagement. Below, the phases are explained on a high level, the next sections elaborate how each stakeholder group will be engaged in each phase.

Stage 1 - idea
In this stage, the problem at hand is analyzed and first ideas about solutions are developed, based on existing documentation and research. Topics to be discussed are:
- Informing the stakeholders about the project.
- Asking community groups and organised stakeholders to choose representatives for the advisory board that will be consulted for decision-making.
- Collecting the up-front opinion of the stakeholders about the project; what concerns, ideas et cetera do they have.
- Collecting baseline information regarding the project, the project area, and the communities: what are the social and environmental characteristics of the area.
- Ask people about their life based on (way of life, culture, community, political system, environment, health and wellbeing, personal and property rights, and fears and aspirations)[3].
- Ask people what challenges they face in their everyday life, for example regarding their livelihoods.
- Ask people for their ideas on how to address social and socioeconomic challenges.

Table 22 Stakeholder engagement during the idea phase

Moment	Method of stakeholder engagement			
	Community groups	**Indigenous communities**	**Organised stakeholders**	**Government entities**
Start of the idea phase	public meetings. focus groups (different livelihoods, women, and youth). interviews	public meetings. focus groups (different livelihoods, women, and youth). interviews	interviews (welcome at public meetings)	interviews (welcome at public meetings)

Stage 2 - profile
During this stage, possible solutions are developed, and non-feasible alternative solutions are discarded, for example solutions that are technically unfeasible. No stakeholder engagement is required at this stage.

Stage 3 - pre-feasibility

[3]https://pure.rug.nl/ws/portalfiles/portal/17534793/IAIA_2015_Social_Impact_Assessment_guidance_document.pdf

In this stage, alternative solutions for the project are assessed, and one preferred solution is chosen. This is based on a high-level design and a preliminary impact assessment.

During the start of the pre-feasibility phase discussions should be about i) collecting ideas for alternative solutions: are there other options than the ones defined in the profile stage, could the design of the alternative solutions be optimized and ii) collecting input for the impact assessment; what knowledge do stakeholders have of the environmental and social impacts of the alternative solutions. At the end of the pre-feasibility stage (but before decision-making) views should be collected on the alternative solutions based on impact information provided by the project team: concerns, are stakeholders pro or con and why, which alternative solution do they prefer?
At the end of this stage at the decision-making the discussion should be about what alternative solution will be chosen as the preferred solution.

Table 23 Stakeholder engagement during the pre-feasibility stage

Moment	Method of stakeholder engagement			
	Community groups	**Indigenous communities**	**Organised stakeholders**	**government entities**
Start of the pre-feasibility phase	public meetings; focus groups (different livelihoods, women, and youth). interviews	public meetings. focus groups (different livelihoods, women, and youth). interviews	interviews (welcome at public meetings)	interviews (welcome at public meetings)
End of the pre-feasibility stage (but before decision-making)	public meetings; focus groups (different livelihoods, women, and youth)	public meetings. focus groups (different livelihoods, women, and youth)	interviews (welcome at public meetings)	interviews (welcome at public meetings)
Decision-making	advisory board meeting, but not involved in formal decision making	not involved (but wise to consider their view, as they have a No-Go power later in the project)	advisory board meeting, but not involved in formal decision making	decision-making workshop

Stage 4 - feasibility
In this stage, the preferred solution is further defined, and its financial, technical, and legal (for example regarding environmental permits) feasibility is determined. The environmental and social impact assessment will be conducted, but it could happen that the ESIA continues in the design stage (stage 5).

At the start of the feasibility stage the following topics need to be discussed:
- Informing the stakeholders about the chosen preferred solution.
- Collecting views on the scoping report and Terms of Reference (ToR) for the ESIA: formal public participation, during which people can share all their concerns, ideas, views regarding the preferred solution and the proposed social and environmental studies proposed in the ToR.
- Collecting input for the ESIA: what knowledge do stakeholders have of the environmental and social impacts of the preferred solution.

At the end of the feasibility stage (but before decision-making) it is important to collect views on the final design of the preferred solution and the ESIA: formal public participation, during which people can share all their concerns, ideas, views regarding the project.

After finalizing all documentation and collecting all stakeholder input, a collective Go/No Go decision needs to be made with the project owner, government entities, and indigenous communities.

Table 24 Stakeholder engagement during the feasibility stage

Moment	Method of stakeholder engagement			
	Community groups	**Indigenous communities**	**Organised stakeholders**	**Government entities**
Start of the feasibility stage	public meetings. focus groups (different livelihoods, women, and youth)	public meetings. focus groups (different livelihoods, women, and youth)	interviews (welcome at public meetings)	interviews (welcome at public meetings)
End of the feasibility stage (but before decision-making)	public meeting	public meetings	interviews (welcome at public meetings)	interviews (welcome at public meetings)
Decision-making	advisory board meeting, but not involved in formal decision making	internal deliberation of Indigenous peoples. dialogue between the parties. decision-making workshop	advisory board meeting, but not involved in formal decision making	decision-making workshop

Stage 5 - design
In this stage, the technical design of the preferred solution will be detailed.

At the end of the design stage (but before decision-making) the stakeholders need to be informed about the final technical design and answering questions. After finalizing all documentation and collecting all stakeholder input, a collective Go/No Go decision needs to be made with the project owner, government entities, and indigenous communities.

Table 25 Stakeholder engagement during the design stage

Moment	Method of stakeholder engagement			
	Community groups	**Indigenous communities**	**Organised stakeholders**	**Government entities**
End of the design stage (but before decision-making)	public meetings	public meetings	interviews (welcome at public meetings)	interviews (welcome at public meetings)
Decision-making	advisory board meeting, but not involved in formal decision making	internal deliberation of Indigenous peoples. dialogue between the parties. decision-making workshop	advisory board meeting, but not involved in formal decision making	decision-making workshop

Stage 6 - execution
In this stage, the chosen solution will be implemented/constructed.

Stakeholder engagement during this stage concerns an ongoing grievance mechanism that allows stakeholders to contact the project owner or take additional (formal) steps in case of concerns during construction.

Stage 7 - operation
During the operation, stakeholder engagement is also in the form of an ongoing grievance mechanism in case of concerns during operation.

General recommendations
Within stakeholder engagement it is essential to guarantee transparency and timely engagement.

Timely engagement
The highest level of freedom in thinking about solutions for a project exists early on in the project stages. Therefore, if stakeholders are engaged early, they can have the largest influence on the project's outcome. The further the project moves forward through the different stages, the smaller the possibility for a stakeholder to influence the project will be. In previous engagement for Queule, stakeholders were first engaged when the type of solution had already been chosen. So, when they came up with alternative solutions for the project, they sensed that a decision on the preferred solution had already been made.

It is therefore important to start the stakeholder engagement process directly at the first stage of the project.

Transparency
It also happens that stakeholders are **asked** to come up with alternative solutions for the project in the design phase, even though the decision for the preferred solution has already been made. This gives stakeholders a false sense of influence, which could cause a breach of trust and should be avoided at all costs.

It is therefore important to be transparent about the influence a stakeholder has (and does not have) on the project in a specific stage of the project. Explain what decision will be made in each stage, how each stakeholder can provide input for this decision, and also indicate the limits of a stakeholder's influence.

6.3 Stakeholder engagement plan Queule - how to move forward?

Short history of the public participation until now in Queule
Public participation in the project has taken place before. The last round of consultations, in 2022, was well designed by focusing on including all social groups, with special attention to gender. People were asked about their concerns, their observations, and their problems and necessities. Surveys were undertaken, informal communication with stakeholders was established, radio-announcements were broadcast, leaflets about the project were shared, and a formal communication e-mail address was instated.

This resulted in the following main takeaways:

- Improvement of the river mouth to develop fishing, tourism, culture and the sustainability of Queule.
- Erosion control to reduce sediments that reach the river.
- Care of the environment and the wetland.
- Discharge of wastewater into the river.
- Correct execution of the studies within the promised timeframes.
- Working table to obtain solutions at an international level for the project.
- Binding citizen participation with the presence of Queulinos and Queulinas.
- Indigenous communities upstream must receive the same expenses as at the river mouth.
- Indigenous consultation for the project.

Public participation has been focused on implementing the solution of construction of a groyne and dredging. People indicated that they felt as if all decisions had already been made, and that the moment for them to influence the project had already passed. Giving more opportunities for people to think along and suggest solutions will therefore be the main focus of the proposed future stakeholder engagement.

Advice: take some steps back in stakeholder engagement roadmap

The Queule project is currently at stage 5, the design stage. Previous consultation took place without the options for NBSs (see chapter 4). The solution presented was the construction of the groyne and dredging. It was mentioned at consultation meetings that a solution had been chosen already, and that people had not been given the opportunity to come up with ideas. Therefore, it is advised that some of the stakeholder engagement steps from previous stages are taken:

- **Stage 1 - idea -** identifying the main social challenges in the project area, and asking people about their way of life are essential for determining the social baseline in the area. This in turn will enable identification of proper mitigation and/or compensation measures for project affected people.
- **Stage 3 - pre-feasibility -** stakeholder engagement should be executed for the new NBSs (chapter 4): enabling stakeholders to share their knowledge and views regarding these solutions, will help to optimize these solutions and to find support for these measures. If stakeholders are genuinely being consulted, it could also increase overall project support.
- **Stage 4 - feasibility -** as the ESIA still needs to be conducted, the related stakeholder engagement also needs to be conducted.

Stakeholder engagement steps from the different stages are to be combined where possible, in order to optimize (reduce) the number of engagement sessions, to avoid participation fatigue. The topics per stage are elaborated above. The following topics need to be discussed:

- Collecting the general opinion of the stakeholders about the project; what concerns, ideas et cetera do they have.
- Collecting baseline information regarding the project, the project area, and the communities (social and environmental characteristics of the area).
- Ask people about their life based on (way of life, culture, community, political system, environment, health and wellbeing, personal and property rights, and fears and aspirations).
- Ask people what challenges they face in their everyday life (regarding their livelihoods).
- Ask people for their ideas on how to address social and socioeconomic challenges.
- Collecting ideas for alternative solutions: are there other options? Could the design of the alternative solutions be optimized.
- Collecting input for the impact assessment; what knowledge do stakeholders have of the environmental and social impacts of the alternative solutions.
- Collecting views on the alternative solutions, based on impact information provided by the project team: concerns, are stakeholders pro or con and why, which alternative solution do they prefer?
- What alternative solution will be chosen as the preferred solution.
- Informing the stakeholders about the chosen preferred solution.
- Collecting views on the scoping report and Terms of Reference (ToR) for the ESIA: formal public participation, during which people can share all their concerns, ideas, views regarding the preferred solution and the proposed social and environmental studies proposed in the ToR.
- Collecting input for the ESIA: what knowledge do stakeholders have of the environmental and social impacts of the preferred solution?
- Collecting views on the final design of the preferred solution and the ESIA: formal public participation, during which people can share all their concerns, ideas, views regarding the project.
- After finalizing all documentation and collecting all stakeholder input, a collective Go/No Go decision needs to be made with the project owner, government entities, and indigenous communities.

Table 26 Advice for stakeholder engagement for Queule

Moment	Method of stakeholder engagement			
	Community groups	Indigenous communities	Organised stakeholders	Government entities
#1 - baseline info and ideas for alternative solutions	public meetings. focus groups (different livelihoods, women, and youth). interviews	public meetings. focus groups (different livelihoods, women, and youth). interviews	interviews (welcome at public meetings)	interviews (welcome at public meetings)
#2 - assessment of alternative solutions	public meetings; focus groups (different livelihoods, women, and youth)	public meetings. focus groups (different livelihoods, women, and youth)	interviews (welcome at public meetings)	interviews (welcome at public meetings)
#3 - decision on alternative solutions	advisory board meeting, but not involved in formal decision making	Not involved (but wise to consider their view, as they have a No-Go power later in the project)	advisory board meeting, but not involved in formal decision making	decision-making workshop
#4 - preferred solution and ToR for the ESIA	public meetings. focus groups (different livelihoods, women, and youth)	public meetings. focus groups (different livelihoods, women, and youth)	interviews (welcome at public meetings)	interviews (welcome at public meetings)
#5 - assessment of the preferred solution	public meeting	public meetings	interviews (welcome at public meetings)	interviews (welcome at public meetings)
#6 - decision on the preferred solution	advisory board meeting, but not involved in formal decision making	internal deliberation of Indigenous peoples. dialogue between the parties. decision-making workshop	advisory board meeting, but not involved in formal decision making	decision-making workshop

Advice: Integrate stakeholder engagement and ESIA

As the main concern expressed by the indigenous communities is about environmental impacts, it is advised to integrate the ESIA process and the stakeholder engagement process: give people the opportunity to share their knowledge and concerns about the environment, and use the information from the ESIA to find approval from the indigenous communities.

Advice: Additional information to be collected

It is advised to collect additional information on the social baseline, environmental impacts, and social impacts in order to optimize the stakeholder engagement.

Social baseline

Community engagement should make sure that all community groups are sufficiently represented; men-women, all age groups, all ethnic groups, all livelihoods, and all project affected people. To ensure sufficient representation, more detailed information on the community profile is required, differentiated between the indigenous community and the overall community, differentiated between men and women, differentiated between age groups.

Information to be gathered:

- Population characteristics (age, gender, education level).
- Livelihoods and poverty.
- Link of the people with Queule River.
- Customs.
- Leadership structure.

- Information about other ways of life (see paragraph 5.3.3).

Also, more information on the structure of the fishing sector is required. Is fishing their only form of livelihood or do they have other livelihoods on the side? Are the fishermen self-employed or do they work for a company? Who owns the fishing boats? Et cetera.

Environmental impacts

As the main concern expressed by the indigenous communities is about environmental impacts, these impacts should be studied and assessed, and shared during stakeholder engagement sessions. Not only is the first order environmental impact essential (turbidity and disturbance caused by dredging), but also second order impacts (the impact on for example the mussel, fish, and other aquatic species populations).

Social impacts

Social impacts will result from the impacts on mussels, fish et cetera, as many people rely on catching and selling these species for their livelihoods. Information on these social impacts should be collected and shared during stakeholder engagement sessions.

7 Roadmap

This chapter presents a roadmap for sustainable management of river mouths. It starts with some general remarks. It is followed by a general road map which is based on the previous chapters and is presented in a table. In 6.3 specific suggestions are given for Queule as it is in stage 5 - design.

7.1 General

The aim of this road map is to work towards sustainable solutions from the first stage. A solution that solves the problems with minimum negative impact, maximum positive impact for lowest life cycle cost. To be able to sustainably manage river mouths it is essential that the system of the river mouth is understood. Based on that system, understanding the root causes of the problems can be found as well as co-benefits of sustainable solutions.

The system understanding consists of the following three systems: natural, socio-economic and institutional. In the different stages solutions will be identified which will be structural (grey (hard), green (soft, NBS) and hybrid)) as well as non-structural. From all solutions the feasibility (technical, financial, legal) needs to be determined as well as their impact on economy, society and environment.

In important role this entire process is for the engagement of the stakeholder as it taps into knowledge of locals and other experts. Through early involvement of all relevant stakeholders, ministries/departments that have the right jurisdiction and right mandate for interventions, as well as stakeholders that might be affected, helps to get sustainable solutions.

7.2 Roadmap

The table is based on the three project phases Ministerio de Desarrollo Social y Familia (MDSF) and its seven stages. For each stage it states the suggested actions for the following columns: technical-economic, social-environmental, financing-funding. To prevent stating the same lines again, reference is made to the relevant chapters.

Phase	Stage	Technical - Economic	Social - Environmental	Financing, funding	Comments / Remarks
Pre - Investment					
	Idea	Identification of the problems and presentation of first ideas for solutions	- Informing the stakeholders about the project. - Asking community groups and organised stakeholders to choose representatives for the advisory board that will be consulted for decision-making. - Collecting the up-front opinion of the stakeholders about the project; what concerns, ideas et cetera do they have? - Collecting baseline information regarding the project, the project area, and the communities: what are the social and environmental characteristics of the area? - Ask people about their life (way of life, culture, community, political system, environment, health and wellbeing, personal and property rights, and fears and aspirations). - Ask people what challenges they face in their everyday life, for example regarding their livelihoods. - Ask people for their ideas on how to address the social and socioeconomic challenges.		
	Profile	- Assessment of existing conditions - Identify required studies and expected results - Preparation, evaluation and selection of alternatives		From this stage (depending on the complexity of the project), funding can be requested for the pre-feasibility, feasibilty, design or execution.	- This stage is carried out by the planning department of DOP. - Project does not necessarily go through each and every stage of the pre-investment phase; this will depend on the complexity of the project and available fundings.
	Pre - Feasibility	- Preliminary studies. - Goals and objectives. - Identification an definition of the problem. - Complete diagnosis of the current situation (natural, socio-economic and institutional system). - Develop solutions (structural (grey, green, hybrid) and non-structural). - Analysis of alternative solutions. - Identification, measurement, and valuation of direct and indirect costs and benefits (economic, social, environmental) of each project alternative. - Determine criteria (solve problem, with minimum negative impact, maximum positive impact for lowest life cycle cost). - Technical and economic evaluation of each project alternative. - Selection of the best alternative. - Summary and conclusions. - Overview of sources of financing. - Detailed budget for all stages. - Estimated investment costs. - Analysis of current supply, demand, future projections, and gaps, considering optimization of the current situation	**Start of the pre-feasibility phase:** - Collecting ideas for alternative solutions: are there other options than the ones defined in the profile stage, could the design of the alternative solutions be optimized? - Collecting input for the impact assessment; what knowledge do stakeholders have of the environmental and social impacts of the alternative solutions? **End of the pre-feasibility stage (but before decision-making):** - Collecting views on the alternative solutions based on impact information provided by the project team: concerns, are stakeholders pro or con and why, which alternative solution do they prefer? **Decision-making:** - What alternative solution will be chosen as the preferred solution?	Projects are financed/funded in two ways (can be mixed): 1. Sectoral Funding (ministry budget) 2. Regional Financing (regional government budget) Financial institutions can provide fundings for NBS initiatives (CAF, World Bank, IDB Invest, etc.)	
	Feasibility	- Executive summary of the Pre-feasibility Study. - Basic engineering studies (including field studies/site investigations, etc.). - Detailed study of the selected alternative.	**Start of the feasibility phase:** - Informing the stakeholders about the chosen preferred solution. - Collecting views on the scoping report and Terms of Reference (ToR) for the ESIA: formal public participation, during which people can share all their concerns, ideas, views regarding the preferred solution and the proposed social and environmental studies proposed in the ToR. - Collecting input for the ESIA: what knowledge do stakeholders have of the environmental and social impacts of the preferred solution? **End of the feasibility stage (but before decision-making):** - Collecting views on the final design of the preferred solution and the ESIA: formal public participation, during which people can share all their concerns, ideas, views regarding the project. **Decision-making:** - After finalizing all documentation and collecting all stakeholder input, a collective Go/No Go decision needs to be made with the project owner, government entities, and indigenous communities	- Projects are financed/funded in two ways (can be mixed): 1. Sectoral Funding (ministry budget) 2. Regional Financing (regional government budget) - Financial institutions (CAF, World Bank, IDB Invest, etc.) can provide fundings for NBS initiatives	In the case of a feasibility study, the selected alternative must be analyzed in depth and more details
Investment					
	Design	- Approved profile, pre-feasibility, or feasibility study. - Architectural/engineering drawings. - Technical specifications. - Gantt chart type schedule (showing duration of activities). - Terms of Reference for the consultancy contract. - Detailed budget for the entire stage. - Detailed investment schedule.	**End of the design stage (but before decision-making)** - Informing the stakeholders about the final technical design and answering questions. **Decision-making** - After finalizing all documentation and collecting all stakeholder input, a collective Go/No Go decision needs to be made with the project owner, government entities, and indigenous communities.		
	Execution	- Updated Pre-investment study (based on the results of previous stages). - Final drawings, technical specifications, budgets and approved by the relevant technical institution. - Work schedule. Expected durations for each activity in the execution phase with their respective funding. - Detailed project budget for each activity (including overhead, profit, and taxes).	Stakeholder engagement during this stage concerns an ongoing grievance mechanism that allows stakeholders to contact the project owner or take additional (formal) steps in case of concerns during construction.		
Operation					
	Operation		During the operation, stakeholder engagement is also in the form of an ongoing grievance mechanism in case of concerns during operation		

7.3 Queule

Queule is in the investment phase in the design stage. So, the steps in the roadmap from the design stage onward can be applied. In addition, it is recommended to follow what is stated in 5.3.3 regarding the stakeholder engagement. There it is stated that the main concern expressed by the indigenous communities is about environmental impacts. Therefore, it is recommended to integrate the ESIA process and the indigenous (and other public) consultation process: give people the opportunity to share their knowledge and concerns about the environment, and use the information from the ESIA to find approval from the indigenous communities. During this process solutions will come from the meetings. In addition to that it is suggested to look in more detail at green, hybrid and non-structural solutions.

8 Conclusions and recommendations

8.1 Conclusions

The following conclusions are drawn:

- The existing system understanding and conclusions on the physical aspects are supported. The main driver of navigability hindrance is sedimentation driven by coastal processes. The situation seems to be aggravated by low average river discharges in the last 15 years.
- Other aspects that affect the system, such as the social and economic dimensions are explored and considered.
- Previous solutions are technical and focused on deepening the water depths at the river mouth by structural narrowing or dredging.
- There has not been much experience in Chile with fundings from Financial Institutions to develop NBS projects. Experience so far has been mostly with complementary studies.
- Public participation sessions which have taken place.

8.2 Recommendations

Opportunities from an early stage

Chapter 6 describes different aspects of the stakeholder engagement which are desired from an early stage of project development. The main points of the chapter are:

- Involve stakeholders from an early stage of the project development and along the different project phases.
- Engage stakeholder groups in different ways according to their level of interest and level of influence on the project.
- Guarantee transparency and timely engagement of stakeholders.
- Benefit from the public contribution by co-deciding, consulting and co-operating with different groups. This can provide advantages in developing alternatives and selection of realistic and implementable solutions.
- This process fosters the support of the stakeholders involved, crucial for later stages of development.
- Non-structural solutions and NBSs also benefit from early engagement.

Recommendations for improving the system understanding

In this report information was utilised that was either publicly available or derived from previous studies. The collection of information has been conducted in a manner that aligns with the time and efforts available for this study. However, to enhance the understanding of the system, it is recommended to analyse or start collecting the following data:

- **Coastal data:** It is advised to use more points in time for coastal data (waves, bathymetry) to better understand seasonal changes and the impact of these indicators.
- **Fluvial data:** It is advised to use longer timeseries for river data (rainfall and discharge) to better understand seasonal changes and the impact of these indicators.
- **River basin:** Using a higher resolution elevation map helps improve the accuracy of the analysis. If this higher resolution map is available for both before and after the earthquake, the impact of the earthquake can be better described.
- **Ecosystem:** To assess the impact on the ecosystem, it is recommended to analyse and map which organisms and ecosystems are present in the area.
- **Social system:** updated and complete information on economic activities in Queule and the composition of different associations and ethnical groups. Particularly an overview of covering all these aspects is missing, which would be useful to also identify overlaps among them.
- **Public participation and expressions:** summary of minutes of all public participation meetings and other communication channels so far reflecting the position of all stakeholders and participating groups. For instance, there is no written record about the indigenous communities' position on the latest proposed interventions (Aguas Consultores SpA, 2022).

Recommendations for currently proposed interventions in Queule

The Queule River Mouth project is currently in Design stage. In this context and accepting the existing solution, a longitudinal dam, the following recommendations are proposed:

- Improve the ecological benefits by adding habitat to the design of the longitudinal dam and optimizing impact on the existing environment.
- Consider limiting the height and thus the volume of the longitudinal dam.
- Consider adjusting the rock sizes along the northern side of the groyne as it will be covered with sand due to the wave action in the foreseeable future.
- Collect additional information on a social baseline, environmental impacts, and social impacts.
- Take some steps back in stakeholder engagement roadmap to include NBSs (see Chapter 6).
- Integrate stakeholder engagement and ESIA.

9 Appendix A: Longlist adaptation measures

Table 27 Longlist adaptation measures with links

Possible measures		Measure	Comparable project links	
MOP/DOP measure		**Longitudinal breakwater**		
Reduce sediment input	Retain sediment along the beach	Offshore parallel breakwater	Sea Palling Eng,	Miami, US
		Small-scale sediment capture structures	Demak, Indonesia	
		Perpendicular beach groynes	Thyborøn Channel, Denmark	
		Sea grass restoration/implemention	Gathaagudu, Australia (in combination with indigenous people)	Wadden sea, Netherlands
		Creating sedimentation basins	New Brunswick, Canada	
	Reduce river sediment input	Dam upstreams	Chilean rivers	
		Reforestation	Valdivian Coastal Reserve, Chile	
		Terracing/contour cropping	Canada/China/Nepal /Indonesia	
Increase channel flow	Changing channel dimensions	Channel narrowing	River Dearne, england	Naturally happened at the river Nuble, Chile
	Increasing upstream discharge	River diversion		
		Wetland restoration/land use change	Wuhan, China	Chile
Adaptive measures	Dredging	Dredging	Scheveningen, Netherlands	ANTOFAGASTA, CHIL
		Optimized dredging	Hamina, Finland	
		Seabed biodiversity (landscaping dredging)	Rotterdam, Netherlands	

10 Appendix B: Scores of phase 1 and 2

Possible measures groups in coastal areas		Measure	Goal achievement	Goal achievement	Goal achievement	Feasibility	Aditional benefits	Going to scoring two
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility, maintenenace effeort, Licensiability, institutional complexity	economy, social / engagement	
MOP/DOP measure		**Longitudinal breakwater**	**+**	**+**	**-**	**-**	**0**	**yes**
Reduce sediment input	Retain sediment along the beach	Offshore parallel breakwater	0	0	-	0	0	no
		Small-scale sediment caputre structures	0	0	+	-	+	no
		Perpendicular beach	+	+	-	-	0	yes
		Sea grass restoration/implemention	-	0	+	-	+	no
		Creating sedimentation basins	+	-	0	-	+	no
	Reduce river sediment input	Dam upstreams	-	-	-	-	0	no
		Reforestation	-	-	+	+	+	no
		Terracing / contour cropping	-	-	+	+	+	no
Increase channel flow	Changing channel dimensions	Channel narrowing	-	0	+	0	+	yes
	Increasing upstream discharge	River diversion	+	+	-	-	-	yes
		Wetland restoration / land use change	-	0	+	+	+	no
Adaptive measures	Dredging	Dredging	+	+	0	-	0	yes
		Optimized dredging	+	+	+	0	+	yes
		Seabed biodiversity (landscaping dredging)	-	-	+	0	+	no
	Harbour location	Change Queule cove (Caleta)	+	+	0	-	-	no
	Fishing boats alteration	Shallow draft of fishing vessels	+	+	0	+	-	yes
	Navigation	Time schedule for boats / information system	+	0	0	+	0	yes
		Signaling system	+	0	0	+	0	yes
		Frequent bathemetry survey	0	0	0	+	0	yes

Figure 33: Scores measure phase one

Possible NbS measures groups in coastal areas		Measure	Goal achievement	Goal achievement	Goal achievement	Feasibility	Feasibility	Feasibility	Feasibility	Aditional benefits	Aditional benefits	Cost	Cost
			Short term effectiveness (0-5 years)	Long term effectiveness (>10 years)	Ecological benefits	Technical feasibility	Maintenance effort	Licensiability	institutional complexity	Economy	Social / engagement	CAPEX (construction)	OPEX (maintenance)
MOP/DOP measure		**Longitudinal breakwater**	++	++	-	+	+	--	+	+	0	-	+
Reduce sediment input	Retain sediment along the beach	Perpendicular beach groynes	++	++	-	+	+	-	+	+	0	-	+
Increase channel flow	Changing channel dimensions	Channel narrowing	-	0	+	+	0	+	-	+	++	0	-
	Increasing upstream discharge	River diversion	+	+	-	-	0	-	--	0	0	--	0
Adaptive measures	Dredging	Dredging	++	+	-	++	-	0	+	-	-	-	-
		Optimized dredging	++	+	0	+	-	0	+	-	-	-	-
		Seabed biodiversity (landscaping dredging)	0	0	+	+	-	0	+	-	-	-	-
	Fishing boats alteration	Shallow draft of fishing vessels	+	+	+	+	+	++	+	--	-	0	0
	Navigation	Time schedule for boats / information system	+	+	0	+	+	+	++	0	-	+	++
		Signaling system	+	0	0	++	+	++	++	0	0	++	-
		Frequent bathemetry survey	0	0	0	+	-	++	++	0	0	+	+

Figure 34: Scores measures phase two

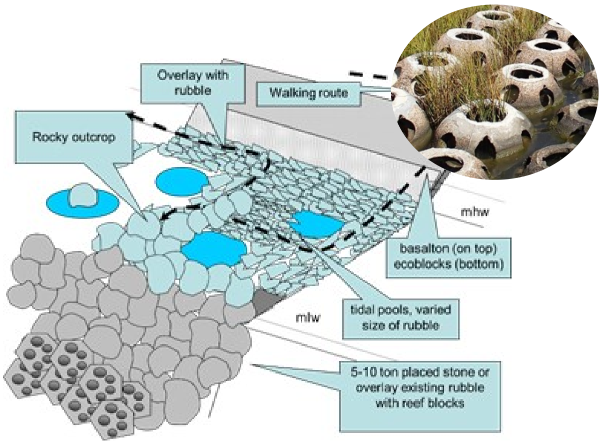
11 Appendix C: Additional information on recommended solutions

11.1 Longitudinal Breakwater Add Ons

The longitudinal breakwater proposed by DOP could be made with less negative impacts for the environment, while simultaneously harnessing the positive impacts of nature. For this purpose, additional measures have been identified.

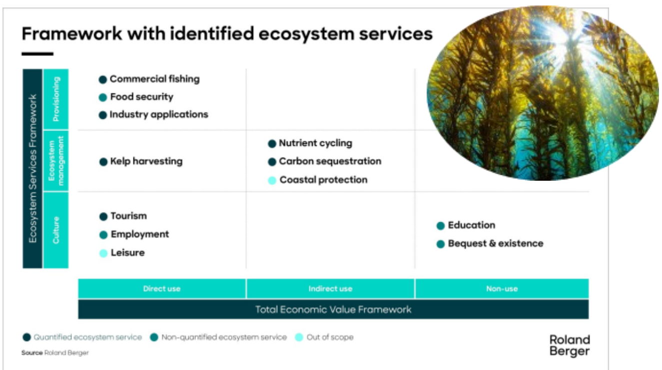
Use of enriched revetments (Ecoshape, n.d.)

- Include small adaptations in texture, form and materials in the hard structures. This creates habitat and supports biodiversity. This can become a feeding ground for birds and fish species.
- Include specialized seawall tiles, Eco blocks, tidal pools, differing sloping gradients in the foreshore and the use of reef blocks. This creates habitat and supports biodiversity. This can become a feeding ground for birds and fish species.
- Analyse and study the foreshore and intertidal morphology, followed by a selection of most promising eco-structures.
- While not affecting the effectiveness, these adjustments increase the ecological value, while it has minimal extra maintenance costs.



Plantation of Kelp forests (Floor van Werven, 2025)

- Reduces the energy of water movement and allows sediments to settle more easily (Jackson, 1983). Kelp forests provide complex structures that trap sediments and organic matter. The dense canopy and holdfasts of kelp create a physical barrier that helps in sediment accumulation (Graham, 2002). Planting kelp at the right location where sedimentation needs to be stimulated or is encouraged to prevent it from happing somewhere else is important. Here planting vegetation on the outer side of the breakwater on a gradient slope from the breakwater could be beneficial.
- Kelp forests are native to Chile, providing all kinds of ecosystem services. The kelp can be harvested for chemical use, provides habitat for fish, increases the biodiversity and captures CO2.



- The measure increases effectiveness as less sand will reach the river (breakwater) mouth, is beneficial for the ecology and economy of the area, and does not need large maintenance efforts

Natural flow of sand as strengthening mechanism (Boskalis, 2018)

- Innovative design to reduce the quantities of rocks used under traditional design.
- Uses the natural flow of sand along the Chilean coasts to strengthen the breakwater after initial construction.
- Due to the reduced quantities in used materials, it decreases the construction and maintenance costs.
- Can be used in combination with the enriched revetments.

The list below provides recommendations for field investigations, studies and modelling to be carried out in the next project phase. This list is not exhaustive.

- Ecological baseline and habitat mapping:
  - Detailed benthic habitat survey by using diver/video transects to map existing habitats and species assemblages at the beach and river mouth.
  - Biodiversity assessment, to identify key species (including protected or invasive species) and ecological functions already present.
  - Reference site studies, to survey the nearby natural rocky shores for target habitat structures and species to replicate or encourage. If possible, study nearby natural kelp forests for species composition, structure, and functioning. Light availability for kelp, water temperature profiling, salinity and nutrient concentrations.
- Substrate and water quality assessment:
  - Sediment and substrate composition analysis, to ensure compatibility of proposed habitat features with local conditions.
  - Water quality sampling and focus on parameters relevant to ecological health (nutrients, salinity, temperature, turbidity, dissolved oxygen).
- Hydrodynamic and morphological modelling (with ecological focus):
  - Detail hydrodynamic modelling around breakwater, to study how local currents, sediment deposition, and scour could influence the addition of habitat structures (cavities, ledges, pools)
  - Morphological stability analysis, to ensure habitat features will not be scoured or buried by sediment movement.
- Structural integration studies:
  - Material compatibility study, to assess local sourcing of eco-friendly materials (e.g., rough-textured concrete, natural rock) and their ecological performance.
- Long-term monitoring plan design:
  - Development of a monitoring protocol, to track ecological performance and structural integrity post-construction.
  - Adaptive management framework, to develop triggers for intervention (e.g., replanting, predator control) if help establishment falters.
- Risk and maintenance assessment:
  - Assessment of maintenance requirements for habitat structures (e.g., risk of clogging, colonization by invasive species).
  - Safety and liability review to assess potential risks to users (if accessible to public) or navigation.

11.2 Nature-based and non-structural interventions

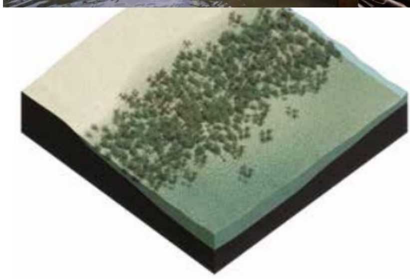
Nature-based solutions, being interventions based on understanding the natural, socio-economic and institutional system, can address the root causes and as a result create many benefits for limited costs. These interventions can be outside the jurisdiction of DOP and require alignment with other governmental agencies or ministries. Furthermore, non-structural measures can address the problem from a different perspective looking at behavioural or socio-economic measures. Below there is a list of solutions with a brief description of its functioning, service, and requirements.

Figure 35 Approximate location of nature-based solutions and non-structural measures

The following solutions have potential to improve the present conditions:

1) Narrowing the river mouth with wooden structures, logs or other natural materials can increase the flow velocities during regular tidal fluctuations and deepen the water depth in the navigation channel. This measure requires maintenance and possibly partial or full restoration after large river floods. The possibility of engaging the local workforce for construction and maintenance could be considered to have additional social benefits.

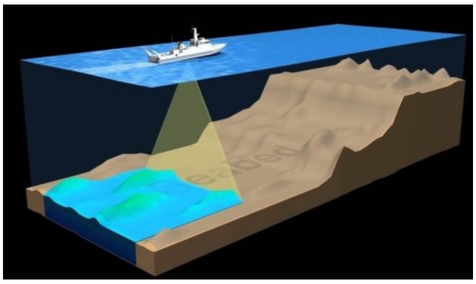
2) The first solution can be complemented by growing vegetation in the river mouth, coastal zone, and/or wetland. Seagrass and kelp can stabilize sediments and provide extra ecosystem services. This measure requires time, and it is more effective in the long term. It is vulnerable to river floods presenting significant drag capacity to cause basal erosion and dislodgment, which depends on the vegetation exposure (location).



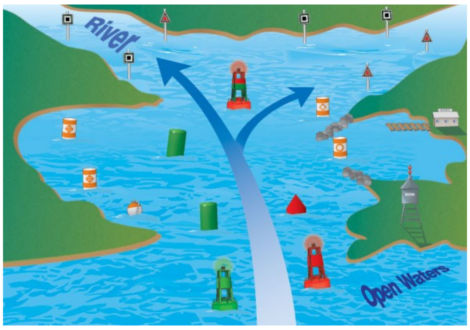
3) The following are non-structural measures that deal with the problem at hand. Several can be applied. These do not change the physical system or bring ecological value, but serve to improve the safety conditions and navigability by adapting to the system as it currently is. They also imply various levels of investment and maintenance.
    a. New vessel designs that enable a lower draught. Using shallow draft fishing boats omits the problem of the limited water depth but may still face issues due to changing conditions. Ecologically, shallower draft fishing boats are less harmful. Technically, replacing existing fishing boats is possible, but may face resistance from fishermen. Economically, it requires new investments in shallower draft fishing boats, possibly with reduced fishing capacity. Social engagement is important as the fishermen need to agree with alterations of their fishing boats.

Capital expenses depend on compensation policies, and operational expenses for regulation enforcement are low.

b. Frequent bathymetry surveys significantly improve navigation by providing updated information to fishermen, though they don't solve sedimentation issues in the river mouth. Ecologically, no benefits are expected, and sonar used for surveys could harm aquatic life. Technically, specialized equipment is required. Maintenance involves conducting surveys regularly. Institutional complexity is low, with responsibility likely falling to the local harbor authority. Economically, no benefits are expected. Capital expenses include acquiring specialized tools and equipment, which is a relatively small investment. Operational expenses are ongoing due to the need for regular surveys. This intervention should be applied together with a signalling system to mark the navigation channel, showing the safe passage, thus reducing the safety issues and potentially saving costs.



c. A navigation channel signalling system aids navigation, but doesn't address sedimentation issues in the river mouth. Over time, fishing boats may still face problems in case the channel migrates. Thes can be solved by conducting frequent bathymetry surveys and relocating the buoys accordingly. Technically, buoys are easy to implement, but can create a false sense of security, as the bathymetry can change. Operation and maintenance involve relocating the buoys as the bathymetry changes. Institutional complexity is low, with responsibility likely falling to the local harbor authority. Economically, if buoys are effective this will result in less safety issues and potentially some cost savings. There is no extra social engagement expected. Construction costs are low, and operational expenses for relocation are limited.



4) Other non-structural measures that might increase safety but not navigability are:
   a. Stronger engines, so in case of strong currents or waves the vessels have more power to navigate.
   b. Live vests, in case vessels overturn the fishermen will stay afloat and have support to come to shore.
   c. Time schedule, implementing a time schedule helps partially by omitting the problem, but can cause peak traffic in the channel. Currently the fishermen already navigate the channel at a time schedule. On the long-term the fishermen may still face issues due to changing conditions. Technically, a tide-based schedule is possible and will be more effective when it is combined with frequent bathymetry surveys and a signalling system to show the safest navigation route. Economically, fishermen may be restricted by the schedule, impacting their activities. Social engagement is limited to daily informing the fishermen. Capital expenses are low, requiring specialized knowledge but minimal labour. Operational expenses could be automated.
   d. Weather forecasting. This will help to know when conditions will become too harsh to leave to sea.
5) Relocation of the fishing cove (Caleta) is a non-structural measure addressing the need to navigate through the cove and passing the sandbar.
6) Reforestation upstream, these can help to limit erosion and sediment supply as it stabilizes and holds the soil. An additional benefit is that it can lower the peak of the discharge flow during extreme rainfall events.
7) Construction of terraces upstream, these can help to limit soil erosion through a flatter surface, which reduces the movement of soil.
8) Construction of dams, these can help to store the rainwater, reducing the peaks of the discharge during extreme rainfall events.

Additional research is required to refine the design and assess the effectiveness of these measures. This research should focus on long-term discharge measures, local climate data, and long-term sediment flow patterns. The long-term data can provide more background knowledge on the changes happening in the system.

The list below provides recommendations for field investigations, studies and modelling to be carried out in the next project phase. This list is not exhaustive.

- General:
  - Integrated modelling to consider developing an integrated model (hydrodynamics, sediment, ecology) for holistic scenario analysis.
  - Long-term monitoring, to implement monitoring programs for all interventions to adaptively manage and optimize the outcomes.
  - Stakeholder engagement, to conduct continuous engagement with local communities for social acceptance and co-management of NbS.
- Narrowing the river mouth with wooden structures/logs:
  - Topographic and bathymetric Surveys, to do detailed survey of the river mouth to determine current morphology and navigation channel depth.
  - Sediment sampling and analysis, to determine grain size distribution, sediment transport rates, and sources to understand sediment dynamics.
  - Hydrological measurements, to determine river discharge, water levels and current velocities during flood conditions.
  - Ecological baseline survey, to make an inventory of existing habitats, flora, and fauna (especially protected species, fish migration routes, and benthic communities).
  - Geotechnical investigations, to assess soil and sediment capacity for structure placement.
  - Hydrodynamic and morphological modelling, to do 2D or 3D numerical models to assess changes in flow velocity, water depth, and channel morphology due to narrowing, including design optimization.
  - Flood risk assessment, by modelling potential backwater effects.
  - Socio-economic impact assessment, to determine the feasibility of engaging local workforce; cost-benefit analysis including potential job creation and social acceptance.
- Vegetation planting (seagrass, kelp, etc.):
  - Habitat suitability survey, to identify suitable sites for planting based on substrate type, salinity, water depth, and light availability.
  - Baseline ecological assessment, to document existing vegetation and faunal communities, including invasive species.
  - Flood and storm event analysis, to assess historical and probable future extreme events.
  - Vegetation establishment and survival Modelling, to predict success/failure rates under different hydrodynamic and sediment conditions and to assess susceptibility of planted areas to uprooting/erosion during floods.
  - Ecosystem services assessment, to valuate potential benefits (e.g., sediment stabilization, biodiversity enhancement).
  - Long-term monitoring plan for vegetation growth, ecosystem response, and maintenance needs.

12 Appendix D: Factsheets

Queule – Possible adaptation measures

Factsheets of potential adaption measures
for the Queule project area

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Legend

Short term effectiveness (0-5 years)	Technical feasibility	Institutional complexity	CAPEX
Long term effectiveness (>10 years)	Maintenance effort	Economy	OPEX
Ecological benefits	Licensiability	Social engagement	

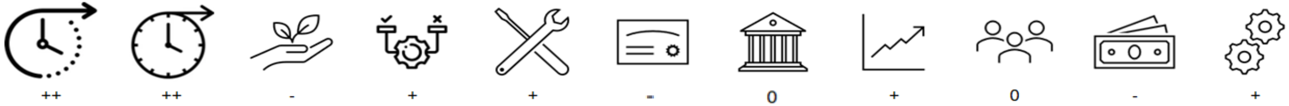
Longitudinal Breakwater

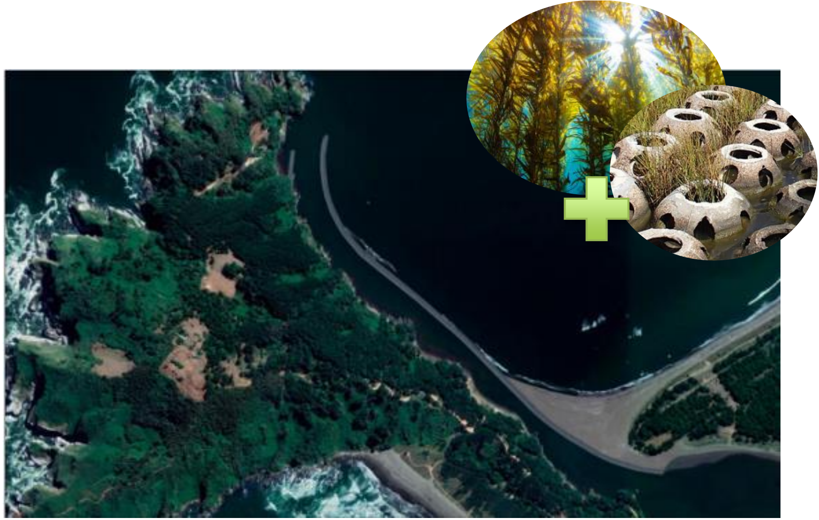
A longitudinal breakwater is a coastal structure designed to protect shorelines, harbors, and ports from wave action and sedimentation. They are also used for channel guidance, creating an artificial channel for boats to enter the sea. For Queule, this means creating an artificial channel that protects the river mouth from sedimentation. The current design can be adjusted with nature-friendly combinations, such as creating enriched revetments to enhance biodiversity or planting kelp forests to slow down longitudinal flow.

Hydraulic and Morphological Design Conditions: Understanding the hydraulic and morphological conditions is crucial. This includes wave and hydrodynamic modeling, subsoil strength information, existing bathymetry, and marine ecology. Integrating sediment transport modeling and seasonal drift patterns into breakwater design can give insight to minimize adverse environmental impacts. Breakwaters and other coastal structures can reduce tidal flushing, leading to increased residence time of water and altered salinity gradients. This can affect nutrient cycling, sediment transport, and the distribution of estuarine species (source 7).

Operational Needs: Monitoring and maintenance are essential. This includes monitoring erosion and sedimentation patterns behind the groynes, including scouring holes, and inspecting the structural integrity above and below water annually and after extreme events. Accretion is commonly observed on the north side of northern breakwaters, while temporary accretion followed by erosion occurs on the south side of southern breakwaters. This is only the case if the longitudinal transport comes from the north to the south, which is the case in Queule (source 6). Although limited maintenance is required, the underwater part can be complex to monitor. Ad hoc replacement or repairs of weakened or damaged rock or concrete elements may be necessary, as well as corrections to stability if needed.

Additions to the design: To make this measure is more nature-friendly and minimize disruption to the ecosystem, several additions can be implemented. or using natural materials can benefit local marine biodiversity. Another option is planting kelp forests which could slow down coastal currents, which reduces the energy of water movement and allows sediments to settle more easily (Source 4). Kelp forests provide complex structures that trap sediments and organic matter. The dense canopy and holdfasts of kelp create a physical barrier that helps in sediment accumulation (source 5). The exact location for planting kelp requires additional study to determine the optimal site.





Additional add-ons:

- Creating enriched revetments to enhance biodiversity
- Planting kelp forest to possibly trap sediments

Citations:

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(Optimized) Dredging

This technique involves removing sediment and debris to maintain depth and prevent flooding. **Normal dredging** would be the most effective manner to remove sediments. However, there are methods like **Water Injection Dredging**, **Natural Sediment Bypassing**, and **Silt Curtain Techniques**, often combined with adaptive measures to enhance efficiency and reduce ecological impact.

Water Injection Dredging involves injecting large volumes of water at low pressure into the sediment using pumps with nozzles on a horizontal jet bar, which fluidizes the sediment by overcoming soil cohesion or internal friction. This fluidized sediment then flows down to deeper areas, creating a density current that minimizes ecosystem disturbance and allows natural sediment transport (Source 5). This dredging technique is most effective during the rainy season as discharge of the river is the highest. Resulting in higher discharge to wash out resuspended sediment. What also should be considered is the tidal in and out flux at the river mouth also influencing the sediment transport. Implementing this measure during low tide, helps as well as the water is retreating. However, the current river discharge may not be sufficient to remove the necessary amount of sediment, necessitating regular dredging.

Natural Sediment Bypassing harnesses natural water currents to transport sediment in a controlled manner. This method is particularly effective in areas with strong tidal or river currents, reducing the need for mechanical dredging. By utilizing natural forces, this technique decreases the ecological footprint of dredging operations (Source 6).

Silt Curtain Techniques is a barrier from the water's surface to the required depth, usually the seabed, designed to prevent fine-grained suspended material from spreading from the work site into the wider environment. (Source 7). This measure is more additionally to dredging to prevent further disturbance of the environment. However, because the project is in the river mouth there is a constant flow of water, and the water can already be quite turbid, is the effectiveness probably limited.

These dredging works can be combined with adaptive measures like signaling systems, frequent bathymetry surveys, and the beneficial reuse of sediments to further enhance navigation safety and environmental protection. Combining dredging with adaptive measures ensures direct improvement in navigability while reducing long-term operational expenses. Regular dredging intervals are necessary to maintain effectiveness, as sedimentation will reoccur over time. Understanding hydraulic design conditions, including wave and hydrodynamic modeling, is crucial for successful dredging projects. Geotechnical investigations provide essential data on soil properties, aiding in the selection of appropriate dredging equipment and methodologies. While at the same time give information about the dredged soil which can reused more accurately for different purposes. Accurate bathymetric surveys are vital for assessing existing seabed conditions and calculating dredging volumes. Additionally, monitoring and maintenance are essential to evaluate channel depth and ensure navigability. When implementing dredging, sediments will be in resuspension influencing the turbidity. This influence of the turbidity change on mussels and fish should be assessed.

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Additional add-ons:

- Signalling system
- Frequent bathymetry surveys
- Reuse of sediments beneficial

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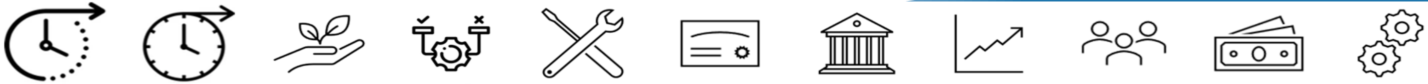

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Nature-based and non-structural interventions

Nature-based solutions and non-structural interventions should be based on understanding the natural, socio-economic and institutional system and should address the root causes of the problem. Next to solving the problem they can also create multiple benefits for limited costs. As these interventions are based on system understanding they can be outside the jurisdiction of DOP and require alignment with other agencies or ministries.

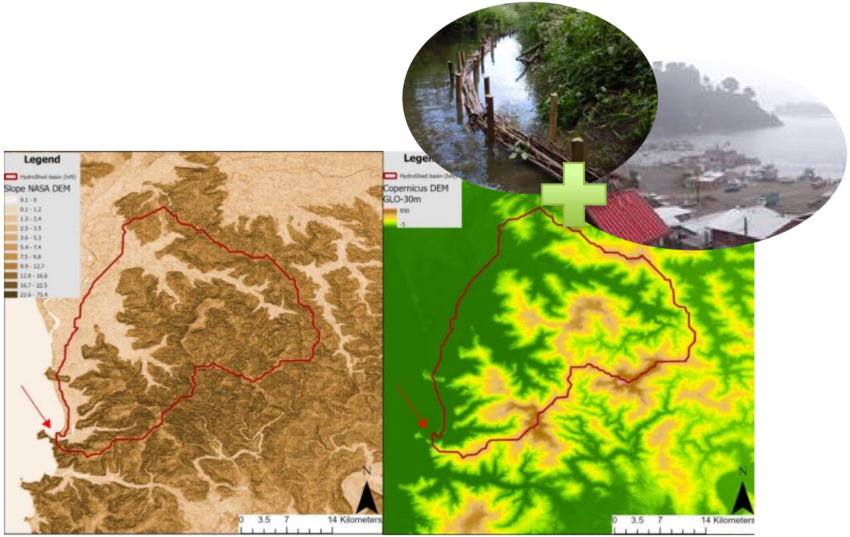
Examples of interventions to limit erosion are upstream reforestation, restoration of vegetation and terraces.

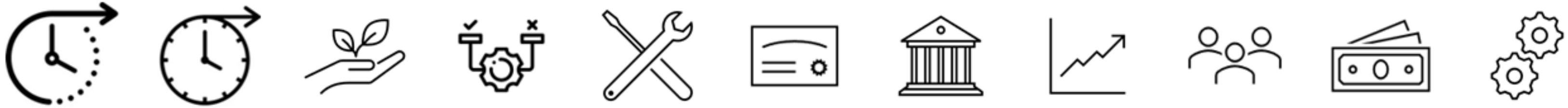
Other interventions can be construction of dams to store rainwater or to channel the river.

Restoration of vegetation in the river mouth and in the coastal zone, like wetlands, seagrass and kelp can stabilise the sediment and provide extra ecosystem services.

Non-structural measures that can improve the safety of navigation can be the relocation of the fishing cove, so the sandbar does need to be passed or changes to the fishing boats like reducing the draught, installing stronger engines and providing life vests.

The safety can also be increased by providing forecasting of the weather and tides, an and regularly surveying the seabed to know the location of the deeper channel(s) and moving the buoys (signalling system) to show the location of the channel.





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