City of Joondalup

Research of Alternative Coastal Adaptation Options

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EXECUTIVE SUMMARY

This report has been prepared for the City of Joondalup's coastal adaptation research study. It summarises the global alternative coastal adaptation options research and includes a list of adaptation options for consideration, the screening Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis, and the subsequent feasibility assessment that underpins the recommendations. The report provides an evidence base drawing on global practice and research, tested against the City's existing technical studies, coastal monitoring records, and the current understanding of local coastal processes.

The review first compiled a comprehensive set of coastal erosion adaptation approaches used in Australia and internationally, spanning nature-based, hybrid, and engineered measures. To support transparent comparison, options were grouped into four typologies: (1) sand management approaches that add, redistribute, or retain sediment to maintain beach volume; (2) submerged or low-crest nearshore measures that modify wave transformation while remaining largely unobtrusive; (3) emerged hard structures that provide direct protection but are typically more visible and can create alongshore impacts; and (4) hybrid and innovative alternatives that combine elements of these approaches or introduce new delivery models. In this report, nature-based measures primarily sit within the sand management and hybrid typologies, while "hybrid" refers to mixes of soft and hard elements (such as buried or low-profile structures paired with sand cover and dune management) as well as integrated packages that couple sediment management with targeted control points.

From this framework, a comprehensive list of options was developed for consideration in the Joondalup context. Each option was then screened using a SWOT matrix to document advantages (strengths and opportunities) and disadvantages (weaknesses and threats), and to identify which measures warranted deeper assessment. Options progressed from SWOT were then evaluated through a feasibility assessment using a consistent multi-criteria lens across technical, environmental, economic, and social considerations. This approach supports clear communication of trade-offs and explicitly recognises that effective coastal adaptation is likely to require combinations of measures, rather than reliance on a single intervention.

The feasibility results indicate that the most credible pathway to maintain beach amenity and improve resilience is a sand-and-dune led portfolio supported by ongoing sediment management, with the potential for selective, targeted control points or hybrid hard structures (i.e. buried seawalls) where evidence shows they materially improve performance. This framing responds to the community's preference for maintaining a natural sandy beach and minimising visual intrusion, while also acknowledging that structural options can be considered where Council wishes to investigate them further.

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We acknowledge the Traditional Owners and Custodians of the lands on which we live, work, and gather across Australia. We recognise their connection to land, waters, and community, and pay our respects to the people, the cultures and to Elders past, present and emerging.

GLOSSARY OF TERMS

Term	Definition
Accretion	Build-up of sediments to form land or shoaling in coastal waters and waterways. It may be natural or artificial.
Adaptive Management Framework	A procedure for implementing management while learning about which management actions are most effective at achieving specified objectives.
Alongshore or longshore	Parallel to and near the shoreline.
Artificial headland	Structures built along the toe of eroding dunes to protect strategic points, allowing natural processes to continue along the remaining frontage.
Artificial nourishment	See ‘beach nourishment’.
Beach	An area that is generally composed of sand or pebbles or similar sediment that extends landward from the lowest astronomical tide to the line of vegetation or bedrock or structure.
Beach drainage	Refers to systems, often buried perforated pipes, that lower the water table in the sand to stabilise beaches, reduce erosion, and promote sediment buildup by enhancing water infiltration.
Beach erosion	Refers to landward movement of the shoreline and/or a reduction in beach volume, usually associated with storm events or a series of events, which occurs within the beach fluctuation zone.
Beach nourishment	Beach restoration or augmentation using clean dredged or fill sand. Dredged sand can be excavated and trucked or hydraulically pumped and placed directly onto an eroded beach or placed in the littoral transport system.
Beach profile	A cross-section taken perpendicular to a given beach contour; the profile may include the face of a dune or seawall, extend over the backshore, across the foreshore, and seaward underwater into the nearshore zone.
Beach scraping (ploughing)	A mechanical intervention to speed up the natural processes of berm and foredune recovery after a storm event.
Breakwater	A man-made structure protecting a shore area, harbour, anchorage or basin from waves.

Bruun Rule	A commonly used method for estimating the response of a sandy shoreline to rising sea levels.
Buffer area	Parcel or strip of land that is designed and designated to permanently remain vegetated in an undisturbed and natural condition to protect an adjacent aquatic or wetland site from upland impacts, to provide habitat for wildlife and to afford limited public access.
Bypassing, sand	Hydraulic or mechanical movement of sand from the accreting up-drift side to the eroding down-drift side of an inlet or harbour entrance. The hydraulic movement may include natural movement as well as movement caused by humans.
Climate change	Occurs naturally in response to long-term variables and is often used to describe a change of climate that is directly attributable to human activity that alters the global atmosphere, increasing change beyond natural variability and trends.
Coastal Adaptation	Adjustment in natural or human coastal systems in response to actual or expected climate change or its effect, to moderate harm or to take advantage of beneficial opportunities.
Coastal asset	Includes natural features of the coastal zone, including landforms, ecosystems and species; and built assets such as infrastructure, public and private buildings or structures.
Coastal control structure	An engineered barrier or modification built to manage erosion, control sediment movement, and protect coastlines from waves and rising sea levels.
Coastal dune	Vegetated and unvegetated sand ridges built-up at the back of a beach. They comprise of dry beach sand that has been blown landward and trapped by plants or other obstructions. Stable sand dunes act as a buffer against wave damage during storms, protecting the land behind from saltwater intrusion, sea spray and strong winds. Coastal dunes also act as a reservoir of sand to replenish and maintain the beach at times of erosion.
Coastal hazard	Usually defined to mean the following: • beach erosion • shoreline recession • coastal lake or watercourse entrance instability • coastal inundation • coastal cliff or slope instability • tidal inundation

- erosion and inundation of foreshores caused by tidal waters and the action of waves, including the interaction of those waters with catchment floodwaters.

Coastal inundation	Coastal inundation occurs when a combination of marine and atmospheric processes raises the water level at the coast above normal elevations, causing land that is usually 'dry' to become inundated by sea water.
Coastal processes	Marine, physical, meteorological and biological activities that interact with the geology and sediments to produce a particular coastal system.
Coastal protection works	Activities or works to reduce the impact of coastal hazards on land adjacent to tidal waters, including (but not limited to) beach nourishment, seawalls, revetments and groynes.
Coastal sediment compartment	An area of the coast defined by its sediment flows and landforms. Coastal sediment compartments may be mapped at primary, secondary or tertiary (local) scales. Boundaries are generally defined by structural features related to the geologic frameworks that define the planform of the coast.
Cost Benefit Analysis	A decision-making framework that systematically compares the total projected costs (explicit, implicit, intangible) of a project or action against its total benefits.
Cross-shore transport	Refers to the sediment moved in a cross-shore direction to the coastline induced by water motions due to waves and currents.
Dune	See coastal dune.
Erosion	The wearing away of land by the action of natural forces. On a beach, the carrying away of beach material by wave action, tidal currents, littoral currents, or by deflation.
Exposure	The potential for assets to be impacted by a hazard based on data or modelling of the hazard.
Extreme storm event	Storm for which characteristics (wave height, period, water level etc.) were derived by statistical extreme value analysis. Typically, these are storms with average recurrence intervals (ARI) ranging from one to 100 years.
Foredune	The larger and more mature dune lying between the incipient dune and the hind-dune area. Foredune vegetation is characterised by grasses and shrubs. Foredunes provide an essential reserve of sand to meet the erosion demand during storm conditions. During storm events, the foredune can be eroded back to produce a pronounced dune scarp.

Flux	The movement, transport, and rate at which sand travels through water.
Geomorphology	A branch of physical geography which deals with the form of the earth, the general configuration of its surface, the distribution of the land, water, etc., or the investigation of the history of geologic changes through the interpretation of topographic forms.
Geotextile (geofabric)	A synthetic fabric which may be woven or non-woven and used as a filter.
Groyne	A shore protection structure built (usually perpendicular to the shoreline) to trap littoral drift or erosion of the shore; or a narrow, shore normal structure built to reduce longshore currents, and/or to trap and retain littoral material. Most groynes are of timber or rock and extend from a seawall, or the backshore, well onto the foreshore and rarely even further offshore.
Groyne Field	A series of groynes along a section of coastline.
Hazard	A process, or activity that affects an asset or value. See also 'coastal hazards' which are the specific hazards defined in the State legislation.
Impacts	Include damage, harm or losses to exposed communities, property, services, livelihoods, access, use and amenity, heritage, ecosystems and the environment because of exposure and sensitivity. Impacts may also be positive.
Infragravity waves	Low-frequency waves (long-period oscillations) generated by groups of breaking short waves. They can dominate water-level fluctuations and runup during storms, especially on gently sloping beaches. Infragravity waves influence swash, dune erosion, and overtopping by increasing the duration and reach of the run up.
Likelihood	The chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given time period).
Littoral	Of or pertaining to a shore, especially of the sea. Often used as a general term for the coastal zone influenced by wave action, or, more specifically, the shore zone between the high and low water marks.
Littoral transport rate	Rate of transport of sedimentary material parallel or perpendicular to the shore in the littoral zone. Usually expressed in cubic metres per year. Commonly synonymous with longshore transport rate.
Longshore transport (littoral drift)	Refers to the sediment moved along a coastline under the action of wave-induced longshore currents. The net drift is the sum of the northwards and southwards sand movement. The gross drift is the sum

	of the drift magnitudes (absolute values). Both gross and net drift are typically averaged over a year and expressed in m^3/yr.
Maintenance dredging	The recurrent dredging of sediment from a waterway, including existing navigation channels, approaches and berths, to allow safe navigation by commercial or recreational boating traffic.
Managed retreat	Also referred to as managed realignment. For the coastal zone (generally the coastal vulnerability area), managed retreat allows the shoreline to migrate landward unimpeded. It allows an area that was not previously exposed to coastal processes and hazards to become exposed, for instance by removing or breaching coastal protection works. Managed retreat may involve the relocation landward, out of a coastal risk area, of homes and infrastructure under threat from coastal erosion, recession or inundation. It may also involve the deliberate setting back (moving landward) of the existing line of sea defence to obtain engineering or environmental advantages. During a managed retreat process, a new foreshore area or new intertidal habitat may be created.
Micro-tidal	Coastal areas with a small tidal range, typically less than 2 meters.
Multi-criteria analysis	A logical and structured decision-making tool for complex problems involving multiple factors or criteria, where a consensus is difficult to achieve. It may involve processes such as ranking, rating (with relative or ordinal scales) or pairwise comparisons. The process allows participants to consider, discuss and test complex trade-offs among alternatives.
Planform	The shape of the coastline or beach when viewed from above (map view). It describes features such as embayments, salients, shoreline alignment, and curvature around structures or reefs. Planform is used to interpret how waves and sediment transport are controlling shoreline position and change.
Recession / retreat	A continuing landward movement of the shoreline; or a net landward movement of the shoreline over a specified time.
Resilience	The ability of a system (human or natural) to adapt to changing conditions (including hazards or threats, variability and extremes) and rapidly recover from disruption due to emergencies. Resilient systems or communities have the capacity to ‘bounce back’ after a disrupting event such as a major storm or an extended heat wave, to moderate potential damages, take advantage of opportunities, maintain or restore function or to cope with the consequences.
Revetment or seawall	A type of coastal protection works which protects assets from coastal erosion by armouring the shore with erosion-resistant material. Large rocks/boulders, concrete or other hard materials are used, depending on the specific design requirements.

Risk	Effect of uncertainty on planning and management objectives, usually characterised by reference to potential hazards, their consequence and their likelihood. Consequence combines the concepts of magnitude, sensitivity and duration.
Salient	A bulge or protrusion of the shoreline that forms in the "lee" (sheltered side) of an offshore obstacle.
Sea level rise	An increase in the mean level of the oceans. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be caused by ocean rising, the land subsiding, or both.
Sediment cells (tertiary)	Small and relatively contained sediment compartments. A tertiary sediment cell may apply to a single beach/embayment.
Sediment transport	The process whereby sediment is moved offshore, onshore or along shore by wave, current or wind action.
Shoreline recession / retreat	Refers to continuing landward movement of the shoreline, that is, a net landward movement of the shoreline, generally assessed over a period of several years. As shoreline recession occurs the beach fluctuation zone is translated landward.
Storm surge	The increase in coastal water level caused by the effects of storms. Storm surge consists of two components - the increase in water level caused by the reduction in barometric pressure and the increase in water level caused by the action of wind blowing over the sea surface (wind set-up).
Storm tide	An abnormally high-water level that occurs when a storm surge combines with a high astronomical tide (e.g. spring tide). The storm tide must be accurately predicted to determine the potential extent of coastal inundation.
Surf zone	The area from the line of the outer most breaking waves to the limit of wave run-up on the beach.
Swash zone	The zone of wave action on the beach, which moves as water levels vary, extending from the limit of run down to the limit of run-up.
Swell waves	Ocean waves that travel beyond the area where they are generated.
Threats	In the coastal management context, a threat is a process or activity which puts pressure on one or more coastal assets or values. Threats may include land uses (e.g. urban, recreation), land management, climate change, industrial discharges, stormwater runoff, overfishing, invasive species as well as the pressures from coastal hazards.

Tombolo	A sandy or gravelly deposit that connects an offshore island or reef to the mainland. It forms when waves refract and shelter the lee side, causing sediment to accumulate in the low-energy zone. Tombolos can stabilise the local shoreline but may also interrupt alongshore sediment transport.
Training walls	Walls constructed at the entrances of estuaries and rivers to improve navigability.
Vulnerability	A function of exposure and sensitivity of assets to a hazard, which determines the potential impacts of the hazard. For instance, the vulnerability of coastal assets may be influenced by the extent and impact of environmental, social and economic factors such as saline contamination of soils from flooding, erosion of built-up and natural areas, loss of vegetation, disruption to use or access, continuity of service, or loss of amenity, corrosion of built structures, undermining of foundations or damage to contents. Vulnerability also considers the adaptive capacity which is the capacity to adapt or the resilience in the system to manage the impacts and changes.
Wave angle	Represents the inclination of a wave's propagation direction relative to a reference line, typically the normal to a coastline.
Wave climate	The seasonal and annual distribution of wave height, period and direction.
Wave energy	The capacity of waves to do work. The energy of a wave system is theoretically proportional to the square of the wave height; a high-energy coast is characterised by breaker heights greater than 50 centimetres and a low-energy coast is characterised by breaker heights less than 10 centimetres.

ABBREVIATIONS

Abbreviation	Meaning
AHD	Australian Height Datum
CBA	Cost Benefit Analysis
CHRMAP	Coastal Hazard Risk Management and Adaptation Plan
MCA	Multi Criteria Analysis
NBS	Nature Based Solutions
NCCARF	National Climate Change Adaptation Research Facility
WEC	Wave Energy Converters

1 INTRODUCTION

1.1 Site Location

The City of Joondalup lies on Perth's northern coast, Western Australia, with approximately 17 kilometres of open, high-energy shoreline stretching from Marmion to Burns Beach. This coastline supports recreation, conservation, and residential land uses, including popular beaches such as Mullaloo Beach and Sorrento Beach and large-scale coastal infrastructure at Hillarys Boat Harbour and Ocean Reef Marina.

1.2 Background

The City's draft Coastal Hazard Risk Management and Adaptation Plan (CHRMAP) from 2023 set out a long-term framework for managing coastal hazard risks in accordance with State Planning Policy 2.6. During consultation, strong community concern emerged around several elements of the proposed coastal adaptation pathways, particularly the reliance on groyne fields. The majority of respondents to the community consultation expressed that these hard structures conflicted with their expectations for a natural, sandy and visually unobtrusive coastline.

These concerns highlighted a gap between the community's values and the coastal adaptation options previously assessed in the draft CHRMAP (2023), which included conventional engineering measures such as groynes and seawalls.

This targeted research project re-examines the coastal adaptation framework and broadens the range of options under consideration. The purpose of this study is to identify practical, evidence-based, and innovative alternatives that are suitable for Joondalup's high-energy environment, complex coastline, and geomorphological setting, while aligning more closely with community preferences.

The project evaluates a wide set of global and Australian approaches, including hybrid, soft and nature-based measures not assessed in earlier CHRMAP work, with the aim of identifying credible pathways that manage erosion risk while maintaining the environmental values, recreational amenity and visual character of the City's coastline.

1.3 Purpose of Report

This report presents the findings of the "alternative coastal adaptation options study". The purpose of this study is to undertake research and deliver research outcomes and a feasibility assessment to:

- identify any existing, new, and/or innovative coastal adaptation options to manage erosion that were not previously considered as a part of the City's draft CHRMAP (2023a).
- determine if any of these adaptation options are suitable to the City's specific coastal and community conditions.

- determine the effectiveness and feasibility of these adaptation options in managing coastal erosion, in comparison to existing, well-known options.

1.4 Methodology

The study applied a staged, evidence-based method that integrates global research with local data and engineering judgement. It commenced with a desktop review of the City's existing technical studies and coastal monitoring records to establish baseline conditions, confirm key constraints, and identify priority knowledge gaps.

A comprehensive international scan was then undertaken to identify the full range of coastal adaptation approaches used globally, spanning nature-based, hybrid (mixing different types of approaches, techniques or technologies), and engineered measures. Findings from the global scan were synthesised into four typologies: sand management approaches; submerged or low-crest structures; emerged hard structures; and hybrid and innovative alternatives.

These typologies were then used as a base for a long list of adaptation options for consideration in the Joondalup context. Each option was then screened using a SWOT matrix to transparently document likely advantages (strengths and opportunities) and disadvantages (weaknesses and threats), and to determine which options warranted deeper assessment.

Options progressed from the SWOT stage were then evaluated through a feasibility assessment using a consistent multi-criteria lens across technical, environmental, economic, and social considerations, including comparison to traditional approaches such as groynes and identification of how measures could be combined into integrated portfolios rather than treated as standalone solutions.

2 DESKTOP RESEARCH OF ALTERNATIVE COASTAL ADAPTATION OPTIONS

2.1 Reviewing Existing Plans and Data

2.1.1 City of Joondalup Coastal Environment

The Perth coastline is predominantly composed of sandy beaches interspersed with short rocky headlands and outcrops. These rocky features consist mainly of Pleistocene-age aeolianite calcarenites belonging to the Tamala Limestone formation, which underlies much of the Holocene coastal deposits and provides the geological framework of the region (Masselink & Pattiaratchi, 2001). Along the Perth coast, the Tamala Limestone forms a complex series of submarine to emergent ridges that strongly influence nearshore bathymetry and coastal geomorphology. The ridge system trends approximately parallel to the shoreline and comprises three principal ridges: the Spearwood Ridge, which forms the foundation of the mainland coast; the Garden Island Ridge, located around 12 km offshore; and the Five Fathom Bank Ridge, about 20 km offshore. Together with Garden Island and Rottnest Island, these offshore ridges provide substantial protection to the mainland coast by dissipating and refracting incoming wave energy.

Masselink and Pattiaratchi (2001) found that variations in beach width along much of the Perth coastline are driven primarily by seasonal reversals in littoral drift direction rather than by changes in overall wave energy. During summer, prevailing sea breezes induce northward sediment transport, causing sand to accumulate on the southern sides of coastal structures, headlands, and rocky outcrops, resulting in wider beaches in these areas. In winter, when storms generate southward longshore transport, these same beaches erode as sediment is redistributed southward. Conversely, beaches located north of such obstacles tend to narrow in summer and widen in winter. The magnitude of this seasonal beach cycle increases with both the size of the obstruction and the beach's proximity to it and can reach amplitudes of up to a 50 metres oscillation from the most eroded shoreline position to the most accreted.

MP Rogers & Associates (MRA, 2022) summarised earlier coastal hazard assessments and described the coastal setting of the City of Joondalup within the framework of the Western Australian Sediment Cell concept. The City's coastline lies predominantly within secondary sediment cells 27 (Trigg to Pinnaroo Point) and 28 (Pinnaroo Point to the Burns Beach salient). These cells are defined by their distinct patterns of contemporary sediment transport, inter-decadal shoreline variability, and geomorphic response. The assessment of shoreline movement for the City, documented in MRA (2016), focused on these two sediment cells.

Coastal hazard assessments incorporated storm erosion modelling based on three simulated repetitions of the July 1996 storm event, long-term historical shoreline erosion derived from approximately 70 years of vegetation line change, and projected shoreline recession due to sea-level rise following the Bruun Rule, estimating average values of 32 m over 50 years and 90 m over 100 years along the Joondalup shoreline. Coastal inundation from storm surge was modelled to reach 4 m AHD for a 500-year average recurrence interval event (MRA, 2022).

Recent coastal monitoring has confirmed that shoreline change is continuing along the City's coast. MRA (2023), reporting on surveys conducted in 2022 as part of the City's biennial monitoring program (initiated in 2015 under the Department of Transport framework), identified areas of both erosion and accretion of up to 6 metres between October 2021 and August 2022. The most pronounced erosion occurred between the northern end of Hillarys Beach Park and Pinnaroo Point, encompassing the Whitfords Dog Beach sector. Overall shoreline movement between 2015 and 2022 was generally less than 5 metres, except at several previously recognised erosion hotspots, including the following sites:

- Hillarys Beach Park
- Pinnaroo Point
- The northern end of Burns Beach

Sections of Whitfords Beach, north of Pinnaroo Point, have continued to experience erosion over the same period. Updated monitoring data from MRA (2024) confirms ongoing shoreline retreat north of Hillarys, particularly at Pinnaroo Point, and highlights a continued upward trend in mean water levels since 1995. As severe storm events typically coincide with elevated water levels, it is reasonable to infer that the progressive rise in sea level has reduced the effectiveness of the offshore ridges and shoals in dissipating wave energy, thereby contributing to increased coastal erosion, exacerbated by Hillarys Boat Harbour reducing alongshore net northward sediment supply.

The geology and geomorphology of the City's coastline are consistent with the broader Perth coastal system described earlier. The shoreline lies at the southern end of the Whitfords-Lancelin sector, which is characterised as a predominantly straight, rocky coast punctuated by isolated accretionary cusps. Within the study area, this is expressed as a sequence of limestone cliffs, headlands, and nearshore reef platforms in the south, transitioning to sandy beaches and dune systems toward the north. A key geomorphic control on coastal orientation within this sector is Little Island and its associated shoals, located approximately two kilometres west of Hillarys Beach. The wave sheltering provided by this feature is thought to be the principal factor responsible for the formation of the salient at Pinnaroo Point over geological timescales.

BMT JFA (2016), in their coastal hazard assessment for the City of Stirling immediately south of Joondalup, identified a strong seasonal sediment transport pattern driven by the prevailing wind and wave climate. During summer, northward longshore transport associated with the sea breeze system is estimated to reach approximately 150,000 m³, with up to 80,000 m³ of this sediment being trapped by Trigg Island (Pattiaratchi et al., 1997). This is largely counterbalanced by southward transport during winter storms, resulting in a net northward transport near Trigg Beach of around 10,000 - 20,000 m³ per year (Stul & Eliot, 2005; MRA, 2010). Net northward transport past Trigg Island has been estimated between 6,000 m³ and 9,000 m³ per year, supplemented by an inferred onshore feed of approximately 5,000 m³ per year from offshore sources north of Trigg. This sediment supply is consistent with the observed increase in calcium carbonate content of beach sands, characteristic of offshore sands, from Trigg Island to Sorrento within the City of Joondalup (Stul & Eliot, 2005).

At Sorrento Beach, the long-shore sediment transport flux prior to the construction of Hillarys Boat Harbour was estimated at 70,000 - 90,000 m³ per year (PWD, 1984). Since the installation of the Sorrento groynes in the early 1980s and the construction of Hillarys Boat Harbour in 1987, the seasonal sediment flux has decreased markedly, with Sorrento Beach accreting at a rate of approximately 1.3 m per year up to 2008 (MRA, 2010). A more recent investigation by MRA (2025) into sand bypassing at Hillarys Boat Harbour estimated a similar net northerly drift of approximately 10,000 m³ per year, with an equivalent volume now artificially bypassed annually during October and November.

Digital Earth Australia (DEA) shoreline analysis between 1988 and 2024 confirmed persistent accretion to the south of the harbour and erosion to the north, with cumulative northern shoreline losses of around 25,000 m³ per year (MRA 2025). These losses are related to the net change within the downdrift shoreline segment. Some of this sand is likely being redistributed further north. These losses have likely been reduced by the City's bypassing program.

In summary, the Joondalup coastline consists of alternating limestone outcrops forming pocket beaches and extensive sandy beach sections. Sediment movement is dominated by offshore transport during major storm events, onshore-directed sand transport during calm conditions and a net northward longshore drift of approximately 10,000 m³ per year around the Hillarys Boat Harbour area. This sediment flow is interrupted by structures such as groynes and harbour breakwaters, leading to sand accumulation on their southern sides and erosion to the north. The most prominent geomorphic feature of the coastline is the Pinnaroo Point salient, which has developed over time due to wave sheltering provided by Little Island and its associated offshore shoals.

2.1.2 Joondalup Coastal Management to Date

There is a long history of shoreline management along the City's coast, with several structures built over the past decades. Groynes, both as single units and in fields, have been installed at various locations to influence sediment transport. The most prominent example is the Sorrento groyne field, which extends only a short distance offshore. Because of its limited length, it generates only minor localised accretion or erosion, and any changes following major storm events typically rebalance once longshore transport re-establishes.

MRA (2022) provides a detailed inventory of the existing coastal protection structures within the City, summarising the range of engineered interventions currently in place:

- Burns Beach Groyne
- Ocean Reef Boat Harbour Breakwaters (recently extended)
- Sorrento Beach Groynes (three) and Seawall

- Marmion Angling and Aquatic Club (MAAC) Seawall

MRA (2022) also documented ongoing sand bypassing operations undertaken by the City to mitigate sand accumulation and erosion associated with Hillarys Boat Harbour. These include:

- December 2018 – 8,400 m^3 of sand bypassed from Sorrento Beach to Hillarys Beach Park
- March/April 2020 – 8,700 m^3 bypassed from Sorrento Beach to Hillarys Beach Park
- March 2021 – 8,000 m^3 bypassed from Sorrento Beach to Hillarys Beach Park
- October/November 2021 – 8,000 m^3 bypassed from Sorrento Beach to Hillarys Beach Park
- October/November 2022 – 8,000 m^3 bypassed from Sorrento Beach to Hillarys Beach Park
- October/November 2023 – 10,000 m^3 bypassed from Sorrento Beach to Hillarys Beach Park
- October/November 2024 – 16,000 m^3 bypassed from Sorrento Beach to Hillarys Beach Park

A subsequent study by MRA (2025) provided a comprehensive analysis and multi-criteria assessment (MCA) of sand bypassing options for Hillarys Boat Harbour, identifying land-based trucking of sand as the most cost effective and practical approach for the current volumes bypassed.

2.1.3 Coastal Hazard Management and Adaptation Plan

The City engaged MP Rogers & Associates to develop a technical Coastal Hazard Risk Management and Adaptation Plan (CHRMAP), which was completed in 2022 (MRA 2022). The City also engaged Water Technology to create a community-facing draft CHRMAP using the MP Rogers & Associates technical CHRMAP which was completed in 2023.

The community-facing draft CHRMAP 2023 - 2033 presented the same information as the technical CHRMAP, in a simpler format, and was released for public consultation in 2023 (MRA, City of Joondalup & Water Technology 2023a). All the technical information presented in the community-facing CHRMAP was sourced from the MP Rogers & Associates technical CHRMAP.

While formatted differently, both reports present the same material in relation to coastal hazard assessment and adaptation planning. Their methodology aligned with WA State Planning Policy 2.6 and associated guidelines employing established risk and vulnerability assessment processes and a structured evaluation of management options.

In summary:

- A standard vulnerability assessment was undertaken for individual assets along the coastline.

- Relevant planning controls and ongoing coastal monitoring programs were identified.
- Adaptation measures were assessed within the widely recognised hierarchy of **Avoid**, **Retreat**, **Accommodate**, and **Protect**.
- The adaptation options considered included *Do Nothing, Seawall, Managed Retreat, Groynes, Headlands,* and *Beach Nourishment*.
- Each option was accompanied by an outline of its advantages and disadvantages.
- The evaluation of options relied primarily on Multi-Criteria Analysis (MCA) and Cost-Benefit Analysis (CBA), supported by the identification of trigger points for each management compartment.
- The CBA, documented separately in MRA (2021), focused exclusively on City-managed assets. Benefits were estimated using visitor data, Western Australian asset valuation data, and New South Wales benchmarks for social and environmental non-use values.
- Advantages and disadvantages were tabulated for each recommended option, leading to a ranked list of preferred adaptation measures.

Based on the combined MCA and CBA results, the Draft CHRMAP identifies the adaptation options to implement across the City's coastal compartments (Table 1).

Table 1. Preferred adaptation option for each coastal management zone after multi-criteria analysis and cost-benefit analysis in Joondalup (MRA, 2023)

Coastal Management Zone	Preferred adaptation option
Marmion	Beach nourishment
Sorrento	Groynes
Hillarys to Kallaroo	Groynes
Mullaloo	Groynes
Ocean Reef	Do nothing
Iluka	Beach nourishment
Burns Beach	Retreat (public only)

2.2 Literature Review and Global Best Practice

2.2.1 Introduction

On micro-tidal, high-energy coasts such as Joondalup, where tides are small, but wave forces are strong, maintaining continuous alongshore sediment movement and promptly replenishing storm losses are the most reliable ways to preserve durable beach width and recreational amenity while avoiding downdrift erosion impacts.

Contemporary best practice has shifted toward sediment-led and low-visibility approaches that align with natural transport pathways, supplemented, only where necessary, by submerged or low-crested control features and carefully positioned hard structures that help stabilise shoreline planform without compromising surf quality. This approach is exemplified on the Gold Coast where the artificial bypassing systems are designed to replicate natural alongshore sand transport, and where submerged artificial reefs (Narrowneck and Palm Beach) act as coastal control structures to enhance the resilience of beach nourishment.

The literature further emphasises a process-based, adaptive management framework: strategically place sand where coastal processes can naturally redistribute it, use subtle structural interventions only when required, and retain flexibility under sea-level rise through scalable and iterative nourishment programs (Stive et al., 2013; Williams et al., 2018; WAPC, 2014).

2.2.2 Frameworks and Approaches for Coastal Hazard Adaptation Options

Many local and state governments in Australia and internationally have developed frameworks and guidelines to assist in selecting appropriate coastal hazard adaptation options. At the national level, *CoastAdapt*, (https://coastadapt.com.au) the guidance platform produced by the National Climate Change Adaptation Research Facility (NCCARF), identifies five broad categories of adaptation responses to climate change and the increasing risks of coastal inundation and erosion:

1. Avoidance
2. Managed retreat
3. Accommodation or limited intervention
4. Hold the line (protection)
5. Loss acceptance

Alternative classifications have also been adopted in other jurisdictions. For example, the City of Christchurch, New Zealand (City of Christchurch, n.d.) uses a five-tier framework expressed in more accessible, community-oriented terms:

- **Maintain - “We enhance what we’re already doing.”**
  Continue living in an area while improving understanding of local environmental

conditions and strengthening community awareness of risk. Typical actions include maintaining existing infrastructure, implementing emergency response measures, applying broad-scale land-use planning, and undertaking environmental monitoring and education.

- **Accommodate - "We live with the hazard."**
  Continue to use land in hazard-prone areas while adapting to the risk, raising tolerance and delaying relocation where feasible. Measures may include elevating buildings, modifying infrastructure, raising land levels, and improving stormwater and groundwater management.
- **Protect - "We keep the hazard away."**
  Reduce exposure by using soft, hard, or hybrid engineering interventions that act as barriers between coastal processes and assets. Examples include beach nourishment, dune enhancement, seawalls, and levees.
- **Retreat - "We move away from the hazard."**
  Relocate people and infrastructure away from areas of unacceptable risk, allowing coastal systems to adjust naturally. Options include voluntary buybacks, land swaps, or leaseback arrangements.
- **Avoid - "We don't move into the way of the hazard."**
  Use forward planning tools such as zoning, setbacks, or development exclusions to prevent new exposure to coastal risks.

2.2.3 Global List of Coastal Adaptation Options

From the local and international literature, many compendia have been presented setting out a range of adaptation options. The following discussion sets out selected examples of the approaches proposed. An early example is the compendium prepared for the Queensland experience developed by Griffith University and GHD (2012), see Appendix Table B-1. Options relevant to Joondalup include beach nourishment, artificial reefs, detached breakwaters, groynes and artificial headlands and seawalls.

The most recent Australian adaptation compendium, prepared for Victoria by BMT (2023), introduces several approaches that may be directly applicable to the Joondalup coastline. These include the use of geofabric structures (such as geotextile containers and tubes) to provide flexible and low-visibility coastal protection, wet sand fencing to promote natural dune building and sediment capture, sand bypassing systems to maintain alongshore sediment continuity, and the restoration or construction of shellfish reefs to enhance coastal resilience through wave attenuation and ecological co-benefits - see Appendix Table B-2.

Baills et al. (2020) undertook a comprehensive review of international literature to identify 51 coastal adaptation measures potentially suitable for application along the high-energy, wave-dominated Aquitaine coast in south-west France. The study aimed to catalogue both traditional and emerging approaches for managing erosion and shoreline change in comparable coastal environments. The results of their assessment are summarised in the Appendix Table B-3. The measures for flexible management of natural areas that focus on soft and hybrid beach-management techniques, and that directly address chronic shoreline erosion on open, sandy, micro-tidal, high-energy coasts, are most relevant to Joondalup.

While Baills et al. (2020) presents a full range of physical, nature-based and hybrid interventions, they also highlight the broader organisational settings and practical actions that support the delivery and long-term effectiveness of these options. Institutional enablers such as governance, planning tools, monitoring and community engagement with selected on-ground measures are also discussed.

In a recent report to the World Bank (2025) on beach stabilisation, the continuum from nature-based approaches to hard-engineering interventions is illustrated, highlighting intermediate techniques such as dune brushing (dune management), the strategic planting of vegetation to promote sand accumulation, and beach ploughing (scraping) to reshape the beach profile (Appendix Table B-4).

Nature-based solutions such as mangroves and saltmarshes are suited to relatively sheltered, low-energy environments, while seagrass meadows and coral reefs can influence beach stability by reducing wave energy. However, even these systems cannot compensate for a fundamental lack of sand supply. On highly dynamic, sediment-starved coasts like Joondalup, the natural behaviour of the beach is driven primarily by sediment availability, meaning habitat-based Nature Based Solutions (NBS) alone are insufficient to address chronic erosion.

Most of the recent international literature on innovative coastal adaptation focuses on the frameworks and governance models through which adaptation is implemented rather than on specific engineering interventions. For example, Lebbe et al. (2021) emphasise the importance of hybrid approaches and adaptive pathways that evolve over time in response to local sociocultural, geographic, and climatic conditions. They highlight that dynamic, participatory policies can foster collective learning, enable social and behavioural change, and strengthen adaptation outcomes. Successful adaptation frameworks typically rely on knowledge co-production, stakeholder engagement, governance across government levels and agencies, continuous policy monitoring, and a sense of territorial solidarity among affected communities.

A complementary strand of literature centres on nature-based and hybrid approaches, such as *Living Seawalls* (Vozzo, 2024). Schoonees et al. (2019) provide a comprehensive overview of the benefits and challenges of nature-based solutions, noting that while soft interventions can enhance ecosystem services, their feasibility is often constrained by local physical conditions. In such cases, integrated hard-soft solutions are often optimal. The authors describe how hard coastal structures can be adapted to reduce adverse morphological, hydrodynamic, and ecological impacts through design enhancements that promote habitat complexity and ecological function. Schoonees et al. (2019) identified the following nature-based adaptations to complement both soft and hard engineering approaches:

Soft Solutions

- Installation of brushwood fences to replicate natural vegetation and promote sediment deposition.
- Hydrologic restoration through selective excavation or filling.

- Targeted sediment nourishment to enhance wave attenuation in front of sensitive ecosystems.
- Integrating natural habitats such as reefs, seagrass or saltmarsh in the foreshore to act as buffers that reduce incoming wave energy.
- Planting or transplanting of native dune and foreshore vegetation.

Hard Solutions

- Increasing surface roughness and structural complexity to improve ecological value.
- Incorporation of microhabitats (e.g., rock pools, habitat units) into existing or new structures.
- Integration with ecosystem restoration projects (e.g., coral reefs, seagrass beds, or vegetated revetments).
- Combining with nourishment campaigns to reduce replenishment frequency.
- Selective modification or removal of seawalls to restore sediment movement.

2.2.4 Out of Scope Adaptation Options

The case studies reviewed in this report show the wide range of coastal adaptation approaches being trialled globally. This review focuses on adaptation options that act on the physical coastal environment and influence open-coast erosion and beach stability (for example sediment management, nature-based, hybrid, and engineered measures) applicable to Joondalup and other parts of the world.

To support transparent community engagement, the analysis also includes some options that are unlikely to be suitable locally, so they can be explained clearly, assessed using the same criteria, and ruled in or out on evidence rather than assumption. In particular, the review intentionally includes the full spectrum of nature-based options, even where local constraints may limit applicability, because these measures are frequently raised in community discussion and international examples.

Options that are outside scope and not assessed further in this report include:

- Storm-surge or inundation focused measures (for example raising land or floor levels, floodproofing, removable or relocatable buildings, and large-scale infrastructure elevation).
- Planned retreat and land tenure mechanisms (for example buybacks, land swaps, and transfer of development rights).
- Statutory planning and development controls (for example zoning changes, hazard overlays, setbacks, managed access, and development conditions).
- Catchment and urban water interventions (for example drainage upgrades and water-sensitive urban design).
- Emergency management and preparedness (for example response planning, community education, and disaster recovery programs).

2.3 Adaptation Options for Further Consideration

The City's Draft CHRMAP (MRA, City of Joondalup & Water Technology, 2023a) identifies beach nourishment and groynes as the primary active interventions for several coastal sectors, alongside the broader strategic options of Do Nothing and Planned Retreat, which are not covered in this report. Nourishment is now widely regarded internationally as a flexible, low-visibility measure that preserves beach amenity while working with natural processes, and available studies indicate that offshore sand reserves are likely sufficient to support ongoing campaigns.

Drawing on global literature and an understanding of Joondalup's coastal processes and hazard drivers, four broad families of adaptation options are assessed in Sections 2.3.1 to 2.3.4. Each family encompasses a suite of measures that vary in visibility, permanence, cost and intervention intensity:

- **Sand management approaches** - including beach nourishment, sand bypassing and backpassing, beach scraping and re-profiling, and dune enhancement or revegetation.
- **Submerged or low-crest structures** - including artificial reefs, submerged breakwaters and islands that dissipate wave energy while maintaining beach amenity.
- **Emerged hard structures** - such as groynes, and other emerged control structures.
- **Hybrid and innovative alternatives** - combining soft, hard, and operational techniques (e.g., dynamic revetments, wet-sand fencing, hybrid dunes, living seawalls, etc.) that align with community preferences for low-visibility and nature-based solutions.

2.3.1 Sand Management Approaches

Sand nourishment remains one of the most widely implemented and adaptable approaches for managing erosion and sustaining beach amenity on exposed sandy coasts. Global experience shows the effectiveness of a range of shoreline nourishment types, and other sand management approaches such as bypassing and backpassing sand, or dune management.

Across all nourishment approaches, best practice emphasises matching sand characteristics and placement geometry to local coastal processes. Grain-size compatibility strongly influences how long material remains in the system and how it behaves under wave forcing, while the depth and shape of the placement control how efficiently natural transport redistributes sediment alongshore and cross-shore. Larger but less frequent campaigns can offer economic advantages where logistics and budgets allow, provided they are governed by monitoring-based triggers that guide targeted interim top-ups (Barnard et al., 2009; McGill et al., 2022).

2.3.1.1 Beach Face Nourishment

Beach face nourishment places compatible sand directly on the visible beach to rapidly widen the beach, increase storm buffer capacity, and improve recreational amenity (Carley et al., 2017). On high-energy coasts, the placed sand is typically redistributed quickly by storms and longshore transport, so benefits are temporary and usually require planned top-ups or repeat campaigns (USACE 2007; AECOM 2010).

For example, a recent high-energy Atlantic case study modelled an effective nourishment lifespan of about 4.5 - 7.5 years (Oliveira et al., 2025). Key limitations are the recurring cost and logistics of repeat placements, short-term construction disruption, a rapid alongshore distribution, potential ecological impacts at both borrow and placement sites, which can constrain approvals and community acceptance if not well managed (Saengsupavanich et al., 2023).

Figure 1. Beach face nourishment at New Jersey Shores, United States. Credit: GLDD.

2.3.1.2 Shoreface or Nearshore Nourishment

Shoreface or nearshore nourishment, involves placing sand in the nearshore waters and is often implemented through submerged feeder berms in water depths of around 3-6 metres, or by spraying from a vessel into the nearshore waters (as pictured in Figure 2). This method relies on natural wave and current processes to gradually transport sand toward the shoreline. This indirect nourishment approach commonly places the berm deeper (so it is less exposed to wave-breaking-induced longshore currents) and designs it with sufficient alongshore length, which helps reduce alongshore displacement and improves sediment retention and onshore migration. It can also reduce turbidity impacts, costs, and ecological disturbance while still achieving measurable increases in beach width over time (Barnard et al., 2009; Johnson et al., 2021, McGill et al., 2022).

Performance depends on depth relative to closure, bar morphology, and seasonal wave climate (Barnard et al., 2009; Huisman et al. 2019; McGill et al., 2022). For example, on the Dutch coast, several shoreface nourishment projects placed sand at 4-10 m depths; over time these have acted as feeder berms that slowly widen the adjacent sandy beach profile while dissipating wave energy (Van der Werf et al. 2025).

Field evidence from high-energy, microtidal environments such as Ocean Beach, San Francisco (Barnard et al., 2009) and Harvey Cedars, New Jersey (McGill et al., 2022) shows that shoreface-placed berms can migrate onshore and widen beaches within months, demonstrating the effectiveness of this method under energetic conditions. Shallower placements typically respond continuously to moderate wave activity, whereas deeper placements tend to mobilise episodically during larger storm events.

Figure 2. Nearshore nourishment at the Gold Coast, QLD, using Trailing Suction Hopper Dredgers. Credit: ICM.

2.3.1.3 Large Scale Sand Nourishment

Large scale sand nourishment is an option involving placement of large volumes (in general above ~100,000 m³) in a single campaign, which is an order of magnitude higher than current nourishment activities. At this scale, unit costs can be lower because mobilisation and dredging/trucking costs are spread over more sand, and the larger buffer can provide longer-lasting increases in beach width compared with small, ad hoc works.

Shoreface nourishment literature similarly frames these projects as placing relatively large volumes offshore, with performance strongly influenced by placement depth, sediment characteristics and the alongshore extent of the deposit (van der Werf et al., 2025). However, large scale nourishment requires a reliable sand source, access and staging areas, longer construction periods, and a clear approvals pathway, with potentially greater turbidity, ecological and community impacts at borrow and placement sites.

For the Joondalup coastline, large scale nourishment is most likely to be feasible where there is sufficient continuous sandy frontage to retain benefits at scale, practical access for construction logistics, and a credible long-term sand supply strategy (including potential integration with bypassing or backpassing). In contrast, very large “mega-scale” volumes (order of millions of cubic metres) are unlikely to be applicable to Joondalup’s relatively short and segmented beach compartments, and would generally be disproportionate in cost, approvals complexity, and construction footprint relative to the scale of the problem.

In addition to importing new sand, several sand management methods operate by recirculating sediment already within the coastal cell, reducing reliance on external sources. These include sand bypassing, sand backpassing, beach scraping and re-profiling, and dune enhancement and revegetation.

2.3.1.4 Sand Bypassing

Sand bypassing involves removing onshore beach sand from one area and depositing it at a different onshore location to mimic natural sand movement that may have been interrupted by engineered structures, such as harbours. Sand bypassing can be completed using various methods, such as excavation via machinery and trucks, or via fixed pipelines. Where harbours or headlands disrupt natural littoral drift, engineered bypassing systems (such as fixed pipelines and offshore discharge points of sand, in the nearshore area) and smaller-scale schemes (including jet-pump transfers) help re-establish alongshore sediment continuity and maintain downdrift beach conditions. Long-running Australian programs, including the Tweed River and Gold Coast systems, demonstrate that reliable volumes and sustained amenity improvements are achievable when operations are guided by monitoring, performance triggers, and adaptive scheduling (CoastAdapt, 2016; GCWA, 2025).

Figure 3. Tweed River Sand Bypass System. The Jetty captures the sand which is transported north across a series of pipes underneath the river. Credit: Gold Coast Waterways Authority.

2.3.1.5 Sand Backpassing and Enhanced Backpassing

Sand backpassing and enhanced backpassing is the repeated, local transfer of sand from accreting areas (e.g. near headlands, training walls or inlet shoals) to nearby erosion hotspots, using loaders and trucks (or short-distance pumping) to maintain beach width without importing new sand. While bypassing moves sand past blockages, backpassing redistributes sand opposite to the sediment transport direction within beaches. Enhanced backpassing uses monitoring and sediment-tracking (e.g. RTK-GPS, drones, shoreline analytics) to optimise when, where, and how much sand is moved so placements last longer and deliver better value.

Control structures or designated harvest zones can further improve efficiency, as demonstrated at the Spit (Gold Coast) and Semaphore (Adelaide) (Vieira da Silva et al., 2021; Beck et al., 2020; Harry et al., 2023, City of Gold Coast 2025). It is important to note that backpassing is only possible if there is an excess of sand at another local location.

Figure 4. Surfers Paradise sand backpassing system scheme. The sand is captured by the Gold Coast Seaway jetty system and pumped back to Surfers Paradise approximately 4 km south. Credit: City of Gold Coast.

2.3.1.6 Beach Scraping and Re-profiling

Beach scraping regrades existing beach sand after storms by moving sand from the lower beach back to the berm or dune toe to restore the profile and access. It is applied primarily as a short-term recovery measure following storm erosion, controlled scraping can rebuild the berm or foredune and provide interim stability while natural recovery proceeds or until scheduled nourishment occurs. Recent experimental work in coastal engineering shows that carefully managed ploughing and scraping can enhance short-term accretion and temporarily widen the dry beach (Pellón et al., 2024).

However, consistent with earlier practice reviews, ecological safeguards and monitoring remain essential, as scraping redistributes existing sand rather than adding new material to the system. Beach scraping and re-profiling redistribute sand from the lower to upper beach following storms to restore beach access and dune function. This technique provides temporary protection but must be used sparingly and linked to nourishment cycles to avoid downdrift erosion (Pellón et al., 2024; Carley et al., 2010).

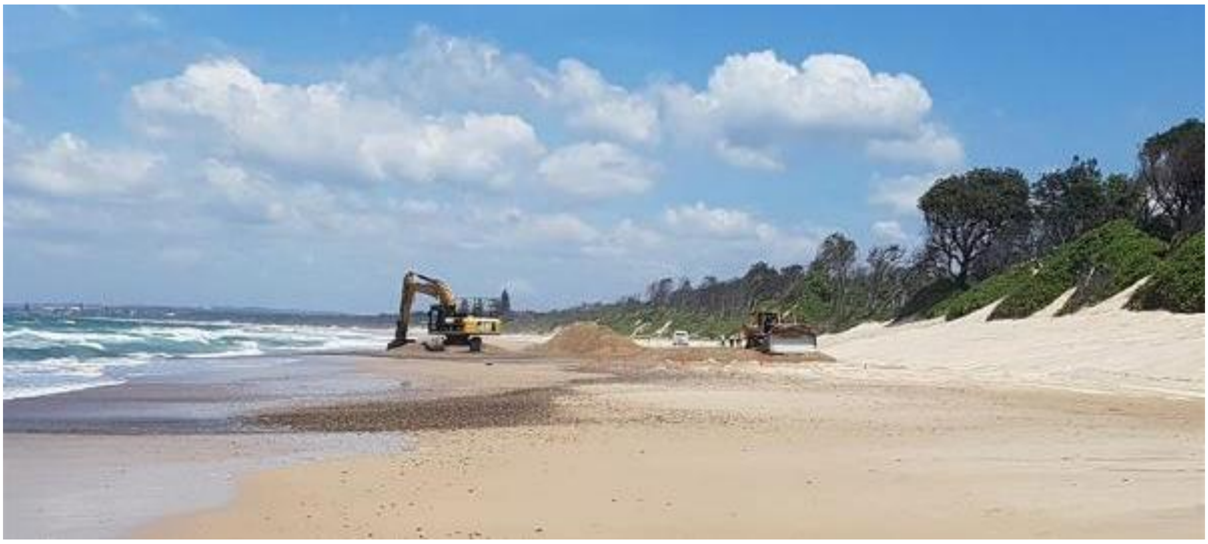

Figure 5. Beach scraping at Old Bar Beach, NSW. Credit: Coastal Wiki.

2.3.1.7 Dune Enhancement and Revegetation

Dune enhancement and revegetation rebuild or strengthen the foredune buffer by reshaping degraded dunes (where appropriate), then stabilising them with native dune planting, sand-trapping measures (e.g. fencing), weed control, and access management (e.g. fencing and boardwalks) to reduce trampling and blowouts (Fernández-Montblanc et al. 2020, White et al. 2024). Dune revegetation, in general, is not strong enough to withstand storm erosion, particularly in high energy environments such as the Joondalup coastline. It is recommended to be linked with other options. Evidence from tourism-impacted coasts shows that elevated boardwalks and controlled access can drive substantial recovery of previously degraded dunes over multi-year periods, provided designs do not create new informal tracks (Ferreira 2023). Limitations are that benefits take time to establish, require ongoing maintenance (especially after storms and high-use periods), and can be constrained where there is insufficient space for dune growth or where repeated storm erosion resets plantings before they mature.

Figure 6. Actively managed dunes along the Gold Coast. Credit: ICM.

2.3.1.8 Mega-nourishments (Sand Motors)

Mega-nourishments (sand motors) involve single, large-scale sand placements that naturally disperse alongshore and onshore, reducing long-term maintenance costs and providing ecological benefits. The Netherlands' 20 Mm^3 Zandmotor remains the benchmark example (Stive et al., 2013; Flikweert et al., 2023). Mega-nourishment, or sandscaping, involves placing very large volumes of sand at a strategic location so that natural coastal processes can redistribute it over time. This creates a long-lasting sand source for adjacent beaches and reduces the need for repeated smaller nourishments. Some disadvantages may include significant and long-term change to current coastal form, and it clearly requires large scale investment beyond the reach of most local governments.

The Netherlands' Sand Engine provides a benchmark example, where a single mega-placement has nourished adjacent beaches for more than a decade while delivering ecological and recreational benefits (Stive et al., 2013; Flikweert et al., 2023).

Figure 7. Sand Motor in the Netherlands. Credit: Zandmotor.

2.3.1.9 Implications for Joondalup

For Joondalup, a sand-led baseline strategy that combines beach-face and nearshore nourishment, with potentially other sand management options such as sand bypassing or backpassing and dune enhancement, may offer a practical, low-visibility way to maintain both amenity and protection in line with the State Planning Policy 2.6.

Sand management should be aligned with the dominant northward littoral drift to maximise natural redistribution and longevity. Ongoing hydrographic and topographic surveys, supported by berm-tracking and volumetric analysis, would allow timely, data-driven interventions before critical erosion thresholds are reached. Where sediment continuity is disrupted by structures or inlets, operational bypassing or backpassing should be incorporated to sustain system-wide sediment balance and long-term coastal resilience.

2.3.2 Submerged or Low-crest Structures

Submerged or low-crest structures serve primarily as morphological steering tools. Rather than replacing sediment supply, they modify wave transformation, influence sediment transport pathways, and help maintain a desired shoreline planform. Global practice consistently shows that these structures perform most effectively when combined with active sand management, particularly where periodic nourishment or bypassing maintains beach volumes over time.

2.3.2.1 Multipurpose Artificial Reefs

Multipurpose artificial reefs are submerged structures designed to reduce wave energy while maintaining beach appearance and, in some cases, improving surf and habitat. Modern submerged reef designs are intended to deliver coastal protection while preserving beach appearance and surf amenity. By attenuating wave energy and stabilising the nearshore zone, they can support shoreline management with minimal visual impact, and modular or eco-compatible materials can add habitat benefits.

Australian examples show reefs working best as part of broader sediment programs: the Narrowneck Reef (geotextile containers) has supported shoreline advancement for over two decades within an ongoing nourishment regime and improved surfing and fish habitat, while the Palm Beach Reef (rock) demonstrates compartment stabilisation without compromising recreation when integrated with sediment management (Jackson et al., 2012; Mortensen et al., 2015; Brullo et al., 2024).

Multipurpose reefs target several benefits (wave attenuation, surfing amenity, habitat), while others are designed primarily for erosion control (for example, the City of Cockburn's C.Y. O'Connor reef). Key drawbacks for both include uncertain performance outside design conditions, potential down-drift or alongshore erosion displacement, and in some settings increased local scour or shoreline retreat.

They can also be costly to construct and monitor, with stakeholder risk around navigation and surf safety if crest elevations or wave breaking differ from expectations. Effective, safe design therefore depends on a robust understanding of local coastal dynamics, supported by field observations and detailed numerical modelling.

Figure 8. Narrowneck Multi-purpose Reef, Gold Coast, Australia. Credit: City of Gold Coast.

2.3.2.2 Submerged Breakwaters and Low-crest Barriers, Including Submerged Islands

Unlike multipurpose artificial reefs (which are typically designed as rough, habitat-forming wave attenuators), submerged breakwaters and islands are generally larger, smoother alongshore (submerged breakwaters) or planform (submerged islands) control elements intended primarily to create a wave-shadow zone and steer shoreline shape.

These linear or modular features operate as low-visibility wave-energy attenuators that gently reshape nearshore morphology. By modifying breaking patterns, they can reduce longshore transport gradients, encourage bar formation, and promote localised accretion. Their influence depends strongly on crest depth, crest width, and planform curvature; even small changes can significantly alter sediment dynamics. For example, small changes in crest depth or gap spacing on low-crested breakwaters can shift the beach response from a mild salient to a fully attached tombolo, with corresponding changes in bypassing and downdrift erosion.

International reviews emphasise that governance, monitoring, and community acceptance are as important as engineering performance, especially where visual amenity and surf quality are valued (Williams et al., 2018).

Figure 9. Submerged or low-crested islands, Liguria, Italy. Credit: www.repubblica.it.

2.3.2.3 Design Considerations for Submerged or Low-crest Structures

Across all structure types, several design principles consistently emerge:

- Crest depth and planform geometry strongly dictate wave breaking, diffraction patterns, and sediment transport; small adjustments can yield large morphological consequences.

- Adaptive design is essential, with iterative calibration using physical and numerical modelling supported by post-construction monitoring.
- Material choice must address both structural and ecological goals; rough natural rock and eco-concrete surfaces reduce scour and promote habitat value.
- Integration with sediment management remains fundamental; reefs and barriers can improve nourishment effectiveness but cannot replace ongoing sediment supply on high-energy, microtidal coasts.

For the Joondalup shoreline, any consideration of submerged or low-crest structures should be framed within the sediment-led adaptation strategy established under the CHRMAP (MRA, 2022). Monitoring from the City's coastal program (MRA 2023; 2024) shows persistent erosion north of Hillarys Boat Harbour and at Pinnaroo Point, driven by sediment transport imbalances associated with the harbour and the prevailing south-westerly wave climate. If ongoing bypassing and nourishment prove insufficient to stabilise these sectors, targeted reef or submerged barrier elements could be assessed as morphodynamic stabilisers to moderate wave-angle asymmetry and enhance local surf quality.

Such interventions should only be advanced within an adaptive management framework that maintains sediment budgets, preserves visual amenity, and aligns with the ecological values of Marmion Marine Park. Feasibility studies would need to include high-resolution wave modelling, detailed assessment of ecological impacts and benefits, and robust community engagement to establish clear objectives and social licence.

2.3.3 Emerged Hard Structures

Emerged structures represent the most visible and interventionist class of coastal protection measures. Unlike submerged or low-crest systems that primarily steer morphology with limited surface expression, emerged structures directly intercept wave energy and longshore transport, exerting a stronger and more immediate influence on shoreline position. Their performance, impacts, and social acceptability vary widely depending on geometry, sediment budgets, and local coastal values. The following reviews the main categories of emerged controls relevant to high-energy sandy coasts and assess their applicability to Joondalup's open shoreline:

2.3.3.1 Rock Groynes

Rock groynes are shore-normal structures built to trap longshore-moving sand and widen the updrift beach, often at the expense of downdrift supply. Groynes interrupt longshore drift to build sand updrift, but they often reduce sediment downdrift and can shift erosion rather than solve it. Performance depends on groyne length relative to surf-zone width and wave angle (also known as the geometric bypass ratio). Short, permeable, well-spaced groynes can moderate drift with less downdrift impact, but only if backed by reliable bypassing or programmed nourishment, plus monitoring triggers (Kristensen et al., 2016; CIRIA, 2020; van Rijn, 2013).

On high-energy, micro-tidal coasts, long groynes can over-trap sand and create strong downdrift deficits, so they must be treated as a system-wide sediment-management intervention.

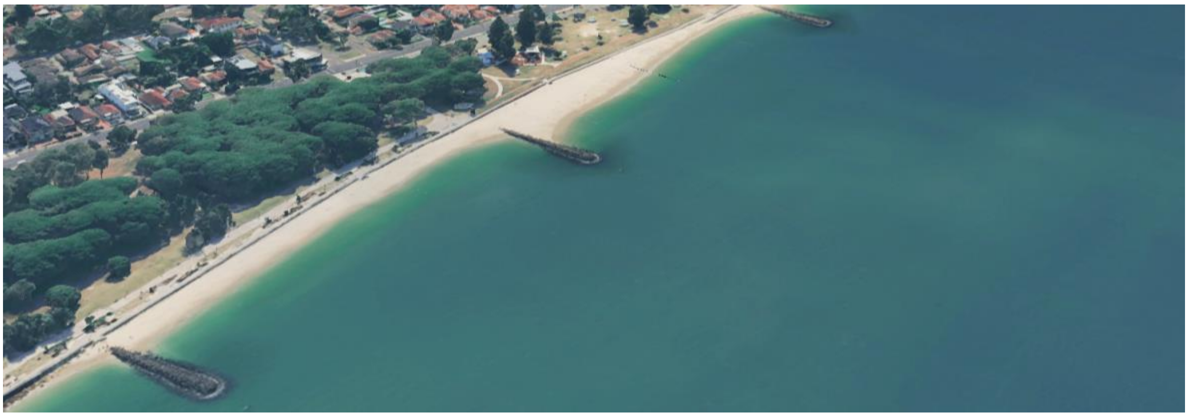

Figure 10. Rock groynes in Botany Bay, Sydney. Credit: Google Earth.

2.3.3.2 Geofabric Groynes

Geofabric groynes are modular structures built from sand-filled geotextile containers. Because they are assembled from discrete units, they can be repaired, re-stacked, resized, or removed if monitoring shows unacceptable impacts, offering a more adaptable alternative to permanent rock or concrete groynes (Restall et al, 2022).

A key Australian example is the Maroochydore (Cotton Tree) groyne field and seawall on the Sunshine Coast, Queensland. The system uses geotextile sand containers to stabilise an erosion-prone beach compartment and protect foreshore assets, operating alongside nourishment and ongoing maintenance (ICM 2024). Sunshine Coast Council has delivered staged renewal works, rebuilding sections of the groyne field with new containers to maintain function and resilience as the coast continues to adjust. Geofabric groynes can degrade over time due to UV exposure, abrasion and vandalism, requiring periodic replacement, and like other groynes they can shift erosion downdrift by trapping sand on the updrift side and reducing supply to adjacent beaches.

Figure 11. Geofabric groynes at Maroochydore, Australia. Credit: ICM.

2.3.3.3 T/Y Head Groynes

Surface-control structures can also be configured to shape a stable bay planform rather than simply trap sand. T or Y head groynes are groynes with a widened head that provide stronger planform control by shaping a bay-like beach compartment. T or Y head groynes combine a shore-normal stem with a short head to emulate headland control, moderating tombolo formation while flattening longshore gradients; similarly, artificial headlands or short breakwater headlands can guide beaches toward a static equilibrium bay shape predicted with headland-bay models.

For example, Playa de Poniente in Gijón, Spain provides a clear case of engineered headland-controlled planform, while Morecambe, UK demonstrates the use of Y and T head groynes to stabilise a series of beaches. These approaches can preserve planform with less visual clutter than full fields of long groynes, but they still require sediment sources and careful diffraction-aware modelling to avoid downdrift deficits, especially under bimodal wave climates (Hardaway & Gunn, 2010; Hsu, 2010).

Figure 12. Fishtail or Y Groyne, Deganwy, UK. Credit: Google Earth.

2.3.3.4 Vertical Seawalls

Vertical seawalls are near-vertical, generally impermeable walls (often concrete or sheet-pile with a concrete face) built at the back of the beach to protect land and infrastructure from erosion and storm-tide impacts. They can provide strong asset protection, but the steep face reflects wave energy, which can increase turbulence at the wall base, drive toe scour, and lower the seabed in front of the structure, increasing overtopping risk and wave loading over time. Vertical seawalls can also reduce amenity by narrowing or eliminating the dry beach in front of the wall during high water levels, restricting access and leaving waves to reach the structure with little or no beach buffer.

Good practice therefore emphasises robust toe and foundation protection (embedment and scour control), allowance for future bed-level lowering, and post-storm monitoring with clear maintenance triggers. Crest retrofits such as recurves can reduce overtopping in some conditions but may increase wave impact forces and must be structurally assessed. (Salauddin & Pearson, 2019; Xu et al., 2022; Dong et al., 2021).

Figure 13. Vertical seawall, Northern Beaches Council, NSW. Credit: NSW Nature Conservation Council.

2.3.3.5 Sloping Rock Revetments or Seawalls

Sloping Rock revetments or seawalls are sloping armour layers that dissipate wave energy to protect the foreshore. They usually provide reliable line-of-defence asset protection against storms and progressive recession but, while the slope provides a more effective mechanism to dissipate waves, it can still reflect energy, elevate runup/overtopping risk, and can induce toe scour and beach narrowing ("passive erosion") where shoreline retreat is otherwise expected under sea-level rise (see Allan et al. 2005). Contemporary guidance requires design checks for overtopping discharges, structural and geotechnical stability (including scour and back-of-wall drainage), and allowances for adaptive crest raising over the asset life.

From a coastal-system perspective, extensive shoreline armouring constrains landward beach migration and can accelerate long-term dry-beach loss under sea level rise, with documented amenity and ecological impacts. Where used, seawalls should be paired with sand management (e.g., buffer nourishment, dune building) to maintain public beach width and mitigate reflection effects (EurOtop, 2018; Griggs, 2019; Nawarat et al., 2024).

Figure 14. Sloping seawall at Exmouth, UK. Credit: Wikimedia Commons.

2.3.3.6 Sea Dikes

Sea dikes are continuous, shore-parallel embankments (typically sand or clay cores) that provide flood and erosion protection by keeping extreme water levels and wave run-up from reaching low-lying land. They are commonly armoured on the seaward face with rock revetment or other robust linings, with crest height and allowable overtopping discharge used as key design controls, supported by established overtopping guidance (EurOtop, 2018). Performance depends strongly on nearshore depth and foreshore slope, and overtopping predictions remain uncertain in very shallow settings where infragravity waves can dominate (Tarakcioglu et al., 2023).

Under sea level rise and more energetic storms, sea dikes often require staged upgrades (raising crests, improving toe scour protection, and strengthening surfaces against overtopping erosion) to maintain reliability (Romão et al., 2025). Sea dikes can also be eco-engineered to improve habitat and biodiversity (for example through surface roughness, berm and vegetation design, and material choices) without compromising core safety functions, but these measures still need to be balanced against inspection, maintenance, and structural performance requirements (Scheres & Schüttrumpf, 2019).

Figure 15. Sea dike in the Netherlands, combined with longshore control structure. Credit: Coastal Wiki.

2.3.3.7 Detached Breakwaters

Detached breakwaters are offshore, shore-parallel structures that create a wave shadow and promote sand build-up as salients or tombolos**.** Shore-parallel breakwater fields (detached, low-crested offshore structures) create a wave shadow that reduces nearshore wave energy and longshore currents, encouraging sand to accumulate as salients or tombolos depending on structure length, spacing, freeboard, and distance offshore. At Kwinana Beach (WA), offshore structures described as artificial headlands were used to address chronic erosion while maintaining beach access and recreation, illustrating how detached offshore protection can reshape nearshore conditions without a continuous seawall frontage.

Internationally, low-crested breakwaters on the Emilia-Romagna coast (for example near Lido di Dante) show they can widen beaches but may also create local scour and other side effects, reinforcing the need for site-specific calibration (Munari et al., 2011). Sea Palling (UK) likewise demonstrates that morphological outcomes vary with geometry and gaps (Dolphin et al., 2012). Studies indicate that closer, longer structures with smaller gaps more readily form tombolos and restrict bypassing, while larger spacing and/or lower freeboard tends to favour salients and partial bypassing, with downdrift risks managed through monitoring and, where needed, bypassing or nourishment (Ming & Chiew, 2000; Jackson et al., 2015).

Figure 16. Detached breakwaters at Saly Beach, Senegal. Credit: Google Earth.

2.3.3.8 Offshore Islands

Offshore islands (engineered islets or segmented “island” elements) are detached, low-visibility control structures placed offshore to create wave-shadow zones, reduce nearshore wave energy, and help stabilise pocket beaches within defined compartments. In practice they behave similarly to detached breakwaters but with a larger footprint and stronger planform control, which can be useful where managers want to moderate wave-angle-driven longshore transport and retain sand in specific cells.

Key risks include downdrift erosion (if compartments interrupt sediment continuity), altered rip-current patterns, water-quality changes in sheltered zones, and high capital and approvals complexity, so they are usually considered only where the benefit of strong shoreline control outweighs environmental and social impacts and where ongoing monitoring can manage secondary effects. (Li et al. 2022; Zhang et al. 2025; Yang et al 2025).

Figure 17. Offshore island for coastal erosion combined with groynes. Liguria, Italy. Credit: Google Earth.

2.3.3.9 Artificial Headlands

Artificial headlands are shore-attached protrusions (rock, geotextile container cores, or hybrid forms) that compartmentalise longshore sand movement to form a stable beach or series of pocket beaches, improving local stability by minimising net drift across each headland-controlled cell. They are often pursued where repeated nourishment is expected but managers want placements to "stay put" longer, or where there is a strong community preference for larger controls mimicking one headland rather than long fields of groynes.

Performance depends on headland spacing, wave climate, and sediment supply. They can transfer erosion to adjacent cells if the compartment design does not match dominant transport pathways, so design typically relies on calibrated modelling plus post-construction monitoring (shoreline mapping, profiles, nearshore bathymetry) with adjustment options such as targeted nourishment or local re-shaping if required in rare cases (Pan et al., 2018; Ge et al., 2023).

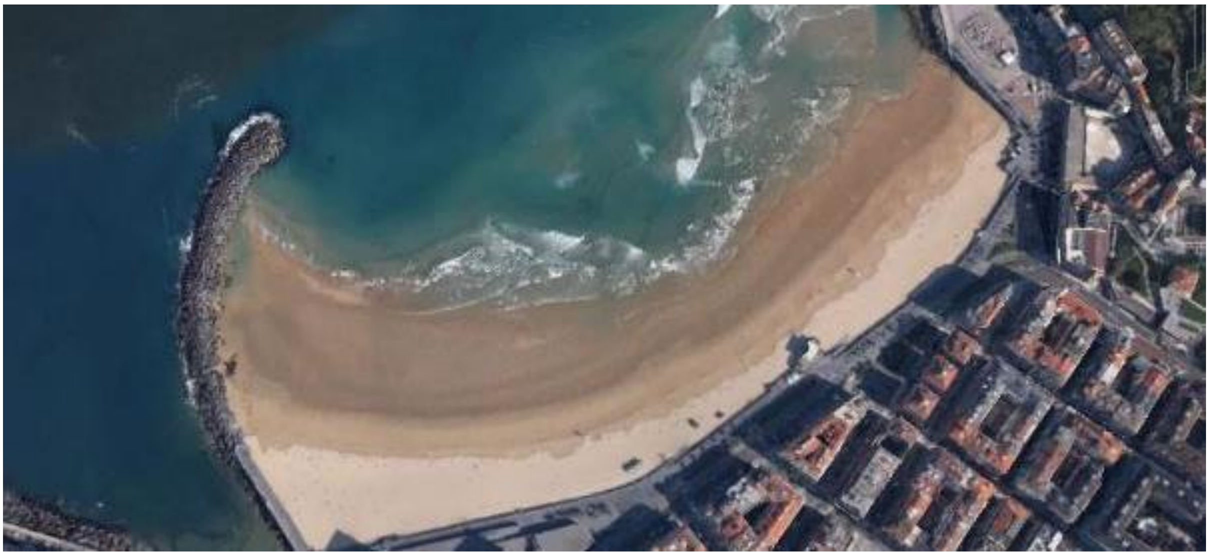

Figure 18. Artificial headland (large groyne), San Sebastián, Spain. A structure of this scale can behave like a headland, interrupting longshore drift and trapping sand to build and stabilise the beach in its lee. Credit: Ministerio de Medio Ambiente, Spain.

2.3.3.10 Design Considerations for Emerged Hard Structures

Design and operational considerations apply across all these emerged structures, as their engineering performance and coastal impacts are governed by common hydraulic, geotechnical, sediment-budget, and ecological factors. Successful application depends on integrating these structures into the broader coastal system, ensuring they function safely under present and future conditions while avoiding unintended downdrift impacts. The following principles summarise the key requirements for planning, designing, and operating any form of emerged coastal protection structures:

- **Hydraulics & safety.** Set freeboards/crest geometries to meet target overtopping discharges for public safety and back-of-structure flooding; check wave transmission/diffraction and induced currents at gaps; account for oblique attack and storm clusters (EurOtop, 2018).

- **Stability & scour.** Provide adequate toe protection, armour gradation, filters, and foundation design against reflection-induced scour and cyclic loading; adopt monitoring/maintenance regimes per rock-structure guidance (USACE (2002) CEM; Rock Manual).
- **Sediment budgets.** Hard controls alter alongshore fluxes; coupling with engineered bypassing/backpassing or scheduled nourishment is essential to maintain cell-wide equilibrium and avoid cumulative downdrift impacts (CIRIA, 2020; van Rijn, 2013).
- **Ecology & amenity.** Low-crested/detached systems and seawalls can be designed with nature-inclusive features (roughness, habitat units, seaward reefs) to enhance biodiversity, but they still modify habitat mosaics; "surfability" and access should be explicitly tested in design (DELOS/eco-design; Suedel et al., 2022).
- **Sea Level Rise (SLR) adaptability.** Hard controls should include staged crest-raising options and sand-buffer strategies; without active sediment management, increasing water levels drive higher overtopping, toe loading, and progressive beach narrowing in front of armouring (Griggs, 2019; EurOtop, 2018).

For Joondalup, if structural protection is required to defend critical assets at specific hotspots, emerged options should be evaluated only within a sediment-led strategy that prioritises:

(i) continuous or programmed sand supply (bypass/backpass/nourishment)

(ii) minimal visual footprint and surf-amenity preservation (favour less invasive and smaller controls compatible with the sediment transport regime over long, impermeable fields)

(iii) adaptive design for SLR (overtopping and crest-raising pathways)

(iv) transparent monitoring to manage downdrift risk

Where community values and Marmion Marine Park considerations weigh heavily against prominent structures, low-visibility configurations (such as short headlands, or limited detached "islands" sized to avoid the creation of tombolos) combined with nourishment and dune enhancement may offer more acceptable risk-reduction, provided thorough modelling, operational bypassing, and performance reporting are in place (CIRIA, 2020; Dally & Pope CETN; Hardaway & Gunn, 2010).

2.3.4 Hybrid and Innovative Alternatives

Hybrid and innovative options combine soft, hard, and operational techniques into low-visibility, adaptive systems that stabilise shoreline morphology while maintaining amenity, ecological value, and community acceptance. These approaches sit between traditional nourishment and conventional engineering structures, offering a more flexible pathway for coastal protection on high-energy coasts. They are designed to work with natural processes, respond dynamically to storms, and minimise long-term visual or ecological impacts. The following approaches represent potential alternatives to conventional adaptation options for high-energy, micro-tidal coasts such as Joondalup.

2.3.4.1 Hybrid Seawall-Dune System

Hybrid dunes, or buried seawalls, combine dune-building measures (fencing, sand trapping and vegetation planting) with a buried structural core such as geotextile, cobble, or cellular grid to improve storm resistance while retaining a natural dune appearance. In practice, they function as a hybrid seawall-dune system: a concealed rock, geobag, or seawall element is placed beneath the dune or nourished beach as a hidden last line of defence, intended to remain buried and only become exposed during extreme erosion.

An example is the Gold Coast (Queensland), where a structural seawall sits beneath the dune and the surface is rebuilt with sand and planted coastal vegetation, supported by ongoing nourishment, sand bypassing and backpassing. Because sea-level rise drives long-term shoreline retreat, these systems typically require periodic sand top-ups to maintain dune volume and keep the buried core covered (Harley et al., 2022).

Figure 19. Hybrid seawall-dune system construction on the Gold Coast, Queensland: a seawall core buried beneath sand, then capped with additional sand and stabilised through dune revegetation. Credit: ICM.

2.3.4.2 Dynamic Cobble-berm Revetments

Dynamic cobble-berm revetments use graded cobbles to create self-adjusting berms that dissipate wave energy during storms while maintaining a sandy beach frontage in calm conditions. Dynamic cobble berm revetments self-adjust because the cobbles are deliberately sized to move under storm waves: during high energy events they roll and regrade into a steeper, more tightly packed armour layer (often with some crest build-up), which increases roughness and dissipates wave energy, reducing runup and erosion.

In calmer conditions, less wave forcing means the cobbles settle and sand can infill around and in front of the berm, helping the beach recover a sandy surface while the cobble layer remains as a resilient storm buffer. Studies confirm their stability and storm resilience when cobble size and geometry are tuned to local hydrodynamics (Bayle et al., 2021; Gostic et al. 2024; Bond et al., 2025). For example, in the Pacific Northwest (USA), a dynamic revetment along the shore at North Cove, Washington, demonstrated substantial reduction in shoreline retreat and wave-driven erosion following installation in 2017.

Figure 20. Dynamic cobble berm at Surfer's Point, Ventura, California. Credit: ICM.

2.3.4.3 Sand Fencing, Brushing, and Dune Trapping

Sand fencing, brushing, and dune trapping are porous barriers and natural materials to slow wind near the surface, so sand deposits and gradually builds the dune toe and incipient dune. Sand fencing and brushwood lines trap windblown sand by reducing near-surface wind speeds and encouraging deposition, helping build dune toes and widen the incipient dune when aligned to the dominant wind direction and combined with planting and access management (Eichmanns & Schüttrumpf, 2021; Eichmanns et al., 2022). This work is currently already being completed within the City of Joondalup.

Practical guidance consistently emphasises keeping fencing above the active swash zone, maintaining it after major storms, and using porous designs so sand can accumulate without the fence failing. For example, Florida guidance recommends fence porosity targets and repositioning once burial reduces effectiveness (Florida Department of Environmental Protection, 2020). Program guidance in Scotland similarly specifies installing sand-blow fencing at right angles to prevailing winds and maintaining it as part of broader dune stabilisation works (Rural Payments and Services, 2015).

Figure 21. Sand fencing with natural materials on dune systems in North Carolina, US. Credit: NOAA.

2.3.4.4 Perched Beaches

Perched beaches are beaches that are “held” on the upper profile by a submerged sill or low-crested reef that reduces offshore sand loss and helps maintain a wider dry beach. They are typically implemented as a hybrid measure, combining a low-visibility nearshore control (rock, reef units, or geotextile elements) with nourishment to build and maintain the perched beach volume.

Perched beach behaviour can be described using equilibrium profile concepts that account for the influence of the offshore control on profile shape and sand retention (González et al., 1999). Field and conceptual evidence also highlights that perched beaches can vary strongly in form and response, depending on the type and geometry of the natural or engineered control, local wave climate, and sediment characteristics (Gallop et al., 2011). As with other structural interventions, careful design, approvals, and monitoring are essential, and perched beaches generally still require periodic top-ups to maintain beach width and manage longer-term sea level rise impacts.

Perched beaches could be considered as a targeted, low-visibility hybrid option for discrete erosion hotspots in Joondalup to retain a sandy beach appearance but improve sand retention and storm buffering without prominent above-water structures. Joondalup’s high-energy, segmented beach compartments mean any perched beach concept would need to be site-specific, with careful attention to interactions with limestone outcrops, nearshore bars, and the prevailing net northward drift. The approach is most likely to be feasible where there is sufficient sandy frontage to retain benefits and a clear approvals and environmental management pathway, noting that ongoing nourishment top-ups and monitoring would still be expected.

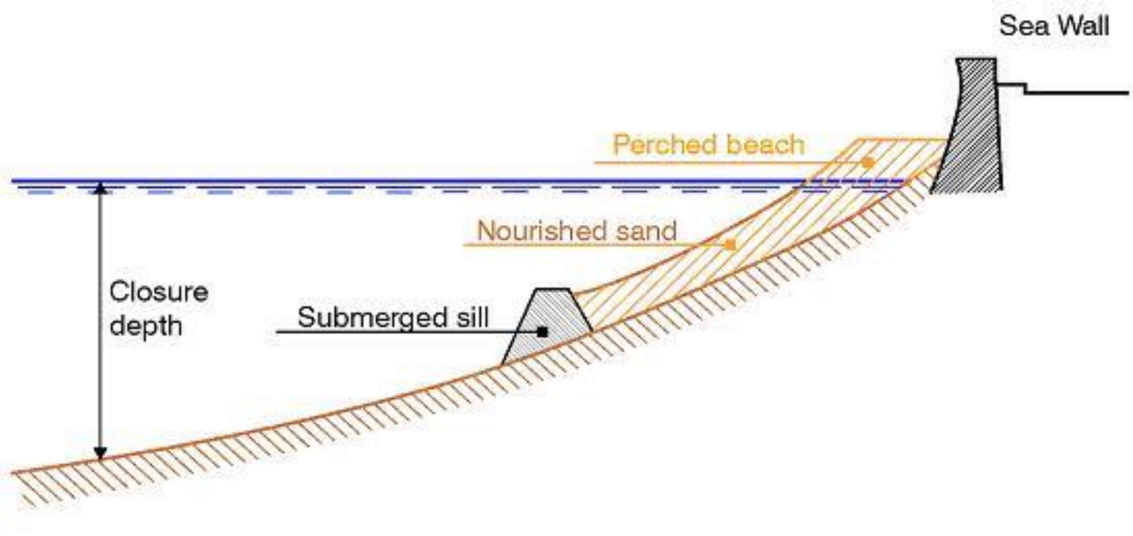

Figure 22. Perched beach cross section diagram. Credits: Coastal Wiki.

2.3.4.5 Beach Drainage and Dewatering

Beach drainage and dewatering systems use buried drains or permeable layers to lower the groundwater table under the beach face, with the aim of increasing infiltration and reducing erosive backwash during uprush-backwash cycles (Fischione et al., 2022).

Evidence remains mixed and strongly site-dependent (Turner & Leatherman 1997). For example, a detailed field study at Alassio (Italy) found limited net shoreline/volume gains over a year under recurring moderate wave events, concluding the system did not reliably counter erosion there (Bowman et al., 2007). Numerical work also shows that drainage layers can reduce mean groundwater levels and offshore-directed surface flows, but effectiveness depends on configuration and incident-wave conditions (Hur et al., 2012). In general, results remain mixed and site-specific, with inconsistent outcomes on high-energy coasts (Schoonees et al., 2019; van Rijn, 2013).

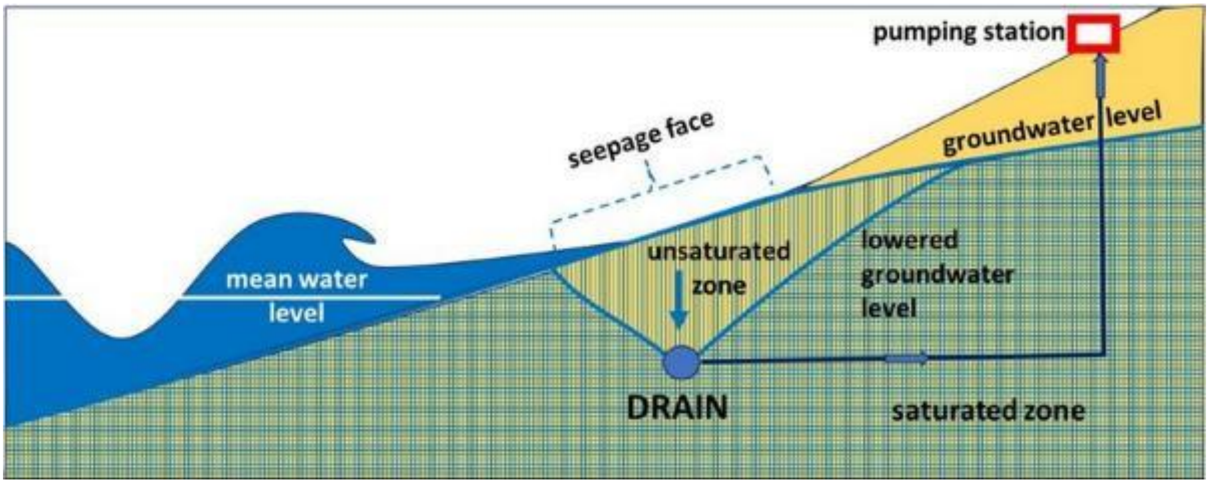

Figure 23. Lowering of beach water table with active beach drainage. Credit: Coastal Wiki.

2.3.4.6 Floating Wave Energy Dissipators and Wave Energy Converters (WECs)

Floating wave energy dissipators and wave energy converters (WECs) are offshore devices or arrays that dissipate wave energy while (in the case of WEC) producing renewable electricity, with potential co-benefits for sediment management and habitat creation (Battisti et al., 2024). Floating wave-attenuation systems that do not generate power, including modular floating breakwaters and wave energy dissipators, have been investigated as a means to reduce transmitted wave energy before it reaches the surf zone, with effectiveness strongly dependent on wave period, water depth, mooring design, and array configuration.

While laboratory and numerical studies show measurable attenuation is achievable, the key evidence gaps for open-coast deployment remain extreme-event survivability, maintenance and navigation constraints, and robust field validation of shoreline and morphodynamic responses over multi-year timescales (van der Zanden et al. 2022). WEC arrays can, in principle, provide a dual function by extracting wave energy while also attenuating wave heights reaching the coast, but performance depends on device type, control strategy, spacing, and array layout (Battisti et al., 2024).

A recent systematic review focused specifically on wave farms for coastal protection reports wave-height reductions commonly in the ~10-50% range (context-dependent), with the strongest attenuation generally associated with nearshore siting and optimised layouts, while highlighting the ongoing need for field validation and long-term morphodynamic assessments (Boodoo et al., 2025). A key limitation of WEC is that nearshore arrays can impose recreational and landscape costs, including visual clutter, constraints on surfing and boating access, navigation and safety exclusions, and potential effects on nearshore ecology and surf breaks that can reduce social acceptability even where engineering performance is promising.

Wave energy converter devices are typically designed for deeper water, outside the surf zone, so they have limited influence on beach erosion unless deployed at very large scale.

Figure 24. Wave energy converter device. Credit: swel.eu.

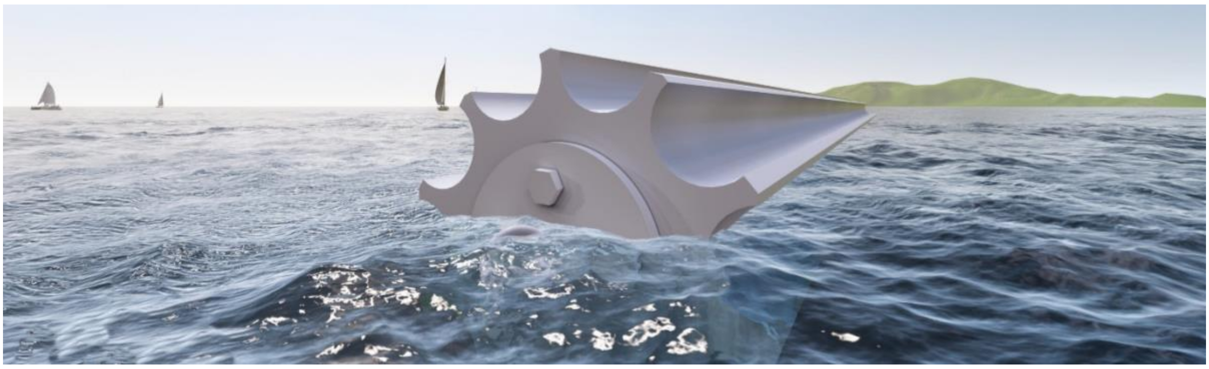

Figure 25. Conceptual design of a wave energy dissipator to decrease wave velocity. Credit: Boston.com.

2.3.4.7 Purpose-sunk Reef and Habitat Modules

Purpose-sunk reef and habitat modules are intentionally placed reef structures, vessels or concrete units installed primarily for habitat enhancement, and unlike the multipurpose artificial reefs discussed earlier, they are not typically designed or optimised to deliver reliable shoreline erosion control. These may employ decommissioned vessels or modular concrete units that can provide ecological enhancement and partial wave attenuation where environmental and navigation constraints allow (Rani et al., 2025; Storlazzi et al., 2025).

However, they require careful design and ongoing management to avoid navigation hazards, contaminants, and unintended environmental impacts (Department of Climate Change, Energy, the Environment and Water, 2023). Unlike multipurpose artificial reefs, which are purpose-designed coastal protection structures (often optimised for wave transformation and surf outcomes), purpose-sunk reefs and habitat modules are primarily deployed for ecological enhancement, with any wave attenuation typically secondary and highly site-dependent. For example, the City of Cockburn's North Coogee engineered fringing reef pilot at C.Y. O'Connor Beach reported around a 10% reduction in wave height and a 20% reduction in wave energy at the shoreline, alongside increased biodiversity, illustrating how modular reefs can deliver measurable coastal and ecological co-benefits in suitable settings (City of Cockburn, 2026).

Australian national guidance sets out permitting and whole-of-life management expectations under the Sea Dumping Act, emphasising risk-based assessment, monitoring, and removal/rectification obligations if the reef becomes hazardous or fails to meet objectives (Department of Climate Change, Energy, the Environment and Water, 2023). Recent research also continues to develop design-oriented approaches for wave attenuation by modular artificial reefs and evaluates feasibility and constraints for artificial reefs as protection measures in specific settings (Dinu et al., 2025).

Figure 26. Purpose built artificial reef for habitat creation, with limited effect of shoreline erosion. Credit: Haejoo.com.

2.3.4.8 Mangrove Restoration

Mangrove restoration is the re-establishment of intertidal mangrove forests (via planting, natural recruitment, hydrological reconnection, and sediment management) to attenuate waves, stabilise shorelines, and reduce storm-surge impacts while delivering habitat and carbon co-benefits. The approach can be highly effective in low energy, sheltered settings (very different from Joondalup's open coast) where mangroves can persist and expand, but it is generally constrained on open, high-energy sandy coasts unless there are protected embayments, lagoonal margins, or engineered shelter that allows seedlings to survive.

Best-practice projects treat mangroves as a living system that changes over time, requiring monitoring of survival, forest width/density, and failure modes under extreme events, and often pairing vegetation with enabling measures (sediment trapping or low-crested shelter) where hydrodynamic stress is high (Gijón Mancheño et al., 2024; Weaver et al., 2024; Juanico et al., 2022).

Figure 27. Mangrove restoration project in Victoria, Australia. Credit: Ozfish.

2.3.4.9 Seagrass Restoration

Seagrass restoration re-establishes meadow-forming seagrasses (through transplanting, seeding, and/or improving water quality and substrate conditions) to dampen waves and currents, reduce bed shear stress, and promote sediment settling, which can stabilise shallow nearshore and estuarine margins over time. Where meadows are continuous and healthy, measured wave attenuation can be meaningful, but outcomes are strongly site-dependent and often require long lead times, sustained water-quality improvements, and protection from physical disturbance (anchoring, dredging, propeller scarring). For Joondalup, this is most likely to be feasible only in sheltered or reef-protected nearshore areas (not the open surf beaches) and would be a long-term habitat and water-quality investment with only modest, site-specific contribution to erosion mitigation.

In coastal-protection applications, restoration is typically coupled with monitoring of meadow extent/biomass and hydrodynamics and positioned as a medium-to-long-term risk reducer rather than a rapid response option for acute erosion hotspots (Jacob et al., 2023; Xu et al., 2025).

Figure 28. Seagrass restoration along Sydney's coastline. Credit: ABC.

2.3.4.10 Living Shorelines

Living shorelines is a broad term that encompasses a range of shoreline stabilisation techniques along estuarine coasts, bays, sheltered coastlines, and tributaries. A living shoreline has a footprint that is made up mostly of native material. It incorporates vegetation or other living, natural soft elements alone or in combination with some type of harder shoreline structure (e.g. oyster reefs or rock sills) for added stability. Living shorelines maintain continuity of the natural land-water interface and reduce erosion while providing habitat value and enhancing coastal resilience. (NOAA, 2015).

In Australia, living shoreline projects span beaches and dunes, vegetated edges, and biogenic reef approaches, but the strongest technical fit is typically in sheltered or moderate-energy settings, whereas fully open, high-energy coasts like Joondalup's often require hybridisation (for example, nourishment plus dune building and strategic low-profile stabilisation) to achieve reliable protection. Good practice includes clear performance objectives, baseline data, and monitoring (profiles, shoreline change, habitat condition) because "success" varies with hazard climate, sediment supply, and maintenance effort. (Morris et al., 2024; Paxton et al., 2024).

Figure 29. A Living Shoreline constructed in Panama City, Florida using plants and oyster shell. Credit: Florida Living Shorelines.

2.3.4.11 Living Seawalls

Living seawalls retrofit (or design-in) ecological complexity onto seawalls using textured panels, habitat modules, and microhabitat features such as crevices, pools and ledges. This can improve biodiversity and, in some cases, provide secondary services such as filtration or nursery habitat, while still delivering the primary asset-protection function of a seawall. Evidence shows added topographic complexity can measurably increase intertidal biodiversity, but outcomes vary with water quality, contamination gradients, and local recruitment conditions, and broader eco-unit services can include disservices that need to be monitored and managed.

In general, these are not designed for coastal erosion management and are more suitable for calm areas within estuaries. Successful programs typically move from pilot trials to scaled deployment through a structured pathway that includes stakeholder engagement, approvals, demonstration sites, and long-term monitoring to confirm ecological gains and avoid unintended impacts. (Vozzo et al., 2024; Clifton et al., 2022; Yen et al., 2025).

Figure 30. Living Seawalls in Sydney, NSW. Credit: Adapt NSW.

2.3.4.12 Rock Filter Units

Rock filter units (often “rock bags” or modular rock-filled units) are permeable, flexible armour elements used for scour protection and erosion control around structures, toe stabilisation, and rapid-response bank or shoreline works. Compared with rigid revetments, they can conform to irregular surfaces and be deployed quickly in constrained sites, but they still require engineering design for stability under wave attack, abrasion, and UV exposure (if exposed), and they can be damaged or displaced if unit sizing, anchoring, or foundation preparation is inadequate.

Performance is strongly linked to hydrodynamic loading and placement geometry and best practice includes physical modelling or validated design methods, plus post-storm inspections and trigger-based maintenance to replace damaged units and prevent progressive failure. (Tooker et al., 2023; Coghlan et al., 2024).

A recent local example is the City of Stirling's Kyowa Rockbags installation at Hamersley Pool, undertaken after storm-driven beach loss, highlighting both the rapid deployment advantages of modular units and the practical constraints around quarry rock sizing, handling logistics, and the need for careful placement and ongoing inspection and maintenance after energetic events.

Figure 31. Rock filter units for coastal erosion control in the City of Sterling Credit: City of Stirling.

2.3.4.13 Living Speed Bumps

Living Speed Bumps are a hybrid sand-retention approach that stabilises beaches by working with natural coastal processes. It uses rounded, compact headlands on the upper beach, an offshore artificial reef and targeted nearshore nourishment to influence wave breaking, nearshore currents and the pathways that move sand along and across the shore. Rather than "trapping" sand, the system is intended to slow and guide sediment transport, so sand remains in the compartment longer, supporting dune recovery while maintaining public amenity and a natural-looking shoreline.

Together, the headlands and reef act as "speed bumps" for sand movement. They help anchor the beach planform, reduce the rate of longshore transport and can form sheltered embayments that improve beach usability and access, without relying on long, continuous groyne fields.

The "living" elements come from ecological features integrated into the reef and shoreline, including habitat complexity on reef surfaces (crevices, ledges and pools), intertidal habitat, retention of the sandy beach environment, landscaping opportunities on the headland and native dune vegetation.

The approach was developed by International Coastal Management through the Re:Beach design competition for Oceanside, California, and is in the detailed design phase.

Figure 32. Concept comparison of an existing armoured seawall shoreline (left) and a proposed "living speed bump" design that blends compact headlands, nearshore reef elements, nourishment and public amenity features to retain sand and improve beach usability (right), a winning design for Oceanside, California, United States. Credit: ICM.

2.4 Alignment with Community Preferences

Community feedback during the 2018 Coastal Values survey and the consultation on the draft CHRMAP in 2023 indicated that Joondalup residents strongly value a natural, sandy, and visually unobtrusive coastline. In response, this research deliberately reviewed the full range of coastal erosion adaptation approaches used internationally, including both established and more speculative concepts, as well as options that may ultimately prove impractical or unacceptable in Joondalup. This approach was adopted to demonstrate that alternative coastal adaptation options have been systematically considered, while ensuring the subsequent screening and evaluation stages can be undertaken transparently.

The options reviewed span four broad typologies:

- **Sand management approaches** include measures that add, move, or reprofile sediment, such as beach face nourishment, shoreface or nearshore nourishment, sand bypassing and backpassing, and beach scraping and re-profiling, alongside dune enhancement and revegetation.
- **Submerged or low-crest structures** include artificial reefs, submerged breakwaters, and offshore islands intended to influence wave transformation and nearshore processes while maintaining beach amenity.
- **Emerged hard structures** include groynes, seawalls, and other surface or near-surface control structures that provide more direct physical control of shoreline behaviour.
- **Hybrid and innovative alternatives** combine soft, hard, and operational techniques, such as wet-sand fencing and dune trapping, hybrid dunes with buried structural cores, dynamic revetments, and living or nature-inclusive structures, and can be configured to support low-visibility outcomes and beach amenity where appropriate.

These typologies were used to develop a long list of adaptation options for consideration in the Joondalup context. This list provides the basis for the subsequent screening and assessment stages, ensuring that both community-aligned measures and higher trade-off structural concepts are captured consistently and can be evaluated using the same transparent decision framework.

2.5 Preliminary Options Long List

Based on the literature review above, a consolidated list of 33 adaptation options has been prepared for SWOT screening. The SWOT screening results highlighted 19 preferred adaptation options to carry forward to a feasibility assessment, followed by a final ranking of the most suitable alternatives.

Sand management approaches

1. **Beach face nourishment.** Direct placement of compatible sand on the visible beach to immediately increase beach width, provide a storm buffer, and support recreation and amenity. This approach is typically implemented as discrete campaigns and may be repeated over time to maintain target beach widths.
2. **Shoreface or nearshore nourishment.** Placement of sand in the nearshore zone, often implemented through submerged feeder berms in water depths of around 3-6 metres, relying on waves and currents to gradually move sand shoreward. It is commonly monitored through bathymetric and beach-profile surveys to track berm migration and shoreline response.
3. **Large scale nourishment.** Placement of large sand volumes (typically >100,000 m^3) in a single campaign to provide a longer-lasting beach buffer and lower unit costs. It requires a reliable sand source, access and approvals, and is best suited to longer continuous sandy frontages, potentially integrated with bypassing or backpassing.
4. **Sand bypassing.** Engineered transfer of sand around interruptions to natural littoral drift (such as harbour structures or headlands), using systems such as fixed pipelines and offshore discharge points, or manually excavated and transported via truck. Operations are generally guided by monitoring and performance triggers to determine timing and volumes.
5. **Backpassing and enhanced backpassing.** Relocation of sand from accreting donor areas to eroding receiver areas to maintain sediment continuity without importing external material. Enhanced approaches can include defined harvest zones, operational triggers, and sediment-tracking tools to optimise placement efficiency.
6. **Beach scraping and re-profiling.** Controlled redistribution of sand within the active beach profile, typically moving material from the lower beach to rebuild the berm or foredune following storm scarping. It is generally used as a short-term recovery measure and relies on ecological safeguards and monitoring because it redistributes existing sand rather than adding new sediment.
7. **Dune enhancement / revegetation.** Measures that strengthen the foredune buffer by trapping and stabilising sand using native vegetation, fencing, and access controls. Works typically focus on building dune volume and resilience through

planting, dune shaping, and management of pedestrian pathways to reduce disturbance and support ongoing dune recovery.

8. **Mega-nourishments.** Single, large-scale sand placements intended to disperse gradually alongshore and onshore through natural processes, functioning as a long-term sediment source. Projects are typically monitored over years to track redistribution patterns and beach-profile response.

Submerged or low-crest structures

9. **Multipurpose artificial reefs.** Submerged reef structures designed to attenuate wave energy and influence nearshore morphology while also supporting recreation and habitat objectives. Designs may use modular reef units or ecologically compatible materials, with performance typically assessed through modelling and post-construction monitoring.

10. **Submerged breakwaters and low-crest barriers, including submerged islands.** Linear or modular underwater features that function as low-visibility wave-energy attenuators and morphological steering tools. By altering wave breaking and nearshore circulation, they can influence sediment transport gradients and bar development, with outcomes sensitive to crest depth, width, and planform geometry.

Emerged hard structures

11. **Rock groynes.** Shore-perpendicular groynes, typically constructed from rock armour units, intended to interrupt longshore transport and influence sand retention and beach width. Design typically considers length relative to the surf zone, crest elevation, toe stability, spacing, and potential scour and downdrift effects.

12. **Geofabric groynes.** Modular groynes constructed from geotextile sand containers that can be configured, adjusted, or removed if required. They are typically considered a lower-permanence alternative to rigid rock or concrete units, while still functioning as structures that modify nearshore transport and sand retention.

13. **T/Y head groynes.** Groyne variants that combine a shore-normal stem with a short head (T or Y form) to influence diffraction patterns and shape a more stable beach planform compared with simple straight groynes. They are typically designed using diffraction-aware modelling and assessed for currents, scour, and alongshore impacts.

14. **Vertical seawalls.** Vertical or near-vertical shore-parallel walls designed to provide a hard line of defence against wave attack and erosion, typically used to protect landward assets where space is constrained. Design commonly considers overtopping, toe scour protection, foundation stability, drainage behind the wall, and future crest raising.

15. **Sloping rock revetments and seawalls.** Sloping rock armour layers placed on an engineered slope to dissipate wave energy and protect the backshore or assets behind. Typical design elements include armour sizing and gradation, filters/geotextiles, toe protection to manage scour, and provisions for inspection and maintenance.

16. **Sea dikes.** Large, continuous shore-parallel embankments or engineered barriers (often with a broad crest and landward tie-ins) designed to prevent flooding and protect low-lying land from storm surge and elevated sea levels. They typically

require crest-height design for extreme water levels, geotechnical stability checks, seepage and piping controls, and provisions for staged raising over time.

17. **Detached breakwaters** Emerged, shore-parallel breakwaters (continuous or segmented, including fields) that reduce nearshore wave energy and can shape shoreline planform by promoting salients or tombolos in their lee. Outcomes depend on freeboard, gap-to-length ratio, distance offshore, and local wave climate, and are commonly assessed using empirical relationships and site-specific modelling.
18. **Offshore islands.** Shore-parallel, surface-piercing island elements (often segmented) that create wave-shadow zones and sheltered compartments, influencing sediment deposition patterns and nearshore circulation. Their effects are strongly controlled by crest level, spacing, and distance from shore, and they are typically assessed together with sediment budgets and alongshore impacts.
19. **Artificial headlands.** Surface-control structures designed to anchor a shoreline compartment and guide the beach toward an equilibrium bay shape. These structures rely on careful alignment with wave climate and sediment processes and are commonly assessed using headland-bay concepts and numerical/physical modelling.

Hybrid and innovative alternatives

20. **Hybrid seawall-dune system.** Concealed last line of defence systems where a rock or geobag seawall is buried beneath a nourished beach and dune (including dune systems with buried structural cores), remaining hidden under normal conditions and exposed primarily during extreme events. These systems are commonly operated alongside routine nourishment, dune management, and monitoring to maintain sand cover and manage exposure risk.
21. **Dynamic cobble-berm revetments.** Berms of graded cobbles designed to regrade under storm waves into a rough, energy-dissipating armour layer that reduces runup and erosion. In calmer conditions, sand can infill around and in front of the berm, while the cobble layer remains as a resilient storm buffer.
22. **Wet-sand fencing, brushing, and dune trapping.** Techniques that accelerate aeolian sand capture by placing fences or brush lines to reduce wind speed and trap blown sand, typically combined with planting and access management. Effectiveness depends on positioning above the swash zone, alignment with dominant winds, and maintenance following major storms.
23. **Beach drainage and dewatering.** Systems intended to lower the groundwater table beneath the beach to enhance percolation and reduce backwash-driven sediment removal. Approaches use subsurface drains or pumping infrastructure, with outcomes typically evaluated through site monitoring of beach-profile change.
24. **Wave Energy Converters.** Offshore devices deployed in arrays to capture wave energy for renewable electricity generation, with potential secondary effects on wave climate and nearshore processes. Concepts are assessed for survivability, maintenance requirements, navigation and permitting constraints, and any measurable wave attenuation co-benefits.
25. **Floating Wave Energy Dissipators.** Offshore devices deployed in arrays to reduce wave energy only, with potential secondary effects on wave climate and nearshore processes. Concepts are assessed for survivability, maintenance requirements,

navigation and permitting constraints, and any measurable wave attenuation co-benefits.

26. **Purpose-sunk reef and habitat modules.** Artificial reef structures such as decommissioned vessels or modular concrete units deployed primarily to create habitat, with potential secondary effects on local hydrodynamics and wave attenuation. Assessments typically cover ecological objectives, navigation safety, permitting, and any measurable nearshore changes.
27. **Mangrove restoration.** Establishment or rehabilitation of mangrove vegetation to stabilise sediments and attenuate waves and currents in suitable environments, while providing habitat and water-quality co-benefits. Projects typically involve site preparation, planting or recruitment support, and monitoring of survival and growth.
28. **Seagrass restoration.** Restoration of seagrass meadows to enhance seabed stability, reduce resuspension, and support biodiversity and water-quality outcomes. Methods can include transplanting, seed-based approaches, and habitat condition improvements, with monitoring focused on coverage, health, and persistence.
29. **Living shorelines.** Nature-based shoreline treatments that combine vegetation, natural materials, and sometimes low-profile structural elements to reduce erosion and provide habitat. They are typically implemented as layered systems designed to work with local hydrodynamics and ecological processes rather than relying on a single hard barrier.
30. **Living seawalls.** Engineered seawalls or revetments designed or retrofitted with ecological enhancement features (such as textured surfaces, habitat niches, or modular units) to promote marine colonisation. The intent is to retain structural function while improving biodiversity outcomes relative to conventional smooth wall surfaces.
31. **Rock Filter Units.** Rock-based filter and armour units placed as permeable protection elements, typically comprising graded rock with filter layers to manage seepage, reduce scour, and dissipate wave energy. They can be configured as localised protection at toes or transitions and are commonly assessed for stability, settlement, and maintenance requirements under design storm loading.
32. **Living speed bumps.** Living Speed Bumps are a hybrid sand retention concept proposed through the Re:Beach design competition at Oceanside, California. The concept combines compact artificial headlands, an offshore artificial reef, and targeted nourishment to influence wave breaking and nearshore sediment transport, with the intent of stabilising the beach while maintaining amenity and a natural-looking shoreline. The concept is in the detailed design phase.
33. **Perched beaches**. A perched beach is a nourished beach retained by a submerged sill or low-crested reef that limits offshore sand loss and helps maintain a wider dry beach within a defined compartment. It is typically delivered as a hybrid system (nearshore control plus compatible sand placement) and requires careful design and monitoring because shoreline response varies with sill geometry, crest depth, wave climate, and sediment characteristics.

3 SWOT ANALYSIS

A SWOT analysis is a structured way to synthesise what an option is likely to be good at (strengths), where it is likely to struggle (weaknesses), what external conditions could help it succeed (opportunities), and what external conditions could cause it to fail or become unacceptable (threats), and it is commonly used as an early-stage screening and prioritisation tool to compare a large set of alternatives in a consistent format (Benzaghta et al., 2021).

In this assessment, we applied the SWOT method uniformly across the 33 adaptation options listed in section 2.5, combining strengths and opportunities into a single “Advantages” field (capturing both inherent benefits and plausible upside under local delivery and governance), while weaknesses and threats were combined into a single “Disadvantages” field (capturing practical limitations, implementation risks, and the most likely failure modes, including social licence and approvals). We then used the “Proceed to feasibility study?” decision as a gate, with the intent that “Yes” options represent those that, based on the SWOT, appear sufficiently plausible and relevant to warrant deeper technical, environmental, cost, and deliverability testing, while “No” options are those where the SWOT indicates fundamental misfit or disproportionate downside at this stage.

The results show a clear pattern in why 19 of the 33 options were progressed to feasibility. The shortlisted options are dominated by sand- and dune-led measures because they directly rebuild or conserve the beach buffer and tend to preserve the sandy beach character and access that the community prioritises, even if they require repeat campaigns and ongoing maintenance. This includes beach nourishment, shoreface placement, bypassing and backpassing, scraping and re-profiling, dune enhancement, and dune revegetation, fencing and sand trapping measures, which the SWOT consistently framed as effective and adaptable but maintenance dependent.

A second cluster taken forward comprises lower-visibility nearshore or hybrid measures that may improve sand retention and storm resilience while reducing visual intrusion, but only if supported by modelling, careful design, monitoring, and an ongoing sediment management program; these were advanced because the SWOT suggests enough promise and precedent to justify feasibility testing despite known design sensitivity and approval risk.

Conversely, the options not progressed were screened out because the SWOT highlighted one or more decisive barriers: some are primarily suited to sheltered or low-energy settings and therefore have a poor physical fit for an exposed coastline; some have inconsistent evidence of measurable erosion reduction or are framed around benefits other than erosion control; and some involve large, visually prominent, or continuous hard structures where the SWOT indicates strong trade-offs against beach amenity, access, and acceptability, or where long-term adaptability under sea level rise is constrained.

The complete SWOT analysis can be viewed in Appendix C, Table C-1.

4 FEASIBILITY ASSESSMENT

A feasibility assessment is a structured way to test whether shortlisted adaptation options are likely to be deliverable and defensible in practice, not just conceptually attractive. It focuses on whether an option can work under the local wave and swell climate and coastal setting (technical feasibility), whether it can be implemented without disproportionate or unacceptable ecological and habitat impacts (environmental feasibility), whether its costs and ongoing maintenance obligations are proportionate to the benefits and funding reality over the lifecycle (economic feasibility), and whether it is likely to achieve and sustain community support given local beach amenity expectations, access needs, and risk tolerance (social feasibility). Used in this way, feasibility assessment provides a transparent bridge between early screening (based on a SWOT analysis) and later stages of detailed design and business case development, because it makes the decision logic explicit and comparable across multiple alternatives.

In this assessment, we applied a consistent four-part feasibility lens across the options progressed from the SWOT gate, using a 1-5 scoring approach for each domain and recording a short narrative rationale for each score to preserve transparency, according to the criteria set in the following table (Table 2).

Table 2. Feasibility scoring rubric (1-5)

Score	Technical feasibility	Environmental feasibility	Economic feasibility	Social feasibility
5	Proven and reliable; straightforward to design and build; adaptable over time.	Minimal, reversible impacts; approvals straightforward.	Low capex and low O&M; limited studies and monitoring.	Enhances amenity and access; minimal visual impact; strong support likely.
4	Feasible with standard studies; manageable sensitivities.	Manageable impacts with mitigation; approvals achievable.	Moderate capex and O&M; scalable; some monitoring.	Mostly consistent with amenity and access; manageable disruption; likely acceptable.
3	Feasible but design-sensitive; needs modelling, trials, or tighter controls.	Noticeable impacts or uncertainty; targeted studies and monitoring; approvals not straightforward.	Moderate to high cost and/or ongoing operations; studies and monitoring are material.	Mixed outcomes; some amenity, access, or surf/safety impacts; acceptance depends on design and engagement.
2	Site-dependent and complex; higher risk of unintended effects; constructability constraints.	Higher impact risk or uncertainty; approvals likely difficult.	High capex and/or high O&M; specialist delivery and monitoring add substantial cost.	Likely opposition due to footprint, access disruption, or perceived industrialisation.
1	Unlikely to work as intended.	Likely unacceptable or not approvable.	Very high cost and lifecycle burden.	Very low social licence likely.

A summary of the results of the feasibility assessment is provided in Table 3.

Table 3. Feasibility Assessment of Options (Summary)

#	Option	Score (Tech)	Score (Env)	Score (Econ)	Score (Social)	TOTAL
1	Beach face nourishment	4	3	2	4	13
2	Shoreface or nearshore nourishment	4	2	3	4	13
3	Large scale sand nourishment	4	2	4	3	13
4	Sand bypassing	4	3	4	3	14
5	Backpassing and enhanced backpassing	3	3	3	3	12
6	Beach scraping and re-profiling	3	2	4	4	13
7	Dune enhancement / revegetation	3	5	5	5	18
9	Multipurpose artificial reefs	2	2	2	2	8
10	Submerged breakwaters and low-crest barriers, incl. submerged islands	2	2	2	2	8
11	Rock groynes	4	2	2	2	10
12	Geofabric groynes	3	2	2	2	9
14	Vertical seawalls	4	1	2	1	8
15	Sloping rock revetments and seawalls	4	2	2	2	10
17	Detached breakwaters	4	1	2	1	8
18	Offshore islands	3	1	2	2	8
20	Hybrid seawall-dune system	4	2	4	5	15
22	Sand fencing, brushing, and dune trapping	3	5	5	5	18
31	Rock filter units	3	2	3	3	11
32	Living speed bumps	2	3	2	4	11

The analysis produced a scoring pattern that reflects how well each option aligns with local preferences for sandy, natural-looking beaches. However, the scores also reinforce that no single measure is likely to resolve chronic erosion on its own, and a combination of complementary options will most likely be required over time.

Dune and sand management measures scored highest overall. Dune enhancement and revegetation (Option 7) and sand fencing, brushing, and dune trapping (Option 22) both scored 18, driven by very strong environmental and social performance and low whole-of-life costs, while acknowledging that their effectiveness depends on correct placement, access control, and ongoing maintenance. The core sand supply measures formed the next cluster: beach-face nourishment (Option 1) and large-scale sand nourishment (Option 3) scored 13, reflecting strong technical fit and social acceptability, moderated by temporary disturbance, approvals constraints in sensitive settings, and the need for ongoing operational governance. Backpassing (Option 5) scored 12 due to donor-site limitations, while beach scraping (Option 6) scored 13 and is best treated as a post-storm recovery tool under defined triggers rather than a primary stabilisation measure.

Mid-range options can strengthen the portfolio in targeted locations. Hybrid seawall-dune systems (Option 20) scored 15, suggesting buried structures can protect priority assets while maintaining a sandy frontage, but only if sand cover can be reliably maintained through monitoring and replenishment triggers. By contrast, more structural or offshore concepts tended to score lower once environmental and social feasibility were weighted, with multipurpose artificial reefs and submerged breakwaters (Options 9 and 10) scoring 8 and groynes (Options 11 and 12) scoring 9-10, reflecting cost, uncertainty, approvals complexity, and social licence risks.

Overall, the scoring supports a combined pathway: pair sand supply and sediment continuity measures (Options 1, 2, 3, 4, and Option 5 where feasible) with dune-building and access management (Options 7 and 22), use beach scraping (Option 6) tactically after storms, and add selective asset-protection layers such as a hybrid seawall-dune system (Option 20) where needed and where a credible sand-cover management pathway exists.

The complete feasibility assessment can be viewed in Appendix C, Table C-2.

5 RECOMMENDATIONS OF ALTERNATIVE ADAPTATION OPTIONS

Based on the feasibility ranking (Table 4), the recommended approach for Joondalup is not to select a single “best” option, but to build a combined portfolio in which high-scoring measures provide the dependable foundation, and mid-ranked measures are used selectively to solve specific problems the foundation cannot solve on its own.

Here local context matters, because the most suitable mix can vary substantially along the coastline depending on sediment pathways, access and staging constraints, existing management practice, and approvals sensitivities; in some locations, sand bypassing may be the most practical backbone option where established systems and pathways already operate, whereas in other locations beach-face nourishment, backpassing from nearby accretion areas, or a hybrid dune layer may be more appropriate. While dune enhancement and revegetation (Option 7) and sand fencing and dune trapping (Option 22) score very strongly and should be treated as essential enabling measures, they are not sufficient by themselves because they do not add sediment to the active coastal system.

The portfolio therefore needs a deliberate “sand supply backbone” to restore and maintain beach volume under ongoing erosion and sea level rise, supported by monitoring, triggers, and clear operational rules. In practice, this means pairing the dune program with repeatable sand-addition and redistribution measures such as beach face nourishment (Option 1), shoreface or nearshore nourishment (Option 2), large scale beach nourishment (Option 3) sand bypassing (Option 4), or backpassing (Option 5), using beach scraping and re-profiling (Option 6) as an operational recovery tool after storm events.

Other options should remain available as targeted control or energy-management interventions, used only where evidence indicates the sand program alone will not meet objectives in persistent hotspots or where critical assets need additional protection. This includes hybrid seawall-dune systems (option 20) as a concealed “insurance layer” in constrained locations, and selective nearshore structures such as multipurpose artificial reefs (option 9) or other low-visibility concepts progressed as staged, monitoring-led pilots to test whether they measurably improve sand retention or reduce wave-energy concentration without unacceptable impacts.

Higher trade-off structural controls such as groynes (Options 11 and 12) or offshore breakwater concepts (Options 10 and 17) can be considered as potential targeted control points, but only as part of an explicitly packaged solution that includes sand management, clear performance objectives, and an adaptive pathway that manages side effects and social licence. In this framing, the feasibility ranking is best interpreted as guidance on what is easiest to deliver and scale, not a prescription of what to build; the decision focus should be on assembling combinations that together provide sand, preserve amenity, and, where needed, add carefully located control points that increase efficiency and resilience. The final ranking of options is provided in Table 4 below.

Table 4. Final ranking of options

Ranking	Option	Score	
1	Dune enhancement / revegetation	18	Essential enabling layer that strengthens the dune buffer, improves post-storm recovery, and delivers strong ecological and social outcomes; best paired with sand supply measures.
2	Sand fencing, brushing, and dune trapping	18	Low-cost dune building and recovery support that helps retain benefits between sand campaigns; depends on correct placement, access control, and ongoing maintenance.
3	Hybrid seawall dune-system	15	Selective asset-protection layer that maintains a sandy frontage if kept buried; performance depends on reliable sand cover, monitoring, and replenishment triggers under sea level rise.
4	Sand bypassing	14	Restores sediment continuity where transport is interrupted; can reduce reliance on hard controls; requires repeat operations, monitoring, and clear operational governance.
5	Beach face nourishment	13	Core on-beach sand addition to rebuild beach width and storm buffer; repeatable but dependent on sand source, access, approvals, and ongoing campaign planning.
6	Shoreface or nearshore nourishment	13	Sand placement offshore to reduce on-beach disruption; outcomes and approvals can be more complex in sensitive marine settings and require monitoring and adaptive management.
7	Large scale sand nourishment projects	13	Larger-volume campaigns that can create a longer-lasting buffer where continuous frontage and reliable supply exist; requires staging areas, approvals, and monitoring.
8	Beach scraping and re-profiling	13	Tactical post-storm recovery tool to rapidly rebuild buffers under defined triggers and limits; not a primary long-term stabilisation measure.
9	Backpassing and enhanced backpassing	12	Operational sand redistribution that can support targeted hotspots where suitable donor areas exist; constrained by donor availability and risk of shifting impacts to the borrow site.
10	Rock filter units	11	Localised or interim toe/transition protection and emergency response option; not a whole-of-frontage erosion solution and may face approvals constraints near sensitive habitats.
11	Living speed bumps	11	Pilotable nearshore roughness concept intended to reduce wave-energy concentration at hotspots; benefit is uncertain on exposed coasts and requires modelling and clear success criteria.
12	Rock groynes	10	Technically able to trap sand but can displace impacts downdrift and impose ongoing governance burdens; generally low social licence due to visible planform control.
13	Sloping rock revetments and seawalls	10	Asset protection option with clear constructability; still entails trade-offs for beach width and amenity and needs careful siting and overtopping/transition management.
14	Geofabric groynes	9	Potential trial-scale control with some reversibility; still carries transport disruption risks and reputational issues if exposed, damaged, or poorly maintained.

15	Multipurpose artificial reefs	8	High design sensitivity and uncertain measurable shoreline benefit; best treated, if at all, as a staged pilot only where modelling indicates clear retention benefits.
16	Submerged breakwaters and low-crest barriers, incl. submerged islands	8	High cost and environmental uncertainty with acceptance risks; only progress where modelling shows clear net benefit and impacts are manageable.
17	Vertical seawalls	8	Proven to protect assets but high trade-offs for beach amenity and approvals; best treated as a targeted last-resort protection measure in constrained locations.
18	Detached breakwaters	8	Potentially effective but typically low environmental and social feasibility; high trade-off option with major approvals complexity and amenity impacts.
19	Offshore islands	8	Transformative, high-cost concept with significant ecological, circulation, and social licence risks.

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Appendix B Adaptation Options Used in Other Contexts

Table B-1. List of adaptation options from the Queensland Compendium (Griffith University and GHD, 2012)

Category	Option
Regenerative options	Beach nourishment
	Dune construction and regeneration
	Riparian corridors restoration and generation
	Wetland restoration
Coastal engineering options	Artificial reefs
	Detached breakwaters
	Groynes and artificial headlands
	Sea dykes or levees
	Seawalls
	Storm surge barriers
Coastal settlement design options	Building retrofitting and improved design
	Flood resilient public infrastructure
	Raise land and floor levels
Planning options	Development setbacks
	Land buy-back
	Land swap

Table B-2. Victorian Compendium of Coastal Adaptation Options (BMT, 2023)

Functional type	Category	Adaptation Action
Land management, planning and design	Land use	Land acquisition, swap, lease-back
		Controlled access
		Planning scheme zone change
		Planning overlays
		Rolling easements
		Removal / relocation of infrastructure
	Resilient design / development	Development setbacks
		Use of resilient materials and design in new and retrofitted infrastructure
	Cultural landscapes	Survey, document, salvage, other*
Nature-based (Nature-based methods use the creation of restoration of coastal habitats for hazard risk reduction[1])	Coastal vegetation and blue carbon ecosystems	Mangrove forests
		Seagrass meadows
		Salt marsh
		Kelp forests
	Beach and dune ecosystems	Beach and dune protection / vegetation / management
		Use of on-site natural materials to reduce erosion
		Wet sand fencing
		Supported littoral vegetation**
Engineering	Nourishment**	Localised beach scraping / dune nourishment / reconstruction
		Beach nourishment
		Sand by-pass system

Functional type	Category	Adaptation Action
	Reefs**	Shellfish reefs
	Dredging	Configuration dredging
	Seawalls	Vertical seawalls
		Eco-engineering of hard surfaces
		Rock revetments
		Geobag revetment / wall
		Rock bag revetment / wall
	Groynes	Groynes (rock, geobag, other)
	Breakwaters	Breakwaters
	Flood/tidal barriers	Levees / dykes
		Tidal / surge barriers
		Tidal valves on stormwater system
		Saline groundwater intrusion barrier
	Drainage	Upgrade of drainage network
		Water sensitive urban design
	Road network	Upgrade of road network

**As led by Traditional Owners - guidance should be sought directly from local groups.*

***May be considered a hybrid engineering and nature-based action, pending detail of the approach*

Table B-3. Characteristics of measures for flexible management of natural areas (Source: Baills et al. 2020)

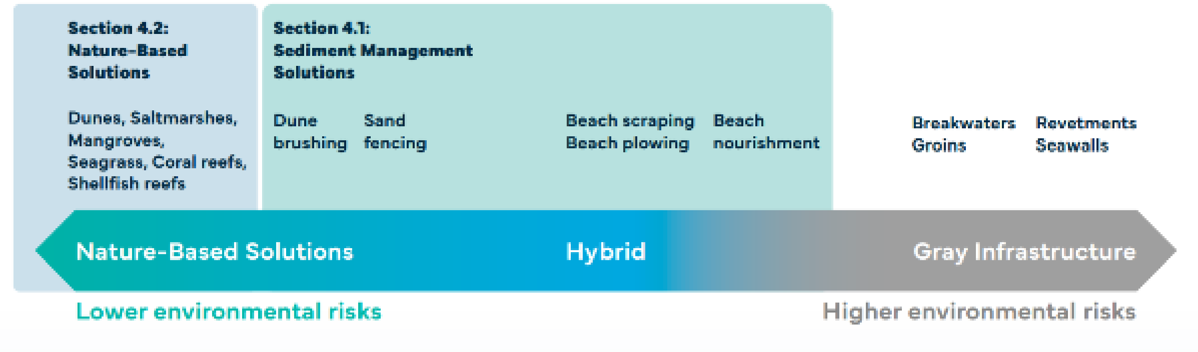
Coastal management approaches	Adaptation measures	Characteristics		
		Physical-environmental	Socio-economic	Institutional
Natural evolution under monitoring (coastal flooding and erosion)	• Creation of monitoring network/ observations	✓	✓	✓
Accompaniment of natural processes	• Sand fences, windbreaks nets, branches, etc.	✓		
	• Cliff foot palisade	✓		
	• Revegetation (on dunes, cliffs, etc.)	✓		
	• Wetland restoration, de-polderisation	✓		
	• Beach access management		✓	✓

Coastal management approaches		Adaptation measures	Characteristics: Physical-environmental	Characteristics: Socio-economic	Characteristics: Institutional
Hazard mitigation (flooding)		• Retreat or removal of existing defences	✓		
		• Wetland restoration, de-polderisation	✓		
		• Second line levee / dyke	✓		
Counteracting a hazard (flooding)		• Dunes restoration or reconstruction / artificial sand dunes	✓		
		• Adjustment/increased height/ creation of hard engineered structures ○ Walls ○ Backshore riprap ○ Breakwaters (natural, artificial, submerged or not; including artificial reefs) ○ Stakes ○ Dykes, dyke embankments, multi-line dykes, etc. ○ Hybrid solutions	✓		
		• Temporary defences	✓		
		• Temporary storm surge dams	✓		
		• Limiting actions liable to cause subsidence (water, gas and oil pumping, etc.)	✓		✓
Soft engineering to control erosion		• Beach and/ or dune nourishment	✓		
		• Beach drainage	✓		
Hard engineering to control erosion	Sandy coast	• Adjustment/increased height / creation of hard engineered structures ○ Groynes ○ Breakwaters (natural, artificial, submerged or not) ○ Stone walls ○ Fence at dune foot ○ Backshore riprap ○ Stakes ○ Dykes ○ Hybrid solutions	✓		
	Sandy coast	• Retreat or removal of existing defences	✓		
	Sandy coast	• Geotextiles, geotextiles tubes & geobags[i]	✓		
	Rocky coast	• Reprofiling	✓		
	Rocky coast	• Adjustment/ increased height / creation of hard engineered structures ○ Riprap at cliff foot ○ Retaining walls ○ Groynes ○ Stone walls ○ Cliff strengthening ○ Terraces building	✓		
	Rocky coast	• Cliff drainage	✓		
	Rocky coast	• Anti-runoff and anti-infiltration devices at cliff top	✓		

Coastal management approaches		Adaptation measures	Characteristics		
			Physical-environmental	Socio-economic	Institutional
Reducing vulnerability to coastal flooding and coastal erosion	Actions on buildings (coastal flooding)	• Flood-proofed buildings (dry or wet)	✓		
		• Floating or amphibious anchored houses	✓		
		• Elevated ground floor	✓		
		• Stilt buildings	✓		
		• Removable buildings	✓		
		• Boat houses	✓		
		• Water and salt insensitive materials	✓		
		• Suitable positioning of utilities networks (electrical, drinking water, sewage ...)	✓		
	Actions on buildings (coastal erosion)	• Removable buildings	✓		
	Other measures to reduce vulnerability	• Building standards adapted to hazard exposure			✓
		• Artificial raising of ground (e.g. artificial islands, mounds under buildings)	✓		
		• Strategic retreat	✓	✓	✓
		• Establishment of land management program (e.g. for land exchanges)		✓	✓
		Crisis management plan :			
		• Council protection plan			✓
		• Height of emergency exits of buildings adapted to the water level expected for a given hazard level	✓		✓
		• Emergency roads raised above the water level expected for a given hazard level	✓		✓
		• Protection of strategic or risk-prone buildings or areas	✓		✓

Coastal management approaches		Adaptation measures	Characteristics		
			Physical-environmental	Socio-economic	Institutional
All	Knowledge	• Monitoring network and/or coastal observatories	✓	✓	✓
		• Hazard and vulnerability mapping		✓	✓
		• Sediment management plan at the hydro-sedimentary cell scale			✓
		• Research network and conferences		✓	
	Education	• Natural risk and climate change training		✓	
		• Research network and conferences		✓	
		• Risk awareness, urban planning, strategic retreat, etc.		✓	
	Information	• Creation of early warning systems	✓	✓	✓
		• Climate services	✓	✓	✓
		• Consultations		✓	
		• Media communication		✓	
	Urban planning	• Integration of climate change and its effects on coastal hazards in urban planning and documents		✓	✓
		• Prohibit building in hazardous areas and preserve buffer zones		✓	✓

Table B-4. Nature-based Solutions for Beach Stabilisation as Opportunities for the Tourism Sector - Report to World Bank (2025)



Appendix C Complete SWOT Analysis

Table C-1. Complete SWOT Analysis

Option	Advantages (Strengths + Opportunities)	Disadvantages (Weaknesses + Threats)	Examples and whether successful	Proceed to feasibility study?	Rationale
1. Beach face nourishment	**Strengths**: Rapidly increases dry-beach width and storm buffer while preserving sandy amenity and access. Opportunities: Suits flexible, trigger-based delivery and can be integrated with dune management, and emerged and submerged defences.	**Weaknesses**: It can be short-lived on high-energy coasts unless repeated every 5-10 years; performance depends on sand compatibility and placement design. Threats: Sand sourcing, approvals, costs, and storm sequencing can reduce longevity and public confidence. Additional threats: sand source availability/quality and escalating costs as demand increases; potential marine impacts (e.g., seagrass smothering, reef and benthic habitat impacts); logistics and access constraints for trucks or dredge vessels due to limestone cliffs and shallow reef systems.	Widely applied internationally with consistent short-term widening benefits (USACE 2007; AECOM 2010) – generally successful, maintenance-dependent over time.	Yes	Well-established, flexible sand-based measure that directly addresses erosion while aligning with community preference for sandy beaches, despite ongoing maintenance needs.
2. Shoreface or nearshore nourishment	**Strengths**: Low-visibility placement that maintains natural beach character and can reduce on-beach disruption compared to beach placement. Opportunities: Can be refined through monitoring of berm migration and beach response to improve reliability as part of a sand-led strategy.	**Weaknesses**: Benefits are slower and less visible; outcomes are sensitive to depth, berm geometry, and seasonal wave climate. Threats: Delayed onshore migration can be perceived as underperformance; offshore environmental constraints may limit design flexibility. Additional threats: placement within/adjacent to Marmion Marine Park may require more complex approvals than beach-face works; sand source availability/quality and cost; potential marine impacts (seagrass, reef and benthic habitat); logistics/access constraints due to limestone cliffs and shallow reef systems.	Feeder berms widened beaches in energetic settings including Ocean Beach (San Francisco) and Harvey Cedars (New Jersey) (Barnard et al. 2009; McGill et al. 2022) – generally successful when well designed and monitored.	Yes	Low-visibility sand management option with demonstrated success when well designed, suitable for testing under local conditions despite slower response times.
3. Large scale sand nourishment projects	**Strengths**: Larger, less frequent sand campaigns can lower unit costs and provide a longer-lasting beach buffer, supporting amenity and storm resilience when designed for local processes.	**Weaknesses**/Threats: Requires a reliable long-term sand source, access/staging areas and a clear approvals pathway; larger footprints and longer construction windows can increase turbidity/ecological impacts and community disruption; performance still depends on placement geometry and wave climate and will require monitoring-led top-ups under SLR.	Implemented widely on exposed sandy coasts (often >100,000 m³ per campaign); successful where sand compatibility, placement design and monitoring-based triggers are in place.	Yes	Explicitly assessed per City request; progressed to feasibility because it can improve cost-efficiency and durability of sand-led pathways, subject to sand-supply strategy, approvals and impact management.
4. Sand bypassing	**Strengths**: Restores sediment continuity around interruptions, supporting downdrift beach condition with minimal visual footprint. Opportunities: Can be formalised as a routine operational program guided by monitoring and triggers.	**Weaknesses**: Requires ongoing operational capacity, access, and stable funding; does not add new sand unless paired with external sources. Threats: Operational interruptions can quickly reduce effectiveness and perceived reliability.	Long-running Australian programs demonstrate reliable outcomes when guided by monitoring and performance triggers (CoastAdapt 2016; GCWA 2025) – generally successful where interruption drives erosion.	Yes	Proven and locally relevant method to restore sediment continuity where infrastructure interrupts drift, with strong alignment to existing management frameworks.
5. Sand backpassing and enhanced backpassing	**Strengths**: Recirculates sand within the coastal cell from accreting to eroding areas, reducing reliance on external borrow sources. Opportunities: Enhanced approaches (harvest zones, triggers, tracking) can improve efficiency and confidence, and target hotspots.	**Weaknesses**: Depends on sustainable donor volumes and workable logistics; may require repeated campaigns. Threats: Perceived impacts to donor areas or poor timing can reduce acceptance and operational feasibility. Key constraint: requires a local donor sand source or accreting beach with a reliable surplus; limited suitable borrow areas can reduce feasibility and increase costs.	Backpassing is effective where donor areas reliably accrete and operations are optimised (Vieira da Silva et al. 2021; Beck et al. 2020; Harry 2022; Harry et al. 2023) – generally successful in suitable donor/receiver settings.	Yes	Efficient use of internal sand resources where donor areas exist, reducing reliance on external sources and supporting adaptive hotspot management.

6. Beach scraping and re-profiling	**Strengths**: Simple, low-cost, visually unobtrusive way to rebuild berms/foredune toe and restore access after storms. Opportunities: Useful as a short-term recovery tool within a broader nourishment and dune program.	**Weaknesses**: Redistributes existing sand only, so benefits are temporary and not suitable as a standalone erosion solution. Threats: Overuse or poor safeguards can create ecological impacts or unintended local deficits.	Studies and practice reviews show short-term recovery benefits when carefully managed with safeguards and monitoring (Pellón et al. 2024; Carley & Cox 2011) – generally successful as an interim tool.	Yes	Low-cost, short-term recovery tool that complements broader sand and dune strategies, appropriate for inclusion despite limited standalone effectiveness.
7. Dune enhancement / revegetation	**Strengths**: Low-visibility, community-aligned measure that strengthens the dune buffer and supports ecological and recreational values. Opportunities: Provides a baseline measure that complements nourishment, access management, and storm recovery.	**Weaknesses**: Cannot resolve chronic sediment deficits alone and requires ongoing maintenance and space to function. Threats: Storm clustering and sea level rise can outpace recovery if sand volumes and access controls are not sustained.	Dune resilience literature supports revegetation and access management as effective baseline measures when maintained (Nordstrom et al. 2020; Harley et al. 2022) – generally successful, maintenance-dependent.	Yes	Foundational, low-impact measure that supports resilience and amenity, suitable as a supporting element even though it cannot resolve chronic erosion alone.
8. Mega-nourishments	**Strengths**: Creates a long-lasting sand source that feeds adjacent beaches over years, reducing frequency of smaller campaigns. Opportunities: Potential for broader recreational and ecological co-benefits and reduced lifecycle intervention frequency.	**Weaknesses**: Requires very large volumes and suitable placement space; distribution of benefits can be uneven through time. Threats: High upfront cost, complex approvals, and uncertainty in redistribution under storm variability and rising sea levels.	The Netherlands Sand Engine is the benchmark mega-placement with multi-year redistribution benefits (Stive et al. 2013; Flikweert et al. 2023) – successful at large scale, context-specific.	No	Scale, cost and approval complexity outweigh benefits for a segmented urban coastline.
9. Multipurpose artificial reefs	**Strengths**: Low-visibility wave attenuation and nearshore stabilisation potential while retaining beach aesthetics; can support habitat and surf objectives if designed appropriately. Opportunities: Can enhance nourishment effectiveness and improve social licence via recreation and ecological co-benefits.	**Weaknesses**: Highly design-sensitive and typically cannot replace ongoing sediment supply. Threats: Ecological approvals and surf-quality concerns can limit feasibility; unexpected circulation or morphology responses can undermine acceptance. Additional weaknesses/threats: can displace erosion alongshore and, in some settings, exacerbate erosion or shoreline retreat; requires robust understanding of local coastal dynamics supported by field observations and detailed numerical modelling to avoid unintended impacts.	Narrowneck Reef and Palm Beach Reef show reefs working alongside nourishment with long-term monitoring (Jackson et al. 2012; Mortensen et al. 2015; Brullo et al. 2024) – generally successful when embedded in sediment management.	Yes	Demonstrated ability to work alongside nourishment while retaining amenity and offering co-benefits, warranting feasibility testing despite design sensitivity.
10. Submerged breakwaters and low-crest barriers (incl. submerged islands)	**Strengths**: Low-crest underwater controls can attenuate waves and steer nearshore morphology with reduced visual intrusion. Opportunities: Can act as morphodynamic stabilisers to improve sand-led management outcomes in persistent hotspots.	**Weaknesses**: Outcomes are highly sensitive to crest level, spacing, and distance from shore; generally still require ongoing sand supply. Threats: Risks include altered circulation, scour, and surf impacts without robust modelling and monitoring. Additional weaknesses/threats: can displace erosion alongshore and, in some settings, exacerbate erosion or shoreline retreat; requires robust understanding of local coastal dynamics supported by field observations and detailed numerical modelling to avoid unintended impacts.	Global reviews highlight variable performance and emphasise governance, modelling and monitoring (Williams et al. 2018; EcoShape 2025) – mixed to successful depending on design and setting.	Yes	Potential to stabilise nearshore morphology with limited visual impact, but requires feasibility testing due to high design and modelling sensitivity.
11. Rock groynes	**Strengths**: Can trap sand and stabilise shoreline position locally by interrupting longshore transport, with relatively rapid response where drift dominates. Opportunities: If ever considered, governance plus bypassing/top-ups can reduce some adverse impacts.	**Weaknesses**: Can displace erosion downdrift and affect surf amenity and natural appearance. Threats: High social licence risk; cumulative downdrift impacts can be significant if bypassing is inadequate.	Guidance emphasises geometry sensitivity and downdrift risks unless coupled with bypassing/nourishment (Kristensen et al. 2016; CIRIA 2020; van Rijn 2013) – mixed outcomes, strongly context dependent.	Yes	Included for transparency and completeness given community interest, but feasibility testing is needed to fully understand impacts and risks in this context.

12. Geofabric groynes (geotextile sand container groynes)	**Strengths**: Potentially lower-impact and reconfigurable alternative to rigid groynes, offering flexibility if impacts emerge. Opportunities: May be used as trial/pilot units supporting nourishment where reduced permanence is valued.	**Weaknesses**: Durability and maintenance demands can be higher; still alters sediment transport and can create downdrift impacts. Threats: Exposure/damage can create reputational issues; acceptance may drop if materials become visible.	Used in Australia including Busselton/Geographe Bay contexts (Hornsey et al. 2011) – mixed performance; maintenance and setting strongly influence success.	Yes	More flexible and potentially reversible alternative to rock groynes, suitable for feasibility testing despite durability and maintenance uncertainties.
13. T/Y head groynes	**Strengths**: Can shape beach planform and potentially reduce visual clutter versus long groyne fields by moderating gradients and diffraction effects. Opportunities: May achieve stabilisation with fewer structures if integrated with sediment supply and modelling.	**Weaknesses**: Still requires sediment sources and careful modelling; can create complex currents and local scour. Threats: Downdrift deficit risk persists; visible structures may face strong opposition.	Design guidance highlights diffraction-aware modelling and sediment budget integration (Hardaway & Gunn 2010; Hsu 2010; Nam et al. 2011) – mixed outcomes, design-sensitive.	No	Adds structural complexity and visual impact without clear advantages over simpler groyne or sand-based options, making it lower priority for further study.
14. Vertical seawalls	**Strengths**: Reliable asset protection and erosion line control at the structure boundary where space is constrained. Opportunities: Can be paired with sand buffers and staged crest-raising, and may be less objectionable if buried beneath maintained nourishment.	**Weaknesses**: Often contributes to beach narrowing by constraining landward beach migration; can increase reflection, scour and overtopping hazards. Threats: Under sea level rise, loading and overtopping risk increases and beach amenity can progressively decline unless ongoing sand management is maintained.	Guidance and reviews document strong asset-defence performance but consistent beach-width trade-offs without sand buffers (EurOtop 2018; Griggs 2019; Allan et al. 2005; Allan et al. 2025; Nawarat et al. 2024) – successful for assets, mixed for beaches/amenity.	Yes	Progressed for feasibility assessment due to proven asset protection performance and existing use along the coastline; high trade-offs remain (beach narrowing, reflected wave energy, amenity), so should be treated as a comparator and targeted hotspot option.
15. Sloping rock revetments and seawalls	**Strengths**: Robust, well-established protection approach that dissipates wave energy more than vertical walls and can be designed for maintainability. Opportunities: Can be “softened” with sand buffers, toe management, and ecological detailing where appropriate.	**Weaknesses**: Footprint can be large, often reduces usable beach width at higher tides, and can affect access and amenity. Threats: Toe scour, settlement, and increasing overtopping with sea level rise can drive escalating maintenance and widening impacts.	Common globally for asset protection; performance is typically strong for defence but often associated with beach-amenity trade-offs unless paired with sand buffers (EurOtop 2018; Griggs 2019) – successful for assets, mixed for beach outcomes.	Yes	Progressed for feasibility assessment due to proven ability to protect assets and compatibility with existing armouring at some locations; trade-offs include footprint, beach narrowing and long-term SLR adaptability, so assessment should focus on targeted applications and mitigation of impacts.
16. Sea dikes	**Strengths**: High standard of flood protection for low-lying land and critical assets; can be staged (raised) over time. Opportunities: Where relevant, can integrate pathways/landscape uses and be designed as part of broader flood-risk management.	**Weaknesses**: Very large, continuous infrastructure with major footprint and landscape impacts; requires strong geotechnical design and long-term governance. Threats: High cost, high social impact, and residual risk from overtopping/breach under extreme events; may conflict with beach amenity objectives.	Applied widely in low-lying delta settings; generally effective for flood defence when well-governed, but often high-impact and context-specific (examples to be confirmed in references list).	No	Large-scale, high-impact infrastructure better suited to low-lying deltaic settings than an open sandy coast focused on beach amenity.

17. Detached breakwaters (emerged, shore-parallel; incl. fields)	**Strengths**: Strong wave attenuation and shoreline planform control; can promote salients/tombolos and improve retention where sand supply exists. Opportunities: Could be tuned (segments/freeboard/gaps) and combined with nourishment to target specific hotspots.	**Weaknesses**: Visually prominent, can alter currents and access; high sensitivity to geometry and gaps. Threats: Downdrift erosion risk if bypassing is not provided; high social licence and ecological risks where amenity and marine values are priorities.	International examples illustrate variable outcomes and need for site-specific calibration (Ming & Chiew 2000; Jackson et al. 2015) – mixed to successful, higher side-effect risk.	Yes	Strong erosion control potential and included to assess whether design refinements could mitigate known social and environmental risks.
18. Offshore Islands (emerged, segmented shore-parallel elements)	**Strengths**: Can create wave-shadow zones and sheltered compartments, shaping deposition patterns and reducing wave energy landward. Opportunities: If ever considered, could be designed for multi-use (habitat/recreation) with careful spacing and objectives.	**Weaknesses**: Strongly modifies currents and sediment pathways; visually prominent and complex to design. Threats: Permitting/navigation risks and high uncertainty without detailed modelling; potential downdrift deficits and scour.	Used internationally in select settings; outcomes are design- and setting-dependent (examples to be confirmed in references list).	Yes	Conceptually relevant for wave shadowing and compartment control, warranting feasibility testing despite high complexity and uncertainty.
19. Artificial headlands	**Strengths**: Anchors compartments and guides toward an equilibrium bay planform, potentially reducing longshore gradients. Opportunities: Can support recreation and place-making if integrated with nourishment and clear design objectives.	**Weaknesses**: Requires careful modelling and sediment supply; can induce downdrift deficits and local scour. Threats: Visible "hardening" can reduce acceptance; unexpected planform responses can undermine confidence.	Headland-bay approaches and examples highlight the need for site-specific calibration (Hsu 2010; Hardaway & Gunn 2010) – mixed outcomes, context dependent.	No	Provides limited advantage over other compartment-based options while carrying higher costs and similar visual and sediment risks. More suitable in urban settings.
20. Hybrid seawall-dune system	**Strengths**: Concealed "last line of defence" maintains sandy appearance while providing backup protection during extremes. Opportunities: Supports staged adaptation, pairing routine nourishment, dune management and monitoring to maintain sand cover and manage exposure risk.	**Weaknesses**: Requires reliable sand supply to remain buried; if sand declines it behaves like exposed armouring. Threats: Sea level rise increases exposure frequency and maintenance needs; acceptance may fall if the structure becomes visible.	Common in long-running integrated systems sustained by ongoing nourishment and monitoring (EurOtop 2018; Griggs 2019) – successful where sand supply and governance are sustained.	Yes	Balances asset protection with maintained sandy appearance, aligning with staged adaptation despite reliance on sustained sand supply.
21. Dynamic cobble-berm revetments	**Strengths**: Self-adjusting cobble berm can dissipate storm energy and reduce runup while allowing a more "natural" dynamic response than rigid armouring. Opportunities: Targeted hotspot use may reduce storm erosion where sand-only measures underperform.	**Weaknesses**: Requires suitable cobble supply and careful calibration; can affect access and perceived beach character. Threats: Acceptance risk if cobbles are frequently exposed; uncertain performance if not matched to local hydrodynamics.	Recent studies report storm resilience when calibrated; North Cove (Washington) is a cited example (Bayle et al. 2021; Gostic et al. 2024; Bond et al. 2025) – promising but site-specific.	No	Promising but highly site-specific and disruptive to beach character, making it unsuitable for further consideration at this stage.
22. Wet-sand fencing, brushing, and dune trapping	**Strengths**: Low-cost method to accelerate aeolian sand capture when positioned and maintained appropriately. Opportunities: Can build dune volume between nourishment cycles and support recovery after storms when integrated with access management and planting.	**Weaknesses**: Effectiveness depends on wind regime, placement and maintenance; not suitable as a standalone response to major recession. Threats: Storm damage, vandalism and inconsistent maintenance can quickly reduce performance; access/aesthetics concerns may arise.	Guidance notes best performance when located above swash zone and maintained after major events (Environment Agency 2020; Eichmann 2021; NRC Solutions n.d.) – generally successful where conditions and maintenance are suitable.	Yes	Low-cost, low-impact support measure that enhances dune recovery and complements nourishment, suitable for inclusion in feasibility assessment.

23. Beach drainage and dewatering	**Strengths**: Low-visibility approach intended to reduce backwash erosion by lowering groundwater beneath the beach. Opportunities: If effective locally, could complement sand management by improving post-storm recovery.	**Weaknesses**: Evidence is mixed and outcomes are inconsistent, especially on energetic coasts; requires power and ongoing maintenance. Threats: Reputational risk if benefits are unclear; potential permitting and environmental concerns depending on groundwater interactions.	Reviews report mixed, site-specific performance and inconsistent outcomes (Schoonees et al. 2019; van Rijn 2013; Medina et al. 2021) – overall mixed success.	No	Evidence of effectiveness is inconsistent on high-energy coasts, creating reputational and performance risk.
24. Wave energy converters (WECs)	**Strengths**: Potential multi-benefit proposition combining renewable energy with possible wave attenuation. Opportunities: Could attract innovation partnerships and pilot funding if coastal protection performance can be demonstrated.	**Weaknesses**: Coastal protection is not the primary design objective; attenuation benefits are uncertain; survivability and maintenance demands are high. Threats: Navigation/permitting constraints and high cost/maintenance risk; reputational risk if shoreline benefits are not measurable.	Literature discusses potential attenuation co-benefits but highlights uncertainty for shoreline outcomes (López et al. 2022; Battista et al. 2024) – coastal protection success uncertain.	No	Coastal protection benefits are uncertain and secondary to energy generation, making it unsuitable for erosion-focused feasibility work.
25. Floating wave energy dissipators	**Strengths**: Potentially reduces incident wave energy with limited seabed disturbance and can be removed/adjusted; may offer niche applications for temporary protection during works.	**Weaknesses**/Threats: Evidence gap for open-coast, high-energy performance and survivability; high capital and O&M for moorings/maintenance; navigation, safety and recreation constraints; likely visual/space impacts and uncertain long-term erosion benefits.	Most applications are in sheltered waters; open-coast concepts remain largely experimental with limited field validation for shoreline outcomes.	No	Assessed per City request; progressed to feasibility as an emerging option, but expected to score low for open-coast erosion management due to survivability and evidence constraints.
26. Purpose-sunk reef and habitat modules	**Strengths**: Strong habitat and education/tourism benefits in suitable locations; may create local roughness and shelter effects. Opportunities: Can align with biodiversity objectives if sited appropriately with clear performance targets.	**Weaknesses**: Coastal protection benefit is often secondary and limited on open, high-energy coasts; effectiveness depends on scale and placement. Threats: High permitting/navigation constraints; reputational risk if positioned as erosion control without measurable shoreline outcomes.	Evidence generally shows stronger success for habitat than for open-coast erosion control (Rani et al. 2025; Storlazzi et al. 2025).	No	Strong ecological value but limited and unreliable erosion control benefit on exposed open coasts.
27. Mangrove restoration	**Strengths**: Strong wave attenuation and erosion reduction in suitable sheltered settings with major ecological co-benefits. Opportunities: Multi-benefit nature-based adaptation pathway where conditions and climate are suitable.	**Weaknesses**: Generally not applicable to temperate exposed open-ocean sandy coasts. Threats: High failure and reputational risk if proposed outside viable ranges or energy settings.	Strong performance documented for sheltered settings; not intended for exposed temperate open coasts (Narayan et al. 2016).	No	Not physically or climatically suitable for a temperate, high-energy open-ocean coastline.
28. Seagrass restoration	**Strengths**: Can support seabed stability and reduce resuspension in suitable environments while delivering biodiversity and water-quality co-benefits. Opportunities: Potentially relevant in sheltered pockets as a complementary measure supporting ecological objectives.	**Weaknesses**: Establishment is sensitive to light, substrate and water quality; protective benefits are limited where wave energy is high. Threats: High failure risk if conditions are unsuitable; long lead times may not match urgent erosion hotspot needs.	Evidence syntheses show coastal protection benefits primarily in suitable lower-energy settings (Narayan et al. 2016).	No	Not suitable as a standalone erosion-control measure on Joondalup's open coast, but important as marine habitat management (conservation and targeted restoration) within integrated coastal management where it supports nearshore stability and ecological values.

29. Living shorelines	**Strengths**: Nature-based approach that can reduce erosion while delivering ecological co-benefits and a natural shoreline interface in suitable settings. Opportunities: Strong social licence potential and multi-benefit framing where exposure is low or where hybridisation is feasible.	**Weaknesses**: Typically best suited to sheltered coasts and estuarine/bay environments; limited applicability on exposed open coasts. Threats: High risk of underperformance if applied outside suitable wave-energy settings; ongoing maintenance and approvals burdens.	Often successful in sheltered settings; not generally intended for high-energy open coasts (NOAA 2015).	No	Generally effective in sheltered settings only, with high risk of underperformance on exposed coastlines.
30. Living seawalls	**Strengths**: Retains structural protection function while improving ecological value and potentially social acceptability versus smooth, conventional walls. Opportunities: Can be applied as retrofit modules or design detailing where seawalls/revetments already exist or are unavoidable.	**Weaknesses**: Does not address underlying sediment deficits or beach-width loss where hardening constrains retreat. Threats: Added complexity/cost and maintenance; ecological outcomes can be underwhelming without appropriate site conditions and monitoring.	Growing portfolio of projects internationally (examples to be confirmed in references list) – generally promising for ecology; neutral on erosion unless paired with sand buffers/sediment management.	No	Improves ecology but does not address underlying erosion drivers or beach-width loss.
31. Rock Filter Units	**Strengths**: Permeable rock + filter-layer detailing can reduce seepage, manage transitions, and improve toe/scour resilience for armoured structures. Opportunities: Can be used as targeted “detail upgrades” at hotspots (toes, transitions, outfalls) rather than continuous hardening. Additional advantages: rapid deployment for emergency response; modular and adaptable in constrained sites; can serve as interim toe/transition protection where traditional rock placement is difficult.	**Weaknesses**: Primarily a structural detail rather than a shoreline-scale erosion solution; may still affect access/amenity if used extensively. Threats: Can be over-specified or misapplied; maintenance and settlement issues can emerge if foundation conditions are poor.	Commonly used as part of engineered revetment/toe protection systems (examples to be confirmed in references list) – generally successful as a durability/scour-management measure.	Yes	Progressed for feasibility assessment as a rapid-deployment, flexible interim/emergency protection measure (noting recent local trials and neighbouring council experience); assessment should test stability, maintenance and amenity impacts under Joondalup wave climate.
32. Living speed bumps	**Strengths**: Low-profile, relatively unobtrusive nearshore roughness features may reduce wave-energy concentration and support habitat objectives if eco-designed. Opportunities: Could be trialled as a pilot-scale, monitoring-led innovation where community preference favours minimal visible structures.	**Weaknesses**: Coastal protection benefit is uncertain and design-sensitive; may be too subtle to meaningfully influence open-coast erosion without scale. Threats: Underperformance risk without robust modelling and monitoring; permitting and ecological constraints may limit options.	Emerging concept with limited mature shoreline-protection track record (examples to be confirmed in references list) – promise likely higher for habitat and local wave-modification than for standalone erosion control.	Yes	Included as an innovative, low-visibility concept to test whether subtle nearshore roughness could deliver measurable benefits under local conditions.
33. Perched beaches (targeted for pocket beaches)	**Strengths**: Can help retain nourishment and maintain a wider dry beach by limiting offshore losses using a submerged sill/reef; low-visibility hybrid option suited to discrete hotspots and pocket beaches.	**Weaknesses**/Threats: Highly site-specific and design-sensitive; requires nearshore construction and approvals, with risks to habitat and currents; may still need periodic top-ups and careful monitoring under storm clusters and sea level rise.	Applied internationally as a hybrid (sill/reef + nourishment) to stabilise compartments; outcomes vary with geometry and local wave climate.	No	Assessed due to relevance for Joondalup pocket beaches; progressed to feasibility to test whether a low-profile control could materially improve sand retention without unacceptable impacts.

Table C-2. Complete Feasibility Assessment

#	Option	Technical feasibility	Score (Tech)		Environmental feasibility	Score (Env)		Economic feasibility	Score (Econ)		Social feasibility	Score (Social)	TOTAL	Integration / combinations	Comparison to groynes	Example location	Example publication
7	Dune enhancement / revegetation	W&S - strengthens foredune buffer and supports sand capture under strong sea-breeze conditions; B&C - aligns with existing dune-backed coast but does not by itself prevent high-energy beach erosion during storms; best as an enabling measure alongside sand supply and access management.	3		C&E - enhances native vegetation, biodiversity and connectivity along coastal strip; MP - supports sandy-beach interface without adding hard footprint.	5		Capital and O&M - low capex with ongoing maintenance and community programs; Proportionality - highly cost-effective for the risk reduction and co-benefits delivered.	5		CU&V - strongly aligned with community preference for natural sandy beaches; Recreation - works best with pathway management to maintain access while reducing trampling.	5	18	Foundation "base layer" that complements all sand measures and is essential to make hybrid dunes/buried systems socially and visually acceptable.	Does not replicate groynes' trapping, but improves buffering with minimal downside and high acceptability.	Many WA beaches; Gold Coast (QLD), numerous beaches in Australia.	Fernández-Montblanc et al. (2020); White et al. (2024); Ferreira (2023)
22	Sand fencing, brushing, and dune trapping	W&S - accelerates aeolian sand capture under strong sea-breeze conditions when correctly aligned and maintained; B&C - supports dune building and recovery but has limited direct effect on active beach-face erosion during high-energy events; best as part of a dune/access management program.	3		C&E - generally positive for dunes and native vegetation when combined with planting and access control; MP - minimal marine footprint and supports beach-dune resilience.	5		Capital and O&M - low capex and scalable; Proportionality - very cost-effective but requires consistent maintenance after storms and vandalism risk management.	5		CU&V - generally acceptable but can have local aesthetics/access trade-offs; Recreation - needs careful pathway design and communication to minimise conflicts and protect views/access.	5	18	Treat as a program embedded in dune enhancement and hybrid dunes; pairs strongly with nourishment and storm-recovery actions.	Does not replace groynes' trapping but supports a natural buffer with much lower downside and higher acceptability.	Numerous dune-fencing programs in Australia, UK, France and United States Atlantic coasts.	Eichmanns & Schüttrumpf (2021); Eichmanns et al. (2022).
20	Hybrid seawall-dune system	W&S - provides concealed "last line of defence" with sand/dune buffer under normal conditions; B&C - retains a beach-looking frontage if sand cover is maintained; CE - protects assets during extremes while the sand system provides day-to-day buffering; SLR - can be staged via crest raising but requires increasing sand management to keep buried.	4		C&E - if kept buried, reduces day-to-day ecological and visual impacts versus exposed armouring; MP - still a hard defence in principle and requires careful design to manage toe/scour and nearshore effects if exposed.	2		Capital and O&M - higher upfront cost than sand-only, but may be cost-effective where excavation is required anyway; O&M depends on maintaining sand cover (top-ups) rather than frequent structural works.	4		CU&V - strongly aligned where the structure remains buried and the frontage stays sandy/natural; Recreation - maintains access and amenity under normal conditions; requires transparent communication about triggers for exposure.	5	15	Best combined with routine nourishment, bypassing/backpassing, and dune management (including fencing/trapping) to maintain cover.	Compared to groynes, it offers asset security without forcing alongshore trapping, but it relies heavily on ongoing sand governance.	Gold Coast (QLD)	Nordstrom et al. (2020); Harley et al. (2022).

4	Sand bypassing	W&S - restores sediment continuity around interruptions; B&C - suited where structures/headlands disrupt alongshore transport; CE - directly relieves interruption-driven hotspots by re-establishing flux; SLR - operational triggers and volumes can adapt as shorelines retreat and levels rise.	4		C&E - localised disturbance at intake/discharge points but supports broader sediment balance; MP - impacts can be managed through siting, timing and monitoring.	3		Capital and O&M - moderate capital with ongoing operational costs; Proportionality - scalable effort suits municipal funding cycles.	4		CU&V - framed as sand recycling and beach-preservation; Recreation - short-term disruptions to beach access and use during excavation/transport, but long-term benefit to beach width and surf amenity.	3	14	Integrates with nourishment, backpassing, dune programs, and any structural option that needs sand cover.	Achieves sediment-continuity outcomes groynes try to force, but without adding new permanent structures.	Tweed River (NSW); Gold Coast (QLD).	CoastAdapt (2016); GCWA (2025).
1	Beach face nourishment	W&S - rapidly increases dry-beach width and storm buffer under Joondalup's high-energy winter swell climate; B&C - compatible with existing beach-dune system and does not introduce hard controls; CE - directly addresses erosion by adding sediment to the active profile; SLR - volumes and placement can be scaled and repeated over time to maintain buffers under 0.5–0.9 m SLR.	4		C&E - temporary turbidity and seabed disturbance, generally reversible with compatible sand and good practice; MP - careful sand sourcing/approvals needed to avoid long-term habitat impacts within/adjacent to Marmion Marine Park.	3		Capital and O&M - moderate to high campaign costs; unit costs depend strongly on sand source (purchase vs dredged vs existing). Proportionality - scalable, but recurring costs increase under tighter sand supply.	2		CU&V - preserves natural sandy appearance with no new visible structures; reliability may be questioned. Recreation - supports swimming/surfing/walking with manageable short-term disruption during works.	4	13	Core sand-led measure; pairs strongly with dunes, bypassing/backpassing, and can be used to keep buried systems covered.	Delivers beach width without fixed structures; less direct "trap" control than groynes but far higher adaptability and acceptance.	Many Australian and international beaches (campaign nourishment).	USACE (2007); AECOM (2010); Saengsupavanich et al., (2023) Oliveira et al. (2025)
2	Shoreface or nearshore nourishment	W&S - compatible with swell-dominated coasts where storms can drive onshore migration; B&C - maintains natural beach character with reduced on-beach disruption; CE - can augment the active profile and support recovery where designed at suitable depth/geometry; SLR - repeatable/scalable, but remains depth and climate sensitive.	4		C&E - temporary turbidity and seabed disturbance; MP - higher approvals complexity if placement is within/adjacent to Marmion Marine Park; requires careful siting to avoid sensitive habitats (e.g., seagrass/reef) and manage monitoring triggers.	2		Capital and O&M - moderate to high campaign cost plus monitoring (bathymetry and profiles); Proportionality - good where it reduces community disruption or improves lifecycle performance versus beach placement.	3		CU&V - low visibility supports social licence; Recreation - minimal long-term interference, but slower/less visible benefits require clear communication.	4	13	Works well with monitoring triggers; pairs with reefs/breakwaters to improve retention if justified; complements dune building.	Less intrusive than groynes and avoids direct transport interruption; relies on sediment processes rather than hard trapping.	Gold Coast (QLD) Ocean Beach (California, USA); Harvey Cedars (NJ, USA)	Barnard et al. (2009); Johnson et al. (2021); McGill et al. (2022); Huisman et al. (2019); González et al. (2023); van der Werf et al. (2025)

6	Beach scraping and re-profiling	W&S - tactical reshaping after storms (berm rebuild, foredune toe recovery) suited to Joondalup storm scarping; B&C - suitable where profiles are wide enough for limited landward redistribution; CE - short-term recovery only; SLR - opportunities may narrow as beaches reduce in width, increasing need for safeguards.	3		C&E - limited, reversible impacts if tightly controlled by volume, season and footprint; MP - repeated disturbance requires clear rules and monitoring to protect intertidal values.	2		Capital and O&M - low unit cost but repeat campaigns can accumulate; Proportionality - best used sparingly with triggers inside a broader sand program.	4		CU&V - seen as routine management if not overused; Recreation - quickly restores access and dry-beach usability, but needs clear communication and timing controls.	4	13	Adjunct to nourishment and dune measures; useful after storm clustering to rebuild buffers quickly.	Much less effective than groynes for stabilisation, but far less intrusive and valuable for rapid recovery.	Wooli Beach (NSW), Byron Bay (NSW)	Carley et al. (2010); Carley & Cox (2011); Pellón et al. (2024)
3	Large scale sand nourishment projects	W&S - increases buffer via large-volume campaigns; B&C - best suited to longer continuous sandy frontages; CE - can materially widen beaches and improve storm resilience if sand is compatible and placement is well designed.	4		C&E - larger footprint and longer works can increase turbidity and habitat disturbance at borrow/placement sites; MP - approvals and environmental management are central for marine-park-adjacent waters.	2		Capital and O&M - potentially lower unit cost than small campaigns, but high mobilisation and approvals; O&M - less frequent but still requires monitoring and occasional top-ups under SLR.	4		CU&V - supports sandy beach values but longer construction periods can disrupt access; social licence depends on clear communication of benefits, sand sourcing and impact management.	3	13	Fits as a backbone sand-supply option combined with dune management and targeted bypass/backpass.	Delivers beach width without hard controls; avoids groyne visual impacts but still requires ongoing sand governance.	Gold Coast (QLD); New Jersey (USA)	McGill et al. (2022); Barnard et al. (2009)
5	Backpassing and enhanced backpassing	W&S - relocates sand from accreting donors to eroding receivers; B&C - feasible only where reliable donor areas exist and harvest limits are sustainable; CE - constrained by limited suitable borrow sites on this coastline, reducing realism at scale.	3		C&E - localised disturbance but maintains sediment within system; MP - impacts manageable with operational controls and monitoring.	3		Capital and O&M - generally moderate and logistics-driven with repeat campaigns; Proportionality - strong where donor areas accrete reliably and access is workable.	3		CU&V - generally acceptable when framed as within-cell sand management; Recreation - short-term disruptions to beach access and use during works; acceptability improves when works are timed and communicated.	3	12	Pairs strongly with bypassing and nourishment; operational bridge between larger campaigns; supports keeping buried systems covered.	Delivers sand to hotspots without hard trapping; far less intrusive than groynes but depends on donor sustainability.	Surfers Paradise (QLD), Noosa Heads (QLD)	Vieira da Silva et al. (2021); Beck et al. (2020); Harry (2022); Harry et al. (2023).
31	Rock filter units	W&S - can provide rapid, modular toe/transition protection and reduce local scour in constrained sites; B&C - suited as interim/emergency works rather than whole-frontage erosion control; performance depends on sizing and placement geometry.	3		C&E - localised footprint and disturbance; impacts depend on extent and whether units remain exposed; MP - approvals may still be needed near sensitive habitats.	2		Capital and O&M - moderate capex with potentially higher O&M if units shift or degrade; Proportionality - can be cost-effective for rapid response compared with large rock works.	3		CU&V - can be acceptable as an interim/emergency measure if kept low-profile and used sparingly; Recreation - may reduce access/safety at the site while exposed.	3	11	Useful as a rapid-response layer alongside sand/dune measures; includes clear maintenance triggers and exit strategy.	Less system-wide sediment disruption than groynes, but does not address underlying sediment deficits.	City of Stirling (WA) trial sites	Tooker (2023); Coghlan et al. (2024)

32	Living speed bumps	W&S - low-profile roughness/nearshore “bumps” intended to subtly modify wave transformation and reduce energy concentration; B&C - would need detailed modelling to show measurable benefit on an exposed open coast; CE - may help reduce hotspot persistence if it slows sand losses when paired with nourishment; SLR - needs an adaptive pathway as depth and forcing increase.	2		C&E - potential for nature-inclusive eco-engineered units and limited footprint; MP - requires careful assessment of habitat effects and circulation/safety changes within/near Marmion Marine Park.	3		Capital and O&M - likely moderate to high investigation and pilot cost plus monitoring; Proportionality - best framed as a staged pilot with clear success criteria and exit options.	2		CU&V - can be framed as low-visibility and nature-inclusive, but acceptance depends on surf/safety outcomes and whether elements become visible; Recreation - engagement and monitoring essential given uncertainty.	4	11	Most credible when paired with nourishment, dune recovery and operational sand transfers, with monitoring-led adaptive management.	Aims to reduce reliance on prominent groyne fields but has higher uncertainty and less direct control than groynes.	Oceanside (California, US)	Re:Beach website, ICM (n.d.).
11	Rock groynes	W&S - proven to trap sand under Joondalup’s energetic winter swells but strongly alter alongshore transport; B&C - can stabilise individual cells but transfers adjustment to adjacent reaches; CE - can address erosion locally but create downdrift hotspots unless bypassing is continuous; SLR - crest raising possible but fixed controls increasingly lock shoreline position.	4		C&E - hardens shoreline alignment and replaces dune/upper beach habitat; MP - modifies nearshore sediment regime and surf breaks within Marmion Marine Park fringe.	2		Capital and O&M - high capex plus ongoing bypassing/nourishment to manage downdrift effects; Proportionality - high governance burden relative to sand-led options.	2		CU&V - highly visible and conflicts with preference for natural sandy beaches; Recreation - interferes with alongshore walking/surfing/swimming patterns and has low social licence.	2	10	Must be coupled with bypassing and/or nourishment; treat as a “high trade-off” comparator and only proceed if Council explicitly wants a ruled-in option.	Baseline for comparison.	Numerous examples along the European Mediterranean and Atlantic coasts (Italy, France, Spain, UK). Numerous examples in WA	Van Rijn (2013); Kristensen et al. (2016); CIRIA (2020).
15	Sloping rock revetments and seawalls	W&S - reliable asset protection with wave-energy dissipation relative to vertical walls; B&C - can still induce beach narrowing/passive erosion where shoreline would otherwise retreat; SLR - toe scour and overtopping increase over time without sediment management.	4		C&E - replaces natural shore habitat with hard substrate; can be eco-designed to improve habitat complexity but remains an armouring impact; MP - approvals/constraints near sensitive reefs/seagrass.	2		Capital and O&M - high capex; O&M includes inspections, toe maintenance and possible staged crest raising; Proportionality - justified mainly for critical assets and transitions.	2		CU&V - more acceptable than vertical walls in some settings but still reduces natural beach character and can limit access; Recreation - impacts depend on footprint and whether sand buffers are maintained.	2	10	Best combined with nourishment/dune enhancement to maintain a sandy beach frontage and reduce reflection effects.	More robust asset protection than groynes but typically worse for beach amenity unless paired with sand buffers.	Exmouth (UK) and many urban coasts	EurOtop (2018); Griggs (2019); Nawarat et al. (2024)

12	Geofabric groynes	W&S - can trap sand but remains sensitive to wave climate, exposure and damage; B&C - still modifies transport and can create downdrift impacts; CE - may provide short-to-medium term stabilisation as a trialable measure; SLR - exposure frequency and maintenance demands likely increase as water levels rise.	3		C&E - smaller hard footprint than rock but introduces synthetic materials; MP - risk if units degrade or become exposed, affecting aesthetics and potentially marine debris concerns.	2		Capital and O&M - lower capex than rock groynes but potentially higher maintenance and replacement risk; Proportionality - sometimes justified as a pilot where reversibility is valued.	2		CU&V - less “permanent” than rock but visible when exposed and can attract strong negative reactions if damaged; Recreation - can affect access and surf patterns similarly to other groynes.	2	9	Only credible with sand supply (nourishment/backpassing) and a clear maintenance/removal plan to manage reputational risk.	Lower permanence than rock groynes but not inherently “low impact”; still carries downdrift and acceptance risks.	Maroochydore (QLD)	Restall (2002); Sunshine Coast Council (2020); Sunshine Coast Council (2022a); International Coastal Management (2024).
9	Multipurpose artificial reefs	W&S - highly design-sensitive on an exposed swell coast; potential for unintended currents and alongshore impacts; effective only where modelling shows measurable wave-energy reduction and sand-retention benefits at a specific hotspot.	2		C&E - nearshore construction and footprint can disturb habitats; MP - approvals and habitat impacts may be material near sensitive reef/seagrass; requires robust baseline studies and monitoring to demonstrate net benefit.	2		Capital and O&M - high investigation/modelling/construction costs and ongoing monitoring; Proportionality - high cost relative to protected area means poor scalability for multiple hotspots.	2		CU&V - low visibility from shore but strong stakeholder risk if outcomes are uncertain; Recreation - may affect surf, access and navigation; social licence depends on clear objectives, safety and demonstrated performance.	2	8	If considered, only as a staged pilot combined with nourishment/backpassing and clear success criteria; not a core program option.	Lower visibility than groynes and potentially more acceptable, but more complex and typically still reliant on ongoing sand management.	Narrowneck Reef and Palm Beach Reef (Gold Coast, QLD).	Jackson et al. (2012); Mortensen et al. (2015); Brullo et al. (2024).
10	Submerged breakwaters and low-crest barriers, incl. submerged islands	W&S - can attenuate waves but performance is highly sensitive to crest level, spacing and storm sequencing; B&C - can alter bar patterns, rips and circulation in open sandy nearshore; CE - can help locally if correctly designed but can shift hotspots if mis-sized; SLR - rising levels can reduce breaking/attenuation unless adaptable.	2		C&E - introduces hard footprint and modifies mixing/circulation; MP - higher uncertainty for benthic communities, sediment dynamics and water quality within/near Marmion Marine Park.	2		Capital and O&M - high offshore capex plus monitoring and potential remediation; Proportionality - difficult to justify unless modelling shows clear retention benefits beyond sand-only options.	2		CU&V - low visual impact, but surf/safety changes can drive opposition; Recreation - offshore hazards/perceptions require careful management.	2	8	Usually needs sand supply and strong monitoring; consider only where modelling suggests clear, localised benefit in persistent hotspots.	Lower visibility than groynes but can still drive side effects if it functions as a hard control without adequate sand management.	Sea Palling (UK); numerous examples along the European Mediterranean coast (Italy, France, Spain)	Williams et al. (2018); EcoShape (2025).
14	Vertical seawalls	W&S - provides strong asset protection where space is constrained; B&C - often leads to beach narrowing and toe scour under reflective conditions; SLR - increasing water levels increase overtopping and maintenance demand without sand buffers.	4		C&E - hard armouring reduces intertidal habitat and can increase scour; MP - potential impacts near sensitive habitats; mitigation via design (toe protection, eco-enhancement) is limited.	1		Capital and O&M - high capital with ongoing maintenance and potential upgrade/crest-raising needs; Proportionality - best reserved for critical assets where alternatives are constrained.	2		CU&V - visible hard structure and loss of dry beach at high water reduces amenity; Recreation - can restrict access and increase safety risks in storms; however, may be accepted where protecting existing infrastructure is the priority.	1	8	Typically paired with sand buffers/dune management to retain beach width; can be a targeted comparator option.	Functions as a hard 'hold-the-line' comparator with higher amenity trade-offs than groynes in many settings.	Northern Beaches Council (NSW), Australia	Salauddin & Pearson (2019); Griggs (2019)

17	Detached breakwaters	W&S - strong wave attenuation and planform control but highly sensitive to freeboard, gaps and offshore distance; B&C - can create salients/tombolos and reshape an otherwise open sandy coast; CE - may stabilise pockets but can starve adjacent sections; SLR - often requires increasing sand management to retain beaches as levels rise.	4		C&E - large hard footprint and altered circulation; MP - difficult fit where conservation values and natural sediment dynamics are priorities.	1		Capital and O&M - high offshore capex plus monitoring and possible bypassing/nourishment; Proportionality - hard to justify versus sand-led measures with lower impact.	2		CU&V - visually prominent and likely perceived as industrialising the seascape; Recreation - can change surf breaks and access patterns with low social licence in a beach-amenity setting.	1	8	Would still require nourishment/bypassing to manage side effects; consider as “assessed and likely screened out” unless Council directs otherwise.	More wave control than groynes, but generally higher visual/environmental impact and comparable or worse social licence risk.	Numerous examples along the European Mediterranean and Atlantic coasts (Italy, France, Spain). Saly Beach (Senegal)	Ming & Chiew (2000); Munari et al. (2011); Dolphin et al. (2012); Jackson et al. (2015).
18	Offshore islands	W&S - can create wave-shadow zones but outcomes are highly geometry-dependent and can generate complex currents; B&C - can reconfigure circulation and sediment pathways substantially; CE - may stabilise sheltered pockets but can shift problems alongshore; SLR - performance shifts as water depths increase, often demanding more sand management.	3		C&E - major alteration of hydrodynamics and ecological mosaics; MP - navigation, habitat and conservation conflicts likely high in a marine park-adjacent setting.	1		Capital and O&M - very high capex and monitoring burden; Proportionality - difficult to justify for municipal-scale erosion management.	2		CU&V - very high visual impact and strong risk of community rejection if framed incorrectly; Recreation - likely conflicts with surf/amenity and safety perceptions. Potential use by swimmers during low energy days.	2	8	Only feasible as a major, transformational project and would still need sand management; best handled as “considered and screened out”.	Even greater landscape and ecological footprint than groynes; typically lower fit for sandy-beach amenity goals.	Liguria (Italy)	Zhu et al. (2024); Zhang et al. (2025).

Scoring Note

- 1 = Very Low
- 2 = Low
- 3 = Moderate
- 4 = High
- 5 = Very High

Total = sum of the four scores.

List of Abbreviations

W&S = Wave and swell conditions

B&C = Beach and coastline characteristics

CE = Current erosion

SLR = Sea level rise

C&E = Climate and ecology

MP = Marine Park / habitats

CU&V = Community use and values

O&M = Operational and maintenance cost