OURCOAST

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COASTAL INUNDATION OPTIONS REPORT

VICTORIA State Government | Environment, Land, Water and Planning

CITY OF GREATER GEELONG

Borough of Queenscliffe
Queenscliff & Point Lonsdale, Victoria, Australia

CORANGAMITE CMA

Bellarine Bayside Coastal Management

BARWON COAST

Foreword

The pressure on our coastal areas is continually increasing. The population of the wider Geelong region (G21 area) increased by nearly 20,000 people between 2006 and 2011, and over the next 20 years the City of Greater Geelong's population is forecast to increase by more than 35% (ID Consulting, 2015). Many of these people are attracted to the region by the relaxed coastal lifestyle on offer with its ready access to major population centres.

This increased population will increase demand for access to coastal areas and resources, and intensification of residential and commercial development on coastal fringes. As a consequence, existing and future communities need to be prepared to respond to the threat of coastal inundation hazards of sea level rise, storm tide, coincident catchment flooding and wave overtopping.

A major study to clarify and document our technical understanding of the nature and extent of the inundation hazards that can affect coastal areas within the City of Greater Geelong and the Borough of Queenscliffe has been completed. However, before location specific coastal inundation adaptation strategies, particularly in urban and high hazard areas can be prepared, an understanding of what options are available to respond to inundation is vital to guide "no-regret" decision making.

This document, *Options for Addressing Coastal Inundation*, provides information on coastal inundation adaptation options in usage within Australia and around the world. Targeted to Geelong and the Bellarine Peninsula, this document is intended to support land managers and the wider community to understand the likely implications of various options, and to refine for further discussion and assessment, the suitability of coastal inundation adaptation options for a particular location.

The options presented can be used to retain existing development, facilitate the intensification of development in areas to be protected, or support gradual retreat from areas at high risk of inundation.

These options for addressing coastal inundation forms part of a suite of tools developed under the *Our Coast* program and previous coastal adaptation programs for specific application within the local government areas of the City of Greater Geelong and the Borough of Queenscliffe.

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Borough of Queenscliffe Queenscliff & Point Lonsdale, Victoria, Australia
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This report has been prepared by GHD for City of Greater Geelong and may only be used and relied on by City of Greater Geelong for the purpose agreed between GHD and the City of Greater Geelong as follows:

- *The purpose of this report is to document potential responses to a technical assessment of coastal hazards* (Cardno, 2015)*.*
- *The report is intended to inform and support the identification and selection of suitable adaptation options for CoGG to consider in the development of coastal hazard adaptation strategies.*

This report was developed in consultation with Borough of Queenscliffe, Department of Environment, Land Water and Planning, Corangamite Catchment Management Authority, Barwon Coast Committee of Management and Bellarine Bayside Coastal Management.

The scope of GHD's engagement was to:

- *Identify adaptation options to manage inundation that may be suitable for implementation within the City of Greater Geelong and the Borough of Queenscliffe (the study area).*
- *Provide an overview of the coastal inundation hazards in the study area as identified by Cardno* (2015)*.*
- *Describe each adaptation option and its relevance to the management of inundation, including key considerations and interactions with other options.*
- *Summarise options for further consideration within various sectors of the study area.*

GHD otherwise disclaims responsibility to any person other than City of Greater Geelong arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report, and relevant at the time of publication. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described throughout this report. It is assumed that the inundation extents and mechanisms presented by Cardno (2015) *are accurate for the purposes of identifying potential adaptation responses within the study area. GHD disclaims liability arising from any of the assumptions being incorrect.*

GHD has prepared this report on the basis of information provided by City of Greater Geelong and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

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1. Introduction

1.1 Approach to hazard planning

The vulnerability of Victorian communities and assets to the impacts of storm tide and projected sea level rise has been of interest to coastal land managers for many years. A key piece of missing information needed to inform long term planning was a detailed understanding of the extent and types of risks posed by coastal hazards.

Under the former Future Coasts program operated by the Victorian Government, funding was provided to develop four Local Coastal Hazard Assessments throughout the State. These assessments were intended to identify in detail the extent of inundation and erosion under a variety of storm tide, coincident catchment flooding and sea level rise scenarios using the most recent sea level rise projections and contemporary modelling techniques. One of the regions identified for a Local Coastal Hazard Assessment comprised the municipal areas of the City of Greater Geelong (CoGG) and the Borough of Queenscliffe (BoQ).

The technical assessment of inundation and erosion hazards has now been completed (Cardno, 2015). However, before decision-making and planning for adapting to these hazards can commence, an understanding of the available options is required.

CoGG, BoQ and their partner organisations are seeking to develop adaptation plans to manage inundation hazards within the coastal zone of Geelong and the Bellarine Peninsula. A detailed coastal hazard assessment by Cardno (2015) identified land at risk of inundation under a variety of storm tide events and projected sea level rise scenarios, and where significant, incorporated coincident local riverine (catchment-based) flooding.

Figure 1 Coastal inundation, Portarlington (supplied by Bellarine Bayside Foreshore Committee of Management)

1.2 Objective of this document

This document seeks to provide an overview of the potential inundation adaptation options considered to be relevant for implementation within Geelong and the Bellarine Peninsula coastline. The selection of preferred responses will be undertaken as part of future site-specific planning activities by land managers.

It is understood that technical hazard assessments prepared for CoGG, BoQ and partner organisations address erosion and inundation hazards separately. For the purposes of this document, coastal hazards related to erosion are excluded and only inundation hazards are considered. It is acknowledged that many of the adaptation options can be used to respond to both inundation and erosion.

2. Types of adaptation options

Options for responding to the impacts of coastal hazards fall into 3 categories – defend, accommodate and retreat.

2.1 Defend

Defend refers to options that maintain the location of existing settlements and land uses without modifications to those settlements and uses. These options can sometimes fix the shoreline in its current location, or provide a physical barrier to inundation, such as tidal gates or sea dykes. These options are commonly used for protecting intensive development such as townships.

2.2 Accommodate

An option to accommodate inundation seeks to allow continued use of an asset or land regardless of an inundation event, whilst applying measures to reduce the risks associated with the inundation hazard. This can be achieved by either modifying the asset or the use of the land. For example, raising infrastructure above flood levels so that it can still function during an inundation event, or rezoning residential land as agricultural land are both examples of accommodating hazards.

2.3 Retreat

Retreat options refer to a conscious or unconscious decision to no longer use an area at risk of inundation. It is most often used for areas that are already or are expected to be regularly inundated, either through projected increases in sea level, or through their position on unstable shorelines, such as coastal sand dunes.

2.4 Description of options

The adaptation options presented in the following chapters can be used as single response options or a combined response mechanism. Each option presented is accompanied with details including:

- A description of the option in general terms.
- A discussion on the suitability of the option for response to inundation from storm tides (episodic inundation) or sea level rise (permanent inundation).
- Key interactions with other management options
- Key considerations for whole-of-life aspects and other impacts.

The interaction of an adaptation option when compared to other adaptation options is presented using the relative ratings system developed by GU/GHD (2012), presented in Table 1.

Table 1 Relative rating system for interaction with other options, adapted from GU/GHD (2012)

Rating	Interaction
✓✓	Very positive interactions
✓	Positive interactions
•	No interaction
×	Negative interaction
××	Very negative interaction

3. Local inundation hazards

The inundation hazards for CoGG and BoQ have been described by Cardno (2015) as:

- Storm tide – the combined water level of a storm surge with an astronomical tide. Storm surges are localised increases in water level caused by strong winds and low atmospheric pressure, often during a storm event. The technical assessment considered a storm tide event of magnitude that it would be statistically expected to occur once every 100 years (i.e. the chance that an event this size may occur in any given year is 1%).
- Coincident catchment flooding – flooding from rainfall in a waterway that occurs at the same time as a storm tide event. Oceanic water levels that exceed levels in the waterway act as a barrier to floodwaters, impacting on local flooding extents.
- Sea level rise – a gradual increase in mean sea level over time. The change in sea level may be caused by warming of the atmosphere, tectonic movements and local land subsidence. Progressive increases in sea level are modelled up to 1.4 m above current levels.
- Overtopping – splashing of waves as they break on coastal protection structures or run up beaches and dunes can result in localised inundation. If left unmanaged, breaching of dunes may result in more widespread, semi-permanent inundation extents.

The key findings for each coastal sector assessed in the technical study are set out in the following sections. Note that the inundation extents all include a 1% Annual Exceedance Probability (AEP) storm tide event.

In built-up areas where dwellings are affected, stormwater, power and other services will also be affected. Cardno (2015) divided the study area into sub-areas (compartments) based on landscape, level of hazard and potential risk. These sub areas are shown in Figure 2 and described in the following sections.

3.1 Breamlea to Blue Rocks

In this coastal sector the majority of the inundation is linked to flooding of low lying areas adjacent to Thompson Creek. Agricultural and floodplain (habitat) areas are affected by storm tide inundation under all scenarios. Under scenarios of a 1% AEP storm tide event with sea level rise of 0.5 m and greater, assets such as dwellings and roads are affected.

Minor inundation of the frontal dune is experienced during the storm events, but the dune is not breached.

3.2 Blue Rocks to Barwon Estuary

This section of coastline is backed by high cliffs and dunes; no inundation extents have been mapped. Retention of dune integrity will be required for ongoing protection of landward areas against inundation.

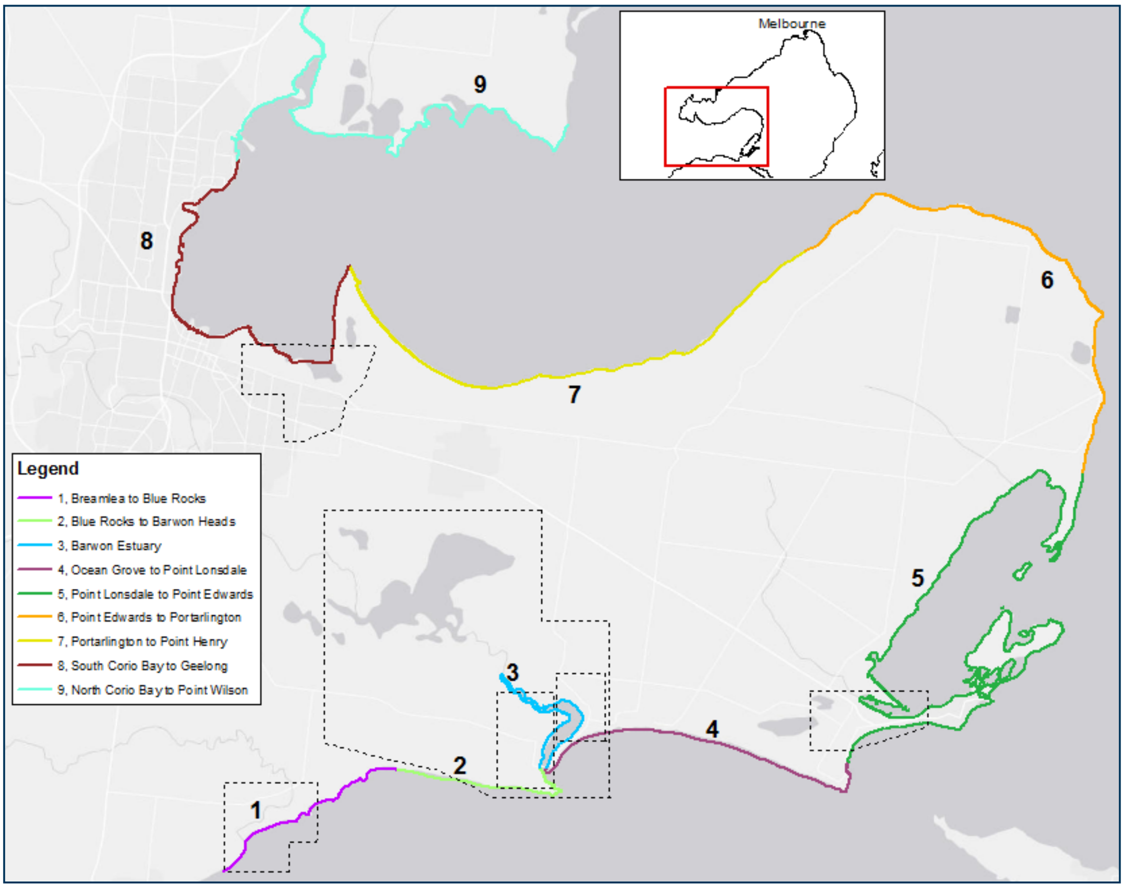

Figure 2 Coastal sectors within the study area (Cardno, 2015)

3.3 Barwon Heads, Barwon Estuary and Lake Connewarre

Low lying, undeveloped areas of the estuary are inundated under a 1% AEP storm tide event with no sea level rise. For all increases on this level in sea level and catchment based flooding, inundation extents increase, with sea level rises of 0.5 m and greater impacting on dwellings at Ocean Grove and Barwon Heads, including some sites remote from the riverfront. A 1% AEP storm tide event with sea level rise of 0.2 m is largely contained within the river channel due to the presence of low-crested revetments along the riverbank. At Ocean Grove, seasonal camping grounds, caravan parks and recreational facilities along the riverfront are also impacted.

Minor inundation of the frontal dune along the Ocean Grove spit is experienced during the storm events, but the dune is not breached.

3.4 Ocean Grove to Point Lonsdale

This section of coastline is backed by high dunes; no inundation extents have been identified. Retention of dune integrity will be required for ongoing protection of landward areas against inundation.

3.5 Point Lonsdale to Point Edwards

Wave overtopping presents a localised inundation hazard at Point Lonsdale, and is influenced by the vertical form of the seawall.

Inundation of dwellings and commercial premises on Fisherman's Flats at Queenscliff can occur during a 1% AEP storm tide event with no sea level rise. As sea levels rise, inundation extents increase.

The adjacent marine precinct approaching the ferry terminal is notably higher and affected by a 1% AEP storm tide event with sea level rises of 1.1 m and above.

The area around Lakers cutting from Swan Bay through to Lake Victoria is affected by a 1% AEP storm tide event with no sea level rise. The existing waterways in this area contain much of this inundation, but extents rapidly increase with only minor increases in sea level rise. Road and rail infrastructure in this area are impacted, as well as private dwellings. Under a 1% AEP storm tide event with sea level rises of 0.8 m and above, properties on the north-western fringe of Point Lonsdale are affected and road connectivity to the Point Lonsdale community is severed.

The Swan Bay coastline is largely undeveloped; habitat may be affected in some locations.

3.6 Point Edwards to Portarlington

Inundation in this coastal sector can occur during a 1% AEP storm tide event with no sea level rise at selected locations, and under regular astronomical tidal conditions with a sea level rise of 0.2 m or greater. Dwellings, camp grounds and other recreational facilities are impacted during these events. Inundation extents into additional developed areas generally increase significantly on a 1% AEP storm tide event with a sea level rise of 0.8 m and above, although small coastal pockets are affected by lower increases in sea level. Road access is also severed in some locations, however alternative access is available in some areas.

3.7 Portarlington to Point Henry

The inundation risk in this area is primarily to a private caravan park and a small residential estate. Inundation extents increase dramatically on a 1% AEP storm tide event combined with sea level rises of 0.5 m and above, however limited additional infrastructure is affected.

3.8 Stingaree Bay to Geelong

Primary inundation risks to road infrastructure occur at water levels of a 1% AEP storm tide event with 0.5 m sea level rise, with dwellings affected by a 1% AEP storm tide event with 0.8 m sea level rise. Large sections of uninhabited land associated with the Moolap salt pans and degraded land at Point Henry are also inundated.

Limited overtopping risks occur along the seawall-lined frontage of central Geelong.

3.9 North Corio Bay to Point Wilson

The coastal fringe of this area is readily inundated by a 1% AEP storm tide event with no sea level rise. As sea level rise increases additional areas are impacted, including roads and stormwater infrastructure; Avalon Beach is also inundated and isolated.

The adaptation options presented have been considered alongside the inundation findings of Cardno (2015), and a preliminary indication of options that may be suitable within each coastal sector is presented in Table 2.

Table 2 Potential options for inundation adaptation, Geelong and Bellarine Peninsula. D = Defend, A = Adapt, R = Retreat

Inundation Options	Breamlea to Blue Rocks	Blue Rocks to Barwon Estuary	Barwon Heads, Barwon Estuary and Lake Connewarre	Ocean Grove to Point Lonsdale	Point Lonsdale to Point Edwards	Point Edwards to Portarlington	Portarlington to Point Henry	Stingaree Bay to Geelong	North Corio Bay to Point Wilson
Beach nourishment	-	-	-	-	-	A R	-	-	-
Dune construction and restoration	D	A	A	A	A	A R	-	-	-
Riparian corridor restoration	A	-	A	-	A	A	-	A	-
Wetland restoration	A R	-	A R	-	A R	A R	R	A R	R
Sea dykes / levees	D	-	D A	-	D	D	D	D	D
Seawalls / revetments	-	-	A	-	A	A	A	A	A
Tidal gates	D	-	D A	-	D A	D A	D A	-	-
Drainage modification	A	-	A	-	A	A	A	A	A
Artificial reefs	-	-	-	-	-	A	-	-	-
Detached breakwaters	-	-	-	-	-	A	-	-	-
Groynes and artificial headlands	-	-	-	-	-	A	-	A	-
Building design elements	A	-	A	-	A	A	A	A	A
Buoyant / moveable structures	A	-	A R	-	A R	A R	A R	A R	A R
Flood / inundation resilient public infrastructure	A	-	A	-	A	A	A	A	A
Raise land levels	D A	-	D A	-	D A	D A	D A	D A	D A
Strategic planning	D A R	A R	D A R	A R	A R	A R	A R	A R	A R
Statutory planning	A R	A R	A R	A R	A R	A R	A R	A R	A R
Emergency planning	D A R	A R	D A R	A R	D A R	D A R	A R	A R	D A R

4. Living shoreline options

Options available to respond to coastal inundation that relate to living shorelines seek to reinforce or replicate natural coastal defence systems. This is done by considering the likely natural response to permanent or temporary increases in sea level.

4.1 Beach nourishment

4.1.1 Description

Beach nourishment is the manual placement of sediment on the beach or in the adjacent nearshore zone of a shoreline, with the intent of widening or raising the beach to provide a physical buffer against erosion and inundation and/or increase the recreational beach width. Nourishment in conjunction with supporting structures such as groynes is often used to assist in stabilisation of the placed material.

Beach renourishment works can take the form of returning a beach to its former dimensions, or can involve the creation of an artificial beach.

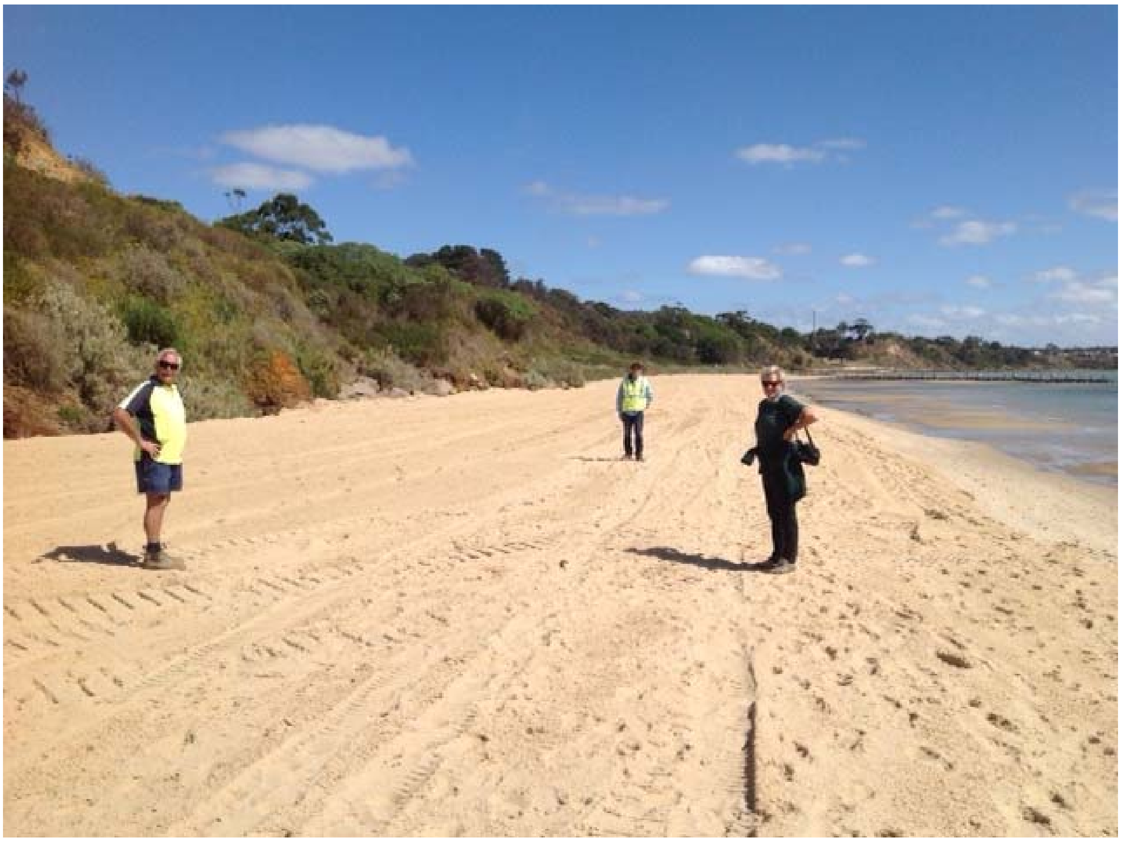

Figure 3 Beach nourishment, Clifton Springs (supplied by CoGG)

Beach nourishment can contribute to the management of inundation by triggering wave breaking (and therefore wave run-up) well seaward of areas to be protected. It also contributes an additional supply of sediments to dune areas. It is of most benefit during low-level inundation events where existing defence systems may only be breached by wave breaking processes. In areas with naturally low dune systems, nourishment up to or in excess of dune levels can increase the volume of dry sediments available for natural transportation and natural dune building processes.

The degree of protection provided from an inundation event will depend on the elevation of sand placement, which affects sand volumes and costs. It is important to note that beach nourishment effectiveness may be reduced owing to the occurrence of a larger than expected storm event resulting in severe cross-shore and longshore sediment erosion. Inspection and maintenance in the form of additional nourishment may be required following these extreme storm events to prolong the effectiveness of the initial nourishment. In areas where small creeks or drains flow to the beach, localised scour of nourishment works may occur, particularly under high flow conditions.

Beach nourishment is not always intended to be a permanent solution, and will likely require periodic renourishment to maintain shoreline protection. If a beach is to be maintained to set dimensions for erosion or inundation protection purposes, ongoing nourishment sources will need to be identified, secured and approved. This can be addressed through coastal management planning processes.

The nourishment of beaches is typically used to supplement low levels of natural sediment supply, and is nearly exclusively undertaken using sand. Beach nourishment can be conducted through:

- Placement of sediment as a nearshore bar or on the beach berm and allowing nearshore processes to redistribute the sediment to an equilibrium position; or
- Placement of sediment over the desired beach profile, minimising the sediment redistribution and allowing smaller quantities to be used.

The selection of an appropriate grain size must take into consideration the desired beach slope and the local wave and tide conditions. Where nourishment of a heavily utilised recreational beach occurs, the grain size and colour of the sand are also important for aesthetics.

The design of any beach nourishment should also include consideration of the potential impacts of introducing large volumes of potentially foreign material to marine organisms. This is particularly important in areas where bird feeding is prevalent in the inter-tidal zone, or where important fish habitats are in the nearshore area, such as seagrass beds, which are vulnerable to smothering.

Clean coarse sand sourced from nearby quarries, or dredged from offshore if suitable inactive deposits can be located, may be suitable for nourishment. Sand may also be available at low or no cost from waterway management works such as navigation dredging. Where accreting coastal forms such as spits occur, sand may be available for nourishing up-drift beaches using back-passing, or re-circulation techniques. Beach scraping (pushing a thin layer of sand from the intertidal zone up the beach to the dune area) is also sometimes considered to be a form of nourishment.

Sand placement may utilise trucks and conventional earthmoving equipment, through to a dredge pumping sand slurry to the beach or adjacent nearshore area. Trucks and earthmoving equipment require reasonable access to the beach and nourishment area.

4.1.2 Role in adaptation to inundation

Beach nourishment has only a limited role in inundation management. Its primary value is in protecting assets from erosion and supporting other inundation defence mechanisms. For example, nourishment can supplement or restore the natural sediment supply to nearby dune areas, which allows the dune to maintain its integrity. Nourishment material placed at the toe of structures such as seawalls reduces the frequency of wave and water level impacts on the structure. This makes it less vulnerable to toe scour, which can undermine the structure and ultimately cause collapse or failure.

Beach nourishment can be employed to maintain a recreational beach area under rising sea levels, particularly if there is limited opportunity for progressive landward migration of the beach. Continual maintenance of the nourishment will typically be required to sustain this.

For inundation protection from a storm tide event, nourishment is of most value if placed to an elevation similar to or higher than the storm tide level. Substantial loss of the nourishment material during a storm event would be expected; however this material would most likely not be lost from the active coastal system but would be progressively returned to down-drift beaches during calmer wave conditions following the storm event. Manual nourishment of the initially nourished area would be required to restore pre-event beach dimensions.

Following an inundation event, high velocity floodwaters at creek outlets can cause scour of adjacent beach areas, particularly at low tide.

4.1.3 Interactions with other adaptation options

Beach nourishment can combine with “hard” engineering options such as seawalls and groynes. In general, nourishment improves the aesthetics of a hardened shoreline and provides consistent recreational access, whilst groynes or reefs increase the longevity of the nourishment by trapping sand on the beach or sheltering the beach from severe wave action respectively.

Table 3 presents an overview of the interactions of beach nourishment with other adaptation options covered in this document.

Table 3 Interactions with beach nourishment, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Dune construction and restoration	✓✓	Dunes are part of the beach system. These options are mutually beneficial.
	Riparian corridor restoration	•	Typically no interference.
	Wetland restoration	•	Typically no interference.
Primary engineering options	Sea dykes / levees	✓	Compatible as it can be carried out on the seaward side of these structures.
	Seawalls / revetments	✓	Compatible if sufficiently large volumes of sand prevent wave action reaching the seawall.
	Tidal gates	•	Typically no interference, although high speed flows from a re-opened waterway may cause localised scour.
	Drainage modification	•	Can be localised impacts, but can be accommodated in design.
Supportive engineering options	Artificial reefs	✓	Can be combined to benefit beach stabilisation and to encourage salient formation.
	Detached breakwaters	✓	Can be combined to benefit beach stabilisation and to encourage salient formation.
	Groynes and artificial headlands	✓	Can be combined to benefit beach stabilisation and to control longshore sediment transport.
Built environment design options	Building design elements	•	Typically no interference.
	Buoyant / moveable structures	•	Typically no interference.
	Flood / inundation resilient public infrastructure	•	Typically no interference.
	Raise land levels	•	Typically no interference.
Planning options	Strategic planning	✓	Supports restoration of recovered coastal space and regeneration of natural functions.
	Statutory planning	✓	Supports restoration of recovered coastal space and regeneration of natural functions.
	Emergency planning	•	Typically no interference. May be some support.

4.1.4 Whole of life aspects

To maintain functionality, beach nourishments need continual monitoring and maintenance, particularly following the passage of storm events.

A coastal or shoreline management plan is an appropriate tool for managing maintenance and monitoring requirements. In this plan, suitable sand sources along with indicative quantities can be identified, such as beach scraping of the lower beach to restore the upper portion of the beach. Any sand blockages cleared from nearby creek systems should always be returned to the active coastal system and placed on the beach, provided the sediment is of suitable quality.

Coastal plans are useful for supporting and securing long-term approvals for undertaking works. Coastal plans also consider impacts from works, and therefore can address the various site-specific risks associated with implementation of various options.

As the local oceanic and weather conditions will reshape a nourished beach, careful design of the initial placement to consider these conditions is vital to reduce initial sediment losses, and maximise the functional life of the nourishment.

4.1.5 Multi-criteria overview

An overview of beach nourishment as an adaptation option to manage inundation is presented in the following table.

Table 4 Multi-criteria overview of beach nourishment, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Nourishment can support maintenance of coastal defence systems by providing a continued supply of sand to the local dune system and increasing the buffer to coastal structures.
	Flexibility	Can it be modified after implementation?	Yes natural shaping will also occur.
	Reversibility	Is it easy to completely remove?	Yes, but may be expensive. Natural sediment transport will also remove and redistribute sediments.
	No regret	Is there any other social or environmental benefit?	Healthy beaches support recreation, accessibility and beach ecosystems.
	Decision horizon	Can it delay the need for major decisions?	Beach nourishment increases the time available for major decision making, e.g. retreat. However, depending on the proximity and cost of nourishment sources, a beach nourishment project may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Accessibility is improved.
	Landscape	Does it impact landscape values?	Landscape values are not affected if the beach size or nourishment material colour doesn't change substantially or is restored to historical extents.
	Recreational use	Does it affect recreational use?	Nearshore nourishment can affect local wave conditions, but recreational conditions and opportunities are generally improved.

Aspect	Issue		Expected response
	Property values	Are private property values affected?	Property values can increase as a consequence of a wider and healthier beach.
	Impact on ecosystems	Does it impact coastal ecosystems?	The ecosystem of both the source and receiving environments can be negatively affected by nourishment activities. The extent of impacts will be site specific. Restoration of sediment supply to beaches down-drift of the nourishment may improve those ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site-specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Sediment supply is generally expensive, and is heavily dependent on sand sources.
	Cost of maintenance	Does it need expensive maintenance?	Maintenance activities can be expensive, particularly to replace eroded sand. Maintenance frequency is dependent on the frequency and severity of storm events, and is best supported by the establishment and funding of a maintenance plan.

4.2 Dune construction and restoration

4.2.1 Description

Beach areas are often backed by a dune system. Made up primarily of sand but also shell and other sediments, natural dunes form when dry beach sediments blown onshore by coastal winds accumulate. The generally coarse and heavy nature of the sediments means that wind-blown sand is readily trapped by obstructions above the high water mark, such as beach fences or vegetation growing at the rear of the beach. Over time, as the vegetation grows the dune also grows. Growth periods are interspersed with periods of erosion (usually as a result of elevated water levels and larger waves). Foredune (i.e. the seaward-most part of the dune) areas are highly mobile, with dune stability increasing with distance landward.

Dunes are vulnerable to damage by development, uncontrolled vehicle, pedestrian and animal access, and loss of vegetation through fire, disease and wilful damage. Future permanent development in dune areas should be avoided. In populated areas, active dune management is required to retain ongoing dune integrity for protection against inundation.

Artificial dunes refer to dunes created by manually placed sediments and vegetation to replicate a natural dune system. Sediment sources may include local dredging or building works, or sand quarries. Materials placed are then shaped using conventional earthmoving equipment.

The height and shape of the dunes is dependent on a number of factors such as coastal exposure and local geology. Dunes are located above the high water mark; any further seaward than this the sediment particles will be constantly rearranged by daily water and wave movements, and the beach may not dry out enough to supply beach particles for wind transportation.

Figure 4 Low dunes, St Leonards (GHD, n.d.)

In general, open coast beaches with larger waves tend to be backed by larger dunes. More sheltered waters with calmer wave climates have smaller dune systems. If the natural sediment supply to the beach is insufficient, there may only be a limited supply of sediment available for dune building. If the sediment supply is not provided or restored, dune erosion will result.

During storm events dunes provide a source of sand to the active beach system, with elevated water levels and large waves eroding the dune. Eroded material transported across the beach and into the nearshore area is temporarily stored on the seabed in the form of bars. This eroded material then augments the natural sediment supply to adjacent beaches post-storm. Erosion at the base of the dune can trigger slumping of the dune if the erosion scarp becomes unstable.

On low dune systems, the elevated water levels and strong onshore winds may result in overtopping of the dune, with dune sediments washed landwards, often onto infrastructure such as roads where it is manually removed for reasons of safety. After a storm has passed, natural dunes generally recover under calmer weather conditions. However, full recovery of the dune may not occur before the passage of subsequent storm events.

Dune restoration therefore refers to manual works such as sand placement and vegetation establishment to reinstate or augment an existing dune system damaged by previous storm events.

Figure 5 Dune erosion at Ocean Grove (GHD, n.d.)

As storminess is often seasonal, dunes function as a flexible coastal barrier to inundation. The higher and more stable the dune, the better the inundation protection afforded.

The type of vegetation growing on dunes is important for dune growth. Vegetation needs to be salt and wind tolerant, and able to cope with occasional inundation. Fore-dune plants tend to comprise rapidly growing vines and grasses with multiple rooting points. This allows them to readily trap wind-blown sand and survive even if another section of the same plant is damaged or uprooted. Further landward, in areas less frequently eroded, small shrubs and tree species can establish.

An example of a healthy natural coastal dune system in southern Victoria such as in the study area comprises low creeping ground covers such as Hairy Spinifex (Spinifex sericeus) on the fore-dune, backed by shrubs like Coast Beard-heath (*Leucopogon parviflorus*) and then small trees including Coast Wattle (*Acacia longifolia ssp. sophorae*) (Corangamite CMA, 2010).

Non-vegetative methods of encouraging dune growth include the use of matting (such as brush or seaweed), and dune fencing, with the latter also controlling access. Fencing can be temporary and consist of biodegradable materials (such as branches), or permanent structures (e.g. post and wire with or without shadecloth mesh) in areas of high pedestrian usage. The design of any fencing also needs to consider usage of and access to the dune by local fauna. Sediments accumulated by these methods need to be stabilised by vegetation.

4.2.2 Role in adaptation to inundation

Dunes are inherently designed to accommodate elevated water levels during frequent storm events, provided sufficient sediment supply exists and dune heights are not lowered through human interference. During extreme inundation events, the dune may not be sufficient to prevent inundation, and artificially raised dune levels can be employed to provide additional inundation protection without adversely impacting on natural coastal dynamics. Maintenance of dunes may be required immediately following storm events to retain the dune's integrity as a barrier to inundation, depending on the assets being protected.

As sea levels rise, the fore-dune is expected to migrate progressively landward (i.e. retreat). Maintenance of dunes in their existing locations will become problematic due to increasing exposure frequency to water and wave movements, and potential changes to sediment supply.

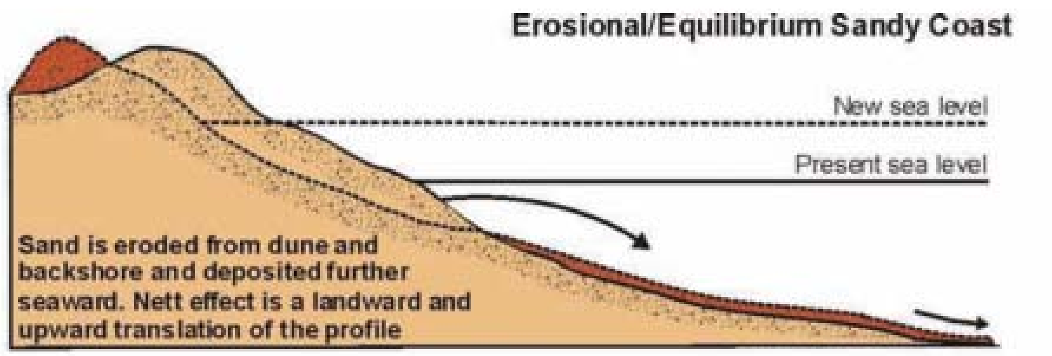

Figure 6 Generalised impacts of sea-level rise on a coastal dune, adapted from Ministry for the Environment (2008)

A suitable width of land is therefore required to accommodate a stable, elevated dune profile and landward dune migration; and to separate the beach from assets to be protected over the medium to long term. Artificial dune design is consequently complex and needs to be cognisant of the local conditions and sediments used.

4.2.3 Interactions with other adaptation options

Due to the potentially large volumes of sediment required, dune construction is usually associated with beach nourishment projects. Restoration of existing dunes is more commonly undertaken than construction of new dunes, with vegetation management and fencing works frequently conducted in coastal areas to encourage natural dune growth. Sometimes, small volumes of sand become available through nearby development activities (e.g. excavating a basement); these smaller volumes are ideal for local dune augmentation.

In some areas with high recreation value and narrow buffers, the shoreline of existing dunes can be fixed by hard coastal engineering structures. In these cases, dune retention serves as an upper inundation protection measure, for stability of structures on the dune, and for aesthetics.

Table 5 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 5 Interactions with dune construction and restoration, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓✓	Dunes are part of the beach system. These options are mutually beneficial.
	Riparian corridor restoration	•	Typically no interference.
	Wetland restoration	•	Typically no interference.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined, but are usually on different types of coast.
	Seawalls / revetments	✓✗	Can be combined, usually when the seawall is buried under dunes, but occasionally to prevent further loss of dunes supporting infrastructure.
	Tidal gates	✓✓	Supports the function of storm surge barriers to flood-proof coastal area.
	Drainage modification	✓	Can be combined to restore/improve drainage and dune stability.
Supportive engineering options	Artificial reefs	✓	Can be combined as part of an integrated defence system.
	Detached breakwaters	✓	Can be combined as part of an integrated defence system.
	Groynes and artificial headlands	✓	Can be combined as part of an integrated defence system.
Built environment design options	Building design elements	•	Typically no interference.
	Buoyant / moveable structures	✓	Can be combined as part of an integrated defence/accommodate system.
	Flood / inundation resilient public infrastructure	•	Typically no interference.
	Raise land levels	•	Typically no interference, however dunes can be constructed on the seaward side of raised land.
Planning options	Strategic planning	✓	Supports restoration of recovered coastal space and regeneration of natural functions.
	Statutory planning	✓	Supports restoration of recovered coastal space and regeneration of natural functions.
	Emergency planning	•	Typically no interference. May be some support.

4.2.4 Whole of life aspects

Continual maintenance and management is required to retain the integrity of dune systems, particularly in populated areas. Maintenance checks will be required following each storm event.

As for beach nourishment, a coastal or shoreline management plan is an appropriate tool for managing any maintenance and monitoring requirements, including identifying suitable sand sources and indicative quantities. In addition to offshore or terrestrial sources, small sand quantities suitable for maintenance works may be available from thin scraping of the beach seaward of the dune, or clearing of sand blockages from nearby creek systems. The plan can also be used to support and secure long term approvals for undertaking these works. Coastal management plans also consider impacts from works, and therefore can address the various site specific risks associated with implementation of various options.

Dune formation is a natural response to the local meteorological, oceanic and geological conditions. However, depending on the physical dimensions and vegetative condition of the dune, it will not provide protection from all inundation threats. Any artificial dune proposed as an adaptation response will need to be specifically designed and maintained for an adopted "recurrence interval" compatible with the life of the assets it is designed to protect.

Figure 7 Low dune overwash and vegetation colonisation, Portarlington (GHD, n.d.)

4.2.5 Multi-criteria overview

An overview of dune construction and restoration as an adaptation option to manage inundation is presented in the following table.

Table 6 Multi-criteria overview of dune construction and restoration, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Fully developed dunes can potentially cope with extreme sea levels and a higher erosion risk under a sea level rise scenario if monitoring and maintenance programs are established.
	Flexibility	Can it be modified after implementation?	Yes, natural shaping will also occur.
	Reversibility	Is it easy to completely remove?	Yes, but may be expensive.
	No regret	Is there any other social or environmental benefit?	Coastal dunes provide natural habitat for flora and fauna, and are a natural formation on sandy coastlines.

Aspect	Issue		Expected response
	Decision horizon	Can it delay the need for major decisions?	Dune rehabilitation increases the time available for major decision making, e.g. retreat. However, depending on the extent, construction of new sand dunes may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Planting vegetation can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Dunes can reduce access to the shore, but offer the benefit of control.
	Landscape	Does it impact landscape values?	The impact on landscape is positive although dune height increases and vegetation growth may reduce sea views, which can cause social conflicts between the community and affected property owners.
	Recreational use	Does it affect recreational use?	No. Recreational activities on the beach are maintained, whilst activities on any introduced/restored dune would be discouraged.
	Property values	Are private property values affected?	May affect property values (positive and negative). Protection of houses from damage/loss due to erosion is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a positive impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction and restoration is generally expensive, and is heavily dependent on sand sources. Community involvement can reduce costs.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring and maintenance costs are low but necessary. If constant maintenance is required costs will be high and alternative options may be more appropriate.

4.3 Riparian corridor restoration

4.3.1 Description

Land directly adjoining a waterway such as a creek, river, estuary or wetland is known as the riparian zone. These areas can be vegetated, cleared, developed or contain other infrastructure. Riparian corridors are commonly associated with riparian zones that have had their width, and therefore function, limited by the presence of landward infrastructure. Riparian zones provide social functions including recreational use, access to the waterway and landscape significance.

The riparian zone contributes to the overall health of the ecosystem through ecological and hydrological functions. A well-vegetated, healthy riparian zone contains vegetation species that work together to bind the soil to provide stable stream banks, by minimising erosion and trapping and filtering sediments, thereby reducing turbidity, nutrients and other pollution in the adjoining waterway. Vegetation provides and influences terrestrial and aquatic habitats by controlling temperature and light filtration.

The density and type of vegetation can play a significant role in wave attenuation during storm events. Studies such as that by Mol (2003) confirm that wave height and energy reduces as waves pass through vegetation, with the degree of attenuation dependent on the type, size and density of the vegetation.

Maintenance of a well-vegetated riparian corridor retains a buffer between the waterway and development. The width of the buffer needs to consider risks such as the proximity of development to flooding extents, local soils and geomorphology, biodiversity needs etc. Linkages to other similarly vegetated areas may be required to maintain species mobility alongside the waterway.

The restoration of the riparian corridor involves either revegetation activities, or natural regeneration through the control of degrading activities, such as uncontrolled access, weed and pest management etc.

4.3.2 Role in adaptation to inundation

Restoration of the vegetation in and within the width of riparian corridors can have a positive benefit in protecting from the impacts of storm tide events, depending on the elevation of the riparian area. Significant attenuation of wave energy results in reduced storm tide levels at the shoreline and therefore storm tide extents, and with a reduced duration of inundation.

Under sea level rise scenarios however, the riparian zone needs to migrate landwards to keep pace and retain functionality for storm events. As sea levels rises, permanent or more frequent salt water inundation of riparian zones will affect the type of vegetation that grows in that area. Erosion of sediments will occur due to increased saturation, although root growth that has bound the soil will slow erosion rates. If the proximity of infrastructure restricts landward migration of the riparian zone (corridor squeeze), progressive vegetation and buffer width loss may result in little to no reduction of flooding during future storm tide events.

4.3.3 Interactions with other adaptation options

The restoration of riparian zones overall provides a positive benefit to the management of inundation, either in isolation or in combination with other options. Whilst not able to prevent inundation, it does reduce the extent and severity of short-term inundation events. It is less adaptable to permanent inundation, particularly if existing infrastructure prevents landward migration.

Table 7 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 7 Interactions with riparian corridor restoration, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference.
	Dune construction and restoration	•	Typically no interference.
	Wetland restoration	✓✓	Can be combined as part of an integrated restoration program.
Primary engineering options	Sea dykes / levees	•	Typically no interference. A levee built too close to the waterway will limit the available corridor.
	Seawalls / revetments	✓	Can be combined for inundation benefit, particularly to hold the shoreline to maintain a vegetative buffer where landward migration is not feasible. A seawall may also limit the width of the available corridor.
	Tidal gates	✓	Can be combined as part of an integrated defence system.
	Drainage modification	✓	Can be combined to restore/improve drainage and hydrological function.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.
Built environment design options	Building design elements	✓	Can be combined as part of an integrated accommodation strategy.
	Buoyant / moveable structures	✓	Can be combined as part of an integrated accommodation strategy.
	Flood / inundation resilient public infrastructure	✓	Can be combined as part of an integrated accommodation strategy.
	Raise land levels	•	Typically no interference, unless filling occurs in vegetated riparian zone.
Planning options	Strategic planning	✓	Can be combined as part of an integrated restoration program on recovered land.
	Statutory planning	✓	Supports restoration of recovered coastal space and regeneration of natural functions.
	Emergency planning	•	Typically no interference. May be some support.

4.3.4 Whole of life aspects

Continual monitoring and maintenance of riparian zones is required for retention of integrity and functionality for inundation management. Active management is necessary where riparian zones adjoin residential areas, as unauthorised dumping of vegetation and selected vegetation removal for views can affect weed management and vegetation health.

The inundation benefit derived from restoring a riparian zone may be small compared to the investment required, particularly for permanent inundation. If no landward migration is possible, then the riparian zone will ultimately be unable to function as a wave attenuator. A major disease event or substantial damage that creates an opening for inundation to penetrate through may also represent failure.

4.3.5 Multi-criteria overview

An overview of riparian corridor restoration as an adaptation option to manage inundation is presented in the following table.

Table 8 Multi-criteria overview of riparian corridor restoration, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Under sea level rise a well-vegetated riparian zone will exhibit slower erosion rates than a similar non-vegetated shoreline, retaining more wave attenuating vegetation for longer. Storm tide inundation extents and durations will be reduced.
	Flexibility	Can it be modified after implementation?	Yes.
	Reversibility	Is it easy to completely remove?	Riparian corridors can be easily reduced in width, but for no inundation benefit.
	No regret	Is there any other social or environmental benefit?	Restored riparian corridors contribute to healthy waterways and coastal ecosystems.
	Decision horizon	Can it delay the need for major decisions?	Riparian corridor restoration can increase the time available for major decision-making, e.g. retreat.
	Synergy with mitigation	Does it help reducing emissions?	Construction works (if required) will contribute carbon emissions. Planting vegetation can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Revegetation works can reduce access to the shore.
	Landscape	Does it impact landscape values?	The impact on landscape is positive although vegetation growth may reduce water views, which can cause social conflicts between the community and affected property owners.
	Recreational use	Does it affect recreational use?	Some recreational activities may be excluded.
	Property values	Are private property values affected?	May affect property values (positive and negative). Protection of houses from damage due to inundation is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a positive impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction and restoration is generally expensive. Community involvement can reduce costs.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring and maintenance costs are low but necessary. Community involvement can reduce costs.

4.4 Wetland restoration

4.4.1 Description

The Victorian government defines wetlands as "*areas of permanent, periodic or intermittent inundation that hold still or very slow moving water which leads to the development of hydric soils, and have developed biota adapted to flooding. Wetlands may be formed by natural processes or human activities*." This definition includes "*saline lakes, swamps and shallow waters in Victoria's estuaries, bays and inlets*" (Department of Environment, Land, Water and Planning, 2016).

Tidal waters inundate some coastal wetlands on only the highest of tides, or by groundwater flows. The size of the wetland directly relates to the topography of the land, with only low-lying areas susceptible to inundation.

Similar to riparian zones, wetlands provide important ecological and hydrological functions. Vegetation such as mangroves and grasses stabilise soils by trapping and filtering sediments, thereby reducing turbidity, nutrients and other pollution in the adjoining waterway. These stabilised soils are then less vulnerable to erosion. Rapid sedimentation due to erosion or flooding can smother species such as seagrass, which rely on light for survival. Dense vegetation increases the roughness of surfaces, which attenuates waves to reduce inundation extents, and holds and slows floodwater that may reduce flooding in other areas.

Wetlands are vulnerable to degradation due to development pressures or poor water quality inputs, including excessive turbidity or nutrients. The restoration of wetlands therefore involves works to restore natural function. This may include selective sediment removal to increase capacity, revegetation activities, or natural regeneration. Works in adjacent riparian areas to control erosion may also assist in vegetation recovery in the wetland. Although wetlands are known for their ability to improve water quality through filtration, additional works to improve the quality of water flowing into the wetland will support re-establishment of suitable vegetation types.

4.4.2 Role in adaptation to inundation

Subject to the magnitude of a storm tide event, restoration of coastal wetland functionality can attenuate wave action, and slow tidal flows, locally reducing storm tide levels and therefore storm tide extents. As vegetation actively traps and slows flows, there may be an increase in the duration of inundation within the wetland itself.

As for riparian zones, under sea level rise scenarios wetland vegetation and sedimentation will migrate landwards as periodic inundation of additional areas occurs. For some vegetation types, natural wetland migration may be unable to keep pace with projected sea level rise. If the proximity of infrastructure restricts landward migration of the wetland vegetation (corridor squeeze), there may be little to no reduction of inundation penetration during future storm tide events, and hence increased inundation extents may result.

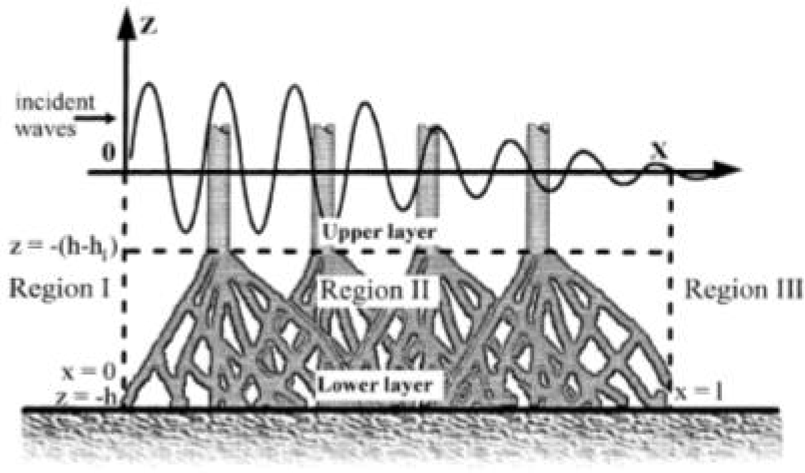

Figure 8 Wave attenuation through mangroves (Massel, Furukawa, & Brinkman, 1999)

4.4.3 Interactions with other adaptation options

The restoration of wetlands provides a positive benefit to the management of inundation. Whilst not able to prevent inundation, it does reduce the extent and severity of short-term inundation events. They have the capacity to naturally adapt and expand in response to permanent inundation, particularly if the indigenous vegetation is fast growing and wetland expansion is not constrained by the proximity of existing infrastructure.

Table 9 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 9 Interactions with wetland restoration, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference.
	Dune construction and restoration	•	Typically no interference.
	Riparian corridor restoration	✓✓	Can be combined as part of an integrated restoration program.
Primary engineering options	Sea dykes / levees	•	Typically no interference. Natural drainage functions must be retained.
	Seawalls / revetments	✓	Can be combined for inundation benefit, particularly a low-profile form to hold the shoreline to maintain a vegetative buffer where landward migration is not feasible.
	Tidal gates	✓	Can be combined as part of an integrated defence system. Some tidal inundation to be retained for biodiversity retention.
	Drainage modification	✓	Can be combined to restore/improve drainage, and hydrological and ecological function.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.

Option type	Option	Interaction	
Built environment design options	Building design elements	✓	Can be combined as part of an integrated accommodation strategy.
	Buoyant / moveable structures	✓	Can be combined as part of an integrated accommodation strategy.
	Flood / inundation resilient public infrastructure	✓	Can be combined as part of an integrated accommodation strategy.
	Raise land levels	•	Typically no interference, unless filling occurs in wetland.
Planning options	Strategic planning	✓	Can be combined as part of an integrated restoration program on recovered land.
	Statutory planning	✓	Supports restoration of recovered coastal space and regeneration of natural functions.
	Emergency planning	•	Typically no interference. May be some support.

4.4.4 Whole of life aspects

Monitoring and maintenance of wetlands is required to retain their integrity and functionality for inundation management. Most maintenance activities will occur in fringe areas or close to inlets and outlets from the system. Wetlands are sensitive to disturbance; therefore, non-essential physical interference should be minimised where possible.

The inundation benefit derived from restoring a wetland may be small compared to the investment required, particularly for permanent inundation. If no landward migration is possible, then the wetland will ultimately be unable to function as a natural wave attenuator or detention basin. A major disease event or substantial damage that creates an opening for inundation to penetrate through may also represent failure.

Slowed flood flows temporarily stored in a restored wetland may increase inundation risks for adjacent low-lying development.

4.4.5 Multi-criteria overview

An overview of wetland restoration as an adaptation option to manage inundation is presented in the following table.

Table 10 Multi-criteria overview of wetland restoration, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Can be effective
	Flexibility	Can it be modified after implementation?	Yes, but not easily.
	Reversibility	Is it easy to completely remove?	No. Removal requires ecological and hydraulic functions to be addressed.
	No regret	Is there any other social or environmental benefit?	Restored wetlands contribute to healthy waterways and coastal ecosystems, and recreational opportunities.
	Decision horizon	Can it delay the need for major decisions?	Wetland restoration for inundation protection purposes may be considered as a major decision in its own right.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Additional vegetation contributes to reducing carbon emissions.

Aspect	Issue		Expected response
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Revegetation works can reduce access to the shore.
	Landscape	Does it impact landscape values?	The impact on landscape is positive although vegetation growth may reduce water views, which can cause social conflicts between the community and affected property owners.
	Recreational use	Does it affect recreational use?	Some recreational activities may be excluded. The quality of passive recreation may be increased.
	Property values	Are private property values affected?	May affect property values (positive and negative).
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a positive impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Restoration is generally expensive. Community involvement can reduce costs.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring and maintenance costs are low. Community involvement can reduce costs.

5. Primary engineering options

The options discussed in this section are engineering works which prevent inundation of landward areas through the provision of a physical barrier or by modifying local drainage. As these options involve major infrastructure, they can be expensive to implement, augment, and if required in the future, remove.

5.1 Sea dykes/levees

5.1.1 Description

Sea dykes and levees are used around the world to prevent inundation of low lying land. Linham and Nicholls (2010) describe a sea dyke as *"… a predominantly earth structure consisting of a sand core, a watertight outer protection layer, toe protection and a drainage channel. These structures are designed to resist wave action and prevent or minimise overtopping.*"

These barrier structures are positioned parallel to the waterbody that is the source of the inundation. Sea dykes can extend for many kilometres along a shoreline depending on the natural land levels and the need to prevent its inundation. Levees are similar structures used in mainly riverine situations. However, there is less allowance in levee design for wave action with levees more focussed on protection against damaging currents.

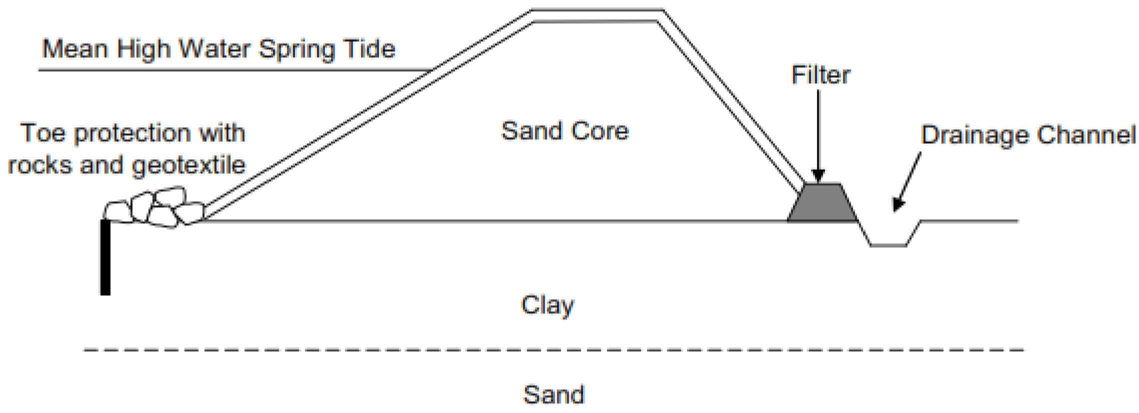

Figure 9 Example cross section of a sea dyke (Linham & Nicholls, 2010)

Sea dykes rely on having a large, impermeable mass for stability against water pressure from high water levels. Because of this, they can have a large footprint, and so may not be suited to locations where coastal squeeze is already an issue. The landward face of the structure is sloped to reduce footprint size, or can be stepped to reduce earth volumes for very high structures if sufficient land is available. Flattening the frontal slope of the dyke increases the footprint but reduces the potential for scour at the seaward toe of the structure due to wave breaking, which reduces the potential for failure during an extreme storm event.

The size of a sea dyke or levee must consider:

- The design water level – this covers extreme sea levels as well as projected sea level rise. Depending on what is being protected, dykes are usually oversized (i.e. have substantial freeboard) as any risk of overtopping is unlikely to be acceptable. Raising crest levels retrospectively will also necessitate an increase in the footprint of the structure to maintain stability.

- Design waves – the higher the design waves, the more robust and therefore costly the structure. This can be managed to a certain extent through careful design of any armouring, but will also influence seaward slopes and crest heights through wave run-up.

Construction of a barrier preventing sea water from entering low-lying areas also means that during times of high rainfall, natural drainage of these same areas may be impeded. Areas landward of sea dykes therefore must be supported by a suitable drainage system, which may include pumping of flood flows. The dyke itself must also be able to drain any water that does manage to penetrate into the core. For this reason, sand is used in the structure core rather than simply using any available local fill. Sourcing sufficient sand for a long and high structure may be costly. These structures also tend to be grassed, as deeper rooted vegetation such as shrubs and trees may penetrate into the core and weaken the structure.

A sea dyke differs from a seawall in that its primary purpose is not to prevent erosion of the shoreline. If sufficient room exists, a sea dyke can be placed well landward of the beach to allow natural beach function to continue without resulting in inundation of landward areas. Armouring part or all of the seaward face helps to protect the structure from damage by wave action. Depending on the availability and elevations of land, some dykes may be functional during normal astronomical tidal cycles, whilst others may only become functional during extreme storm tide events. The frequency of functional use will increase as rising sea levels are realised.

Sea dykes and levees are primarily used for “defend” adaptation strategies. Once a sea dyke is in place, landward development may become intensified, and any potential for future retreat is resisted by the community. Depending on the crest height relative to land levels landward of the structure, the community may consider a sea dyke to be aesthetically displeasing, and coastal views from landward areas may be affected.

5.1.2 Role in adaptation to inundation

Sea dykes and levees are very effective at preventing inundation of low-lying areas. However, the integrity of the entire structure must be maintained to provide inundation protection. A small breach can cause further weakening of the structure, resulting in rapid inundation of a large area.

Whilst the crest level of sea dykes can be raised to respond to future sea level rise, additional land is required (i.e. the footprint increases) if landward slopes are maintained. Steepening landward slopes may decrease stability of the structure. Seaward expansion of the structure reduces land take, but may permanently sever access along the coast unless accompanied by a beach nourishment program, and be costlier to construct and maintain due to increased wave exposure and material volumes.

5.1.3 Interactions with other adaptation options

Sea dykes and levees generally compliment other options. However, construction of these structures too close to the shoreline may limit the effectiveness of these other options.

In some areas sea dykes may allow continued use of an area until defence of the area becomes untenable and a retreat strategy must be implemented. Depending on the specific aspects of the site, this could be a very expensive exercise.

Table 11 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 11 Interactions with sea dykes/levees, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Compatible as it can be carried out on the seaward side of these structures.
	Dune construction and restoration	✓✗	Can be combined, but are usually on different types of coast.
	Riparian corridor restoration	•	Typically no interference. A levee built too close to the waterway will squeeze the available corridor.
	Wetland restoration	•	Typically no interference, unless the dyke blocks drainage of the wetland. Natural drainage functions of the wetland must be retained.
Primary engineering options	Seawalls / revetments	✓✗	Can be combined, but seawalls primarily address erosion rather than inundation.
	Tidal gates	✓✓	Can be combined as part of an integrated defence system. Supports the function of a dyke to flood-proof coastal areas.
	Drainage modification	✓	Must be combined to avoid landward inundation under high rainfall.
Supportive engineering options	Artificial reefs	✓✗	Can be combined, but artificial reefs primarily address erosion rather than inundation.
	Detached breakwaters	✓✗	Can be combined, but detached breakwaters primarily address erosion rather than inundation.
	Groynes and artificial headlands	✓✗	Can be combined, but groynes and artificial headlands primarily address erosion rather than inundation.
Built environment design options	Building design elements	✓✗	Can be combined as part of a staged defence/accommodate approach.
	Buoyant / moveable structures	✓✗	Can be combined as part of a staged defence/accommodate approach.
	Flood / inundation resilient public infrastructure	✓✗	Can be combined as part of a staged defence/accommodate approach.
	Raise land levels	✓✗	Can be combined as part of an integrated defence system.
Planning options	Strategic planning	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Emergency planning	✓	Can reduce need for emergency response and retain emergency access.

5.1.4 Whole of life aspects

Construction of a sea dyke or levee can represent a significant cost to the community over its lifespan, as these are major structures with a design life in the order of 50 to 100 years. Before a decision to design or construct is made, serious consideration of the long term practicality and sustainability of defending and maintaining low-lying areas landward of the structure is needed. This includes areas that may contain or adjoin important wetland and riparian habitats.

Inundation failure can occur due to wave or tide overtopping. Sea dyke failure may be caused by poor quality construction materials and methods, poor design of geotechnical aspects, and/or the selection of frequently exceeded conditions for design waves and water levels.

Regular monitoring and maintenance of these structures is required to ensure that functional integrity is maintained at all times. If the structure is overtopped or localised slumping occurs, the resultant inundation could be catastrophic to the local community. As sea levels are projected to progressively rise, the risk of overtopping will increase over time, as will the frequency of immersion of the toe of the structure.

5.1.5 Multi-criteria overview

An overview of sea dykes and levees as an adaptation option to manage inundation is presented in the following table.

Table 12 Multi-criteria overview of sea dykes and levees, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Sea dykes and levees are effective measures to protect coastal settlements from storm tide and projected sea level rise.
	Flexibility	Can it be modified after implementation?	Yes. However, modifications may be expensive and constrained by the proximity of development.
	Reversibility	Is it easy to completely remove?	No, will be expensive.
	No regret	Is there any other social or environmental benefit?	Land occupied by a sea dyke or levee can be made accessible to the public for recreation purposes. Implementation of a dyke may prevent the need to relocate a whole community.
	Decision horizon	Can it delay the need for major decisions?	Sea dykes represent a major decision that can have significant impacts on the natural system.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Planting vegetation can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Sea dykes and levees may impede but not prevent access to the shoreline. Locating the structure in a landward location may improve public access if the land was previously privately held.
	Landscape	Does it impact landscape values?	The impact on landscape is negative but can be visually reduced by vegetative cover. Grasses rather than trees and taller vegetation minimise impacts on sea views, which can cause social conflicts between the benefitting community and affected property owners.
	Recreational use	Does it affect recreational use?	Yes, can impact on existing recreational uses, but may also increase recreational opportunities.
	Property values	Are private property values affected?	May affect property values (positive and negative). Protection of houses from damage/loss due to inundation is the primary positive benefit. Landscape impacts are negative values.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a negative impact on coastal ecosystems, e.g. by isolating wetlands from natural periodic salt water inundation.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Designed to prevent the occurrence of disasters but failure occurs may create substantial impacts (disastrous in scale).
Costs	Initial cost	Is the initial cost high?	Construction is generally very expensive, and is heavily dependent on material sources.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring and maintenance costs are low but necessary.

5.2 Seawalls/revetments

5.2.1 Description

Seawalls, also known as revetments, are structures primarily designed to prevent the erosion of land due to wave action. They have a secondary function of limiting the oceanic inundation of landward areas. A seawall can take many forms, but usually comprises a vertical to sloping seaward face of a hard material such as rocks, concrete or steel sheets, backed by filter materials and cohesive sediment layers to prevent loss of natural sediments behind the wall. The structure itself is positioned parallel to the shoreline, and can extend over a distance of metres to kilometres. Seawalls are commonly constructed on existing active erosion scarps.

The seawall form is dictated by the usage of the seaward and landward areas, and by the economical availability of suitable materials. Access to the beach can be provided as part of the seawall design. Vertical walls are common where there is limited space landward of the shoreline to accommodate a wall, or where deeper water is required at the wall for navigation purposes. In general, the smoother and more vertical the seawall, the less wave energy is dissipated by the wall, and the greater the potential for scour at the seaward base of the structure, which can ultimately lead to undermining.

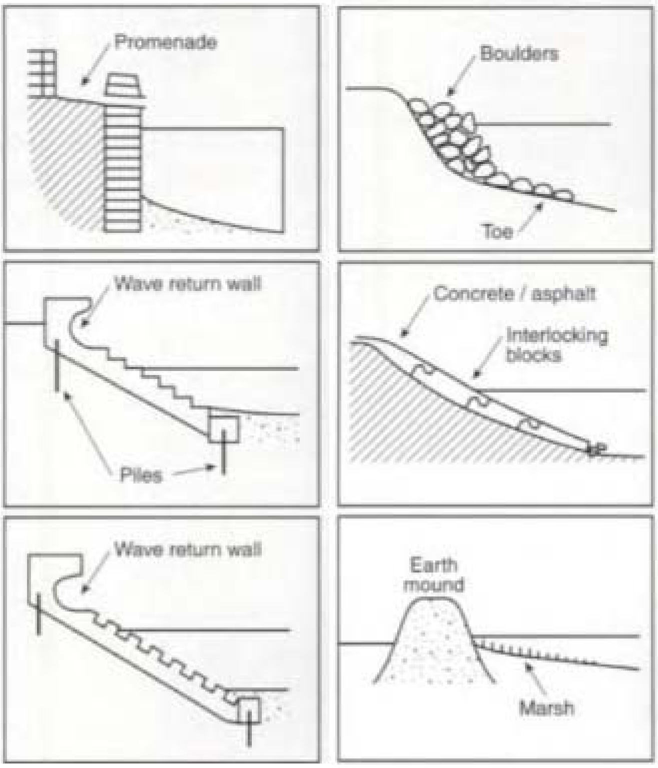

Figure 10 General seawall forms (French, 2001)

If too permeable, a seawall will be unable to withstand routine inundation. Natural sediments behind the wall will be progressively washed out of the wall, ultimately leading to slumping. To a limited extent, rubble mound (rock) seawalls can maintain some integrity against wave action under these circumstances, as the rock is able to slump to follow the new surface. However, the crest level will be locally affected and may provide an opening for inundation of landward areas. In reality, only impermeable seawalls such as those constructed from sheet piles, provide effective protection against inundation.

Poorly designed seawalls can rapidly deteriorate, littering the foreshore and allowing coastal erosion to continue.

Figure 11 Informal seawalls and other stabilisation works, Clifton Springs (supplied by CoGG)

Whilst seawalls are useful for preventing further erosion of protected land, they can exacerbate the impacts of an existing deficit in sediment supply, and lock up sand sources used to supply adjacent beaches (French, 2001). The impact of seawalls on erosion is therefore complex and significant erosion impacts on adjoining unprotected shorelines can be generated by them.

5.2.2 Role in adaptation to inundation

The effectiveness of a seawall at preventing inundation is twofold. Firstly, an impermeable seawall will prevent inundation of landward areas, as long as the water level, inclusive of wave run-up remains below the crest level. Secondly, the seawall may be backed by land that is notably higher than areas further landward (e.g. a seawall against a sand dune backed by a wetland). Allowing erosion of higher land areas may cause a breach, exposing this low-lying area directly to inundation under daily astronomical tidal conditions.

Seawalls can prevent occasional inundation as a result of storm tide events, but generally are unsuitable against permanent inundation.

Temporary seawalls constructed out of permeable materials such as geofabric sandbags are unsuitable for protection of landward areas from inundation.

As sea levels progressively rise, water depths (and therefore wave heights) at the seawall will increase. Future and existing seawalls will need to consider the impacts of these changes to remain effective against inundation.

5.2.3 Interactions with other adaptation options

Seawalls represent a "*last line of defence*" (Bowra, Hunt, McGrath, & Pistol, 2011) against shoreline retreat rather than inundation. They can be used in combination with other options, but are intended to function when all other physical options have failed.

Figure 12 Seawall with groynes in background, Point Lonsdale (supplied by CoGG)

Table 13 presents an overview of the interactions of this option with other adaptation options.

Table 13 Interactions with seawalls, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Compatible if sufficiently large volumes of sand prevent wave action reaching the seawall.
	Dune construction and restoration	✓✗	Can be combined, usually when the seawall is buried under dunes, but occasionally to prevent further loss of dunes supporting infrastructure.
	Riparian corridor restoration	✓	Can be combined for inundation benefit, particularly to hold the shoreline to maintain a vegetative buffer where landward migration is not feasible.
	Wetland restoration	✓	Can be combined for inundation benefit, particularly a low-profile form to hold the shoreline to maintain a vegetative buffer where landward migration is not feasible.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined, but seawalls primarily address erosion rather than inundation.
	Tidal gates	✓	Can be combined as part of structure transition to shoreline.
	Drainage modification	✓✗	Can be combined to reduce potential for seawall failure due to saturation.

Option type	Option	Interaction	
Supportive engineering options	Artificial reefs	✓	Can be combined as part of an integrated defence system.
	Detached breakwaters	✓	Can be combined as part of an integrated defence system.
	Groynes and artificial headlands	✓	Can be combined as part of an integrated defence system.
Built environment design options	Building design elements	•	Typically no interference.
	Buoyant / moveable structures	•	Typically no interference.
	Flood / inundation resilient public infrastructure	•	Typically no interference.
	Raise land levels	•	Typically no interference, however seawalls can be used to stabilise the seaward side of raised land (e.g. a reclamation).
Planning options	Strategic planning	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Emergency planning	✓	Can reduce need for emergency response and retain emergency access.

5.2.4 Whole of life aspects

Owing to the expense associated with their construction, seawalls are generally of a permanent nature, and designed for a life of 50 to 100 years. Over this lifespan, a design review should be undertaken to determine ongoing efficacy for projected future storm tide levels. Routine monitoring and occasional maintenance of the wall is required to maintain functionality, particularly following severe storm events.

Failure from an inundation perspective can occur due to wave or tide overtopping. Wall failure may be caused by poor quality construction materials and methods, poor design of geotechnical aspects, and selection of frequently exceeded conditions for design waves and water levels. Ongoing monitoring and maintenance will be required to for continued integrity and functionality.

5.2.5 Multi-criteria overview

An overview of seawalls as an adaptation option to manage inundation is presented in the following table.

Table 14 Multi-criteria overview of seawalls, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	May require expensive upgrades in the long term under rising sea levels.
	Flexibility	Can it be modified after implementation?	Yes, but will be expensive.
	Reversibility	Is it easy to completely remove?	No, will be expensive.
	No regret	Is there any other social or environmental benefit?	Yes, when combined with living shoreline options. However, seawalls can lead to major regret.
	Decision horizon	Can it delay the need for major decisions?	Seawalls represent a major decision that can have significant impacts on the natural system.

Aspect	Issue		Expected response
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Planting vegetation landward of the seawall can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Seawalls can affect access to the shore, but can include specifically designed access points and be supported by beach nourishment and dune restoration works.
	Landscape	Does it impact landscape values?	Exposed seawalls can have a negative impact on coastal landscape values.
	Recreational use	Does it affect recreational use?	Exposed seawalls can reduce recreation opportunities on the beach, but may preserve landward recreation opportunities.
	Property values	Are private property values affected?	May affect property values (positive and negative). Protection of houses from damage/loss due to erosion is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a negative impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction is generally expensive, and is heavily dependent on sources of materials.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring and maintenance costs are low but necessary. Infrequent high cost maintenance may be required after severe storm events or near the end of the design life of the structure.

5.3 Tidal gates

5.3.1 Description

Tidal gates are moveable structures that restrict tidal inundation into a waterway during periods of elevated water levels. They can range from major structures that span a navigable waterway, through to one-way flow valves and flaps on stormwater infrastructure such as pipes and culverts. Depending on their function, the gates allow maintenance of normal environmental flows for the majority of time, or egress of flood flows. They can be configured to prevent the upstream penetration of all tidal flows (e.g. a flap gate on a pipeline), or to only be activated under extreme conditions, such as during a storm tide event or very high tides.

The gates operate by two main methods. The first method involves the gate held in an “open” position until meeting a set condition. This may be that the water level at the gates has reached a set threshold; above this water level flooding upstream of the gates may affect important assets. This method allows the gate to be closed on a temporary and “as needs” basis. Once downstream water levels recede to acceptable levels, re-opening of the gates allows normal hydraulic processes to resume.

The alternative mechanism is a one-way flow structure, such as a valve, where water passes through the gate in one direction only (usually from upstream to downstream). This allows upstream flows to continue to drain under a variety of downstream water level conditions. Valve design for pumped flows, such as in some stormwater systems, can permit flow discharge even if the downstream water level is higher than upstream.

Figure 13 One way-tidal gates, Tooradin (Water Technology, 2014)

On larger waterways, gates can form a series of moveable barriers between permanent buttresses constructed across the entire width. The size of each gate is dependent on the design mechanism, the tidal forces and functional usage (such as navigation). Protection of areas upstream of the gates from tidal inundation occurs as long as water levels remain below the level of the gate structure.

Figure 14 Navigable tidal gates, Glenelg, South Australia (GHD, n.d.)

Integration with existing infrastructure such as bridges may be possible to reduce visual impacts. The design of the structure can incorporate infrastructure to support continued public access along the coastline.

Tidal gates can provide inundation protection for very large areas of low-lying land using a relatively small structure; this requires a narrow constriction not easily bypassed by inflows to make construction of this barrier economically viable. Existing waterways and drainage lines are suitable candidates for further consideration of this approach. If there is no narrow construction, a significantly larger structure incorporating a levee may be required.

Tidal gates will only provide inundation protection to the portion of a waterway upstream of the gate; no protection of open coastal areas is provided.

5.3.2 Role in adaptation to inundation

Tidal gates retain or allow an increase in the existing function of land under future and extreme water level scenarios. However, restricting the incursion of higher water levels into an area may have adverse environmental impacts as gate operation can artificially compress the tidal range. This is particularly relevant in areas reliant on regular tidal variability for habitat and species diversity. One-way flow devices may also restrict the free movement of marine species into brackish waterways.

5.3.3 Interactions with other adaptation options

Tidal gates must be used in conjunction with other physical terrestrial barriers to provide effective, continuous protection against inundation. In isolation, they will have only a localised effect on that watercourse, and only insofar as adjoining terrestrial areas are not otherwise breached (e.g. a low point in an adjacent dune may provide a path for storm tide inflow).

Table 15 presents an overview of the interactions of this option with other adaptation options.

Table 15 Interactions with tidal gates, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference. Restriction of high water levels upstream by the gate may reduce scour of adjacent nourished beach areas following gate re-opening.
	Dune construction and restoration	•	Typically no interference. Gates may need to be keyed into dune systems in places.
	Riparian corridor restoration	×	One-way flow devices can restrict normal inflows, impacting both species and habitats.
	Wetland restoration	×	One-way flow devices can restrict normal inflows, impacting on species and habitats.
Primary engineering options	Sea dykes / levees	✓✓	Can be combined as part of an integrated defence system. Supports the function of a dyke to flood-proof coastal areas.
	Seawalls / revetments	✓	Can be combined as part of structure transition to shoreline.
	Drainage modification	✓×	Can be combined with drainage improvements. May limit marine species diversity and habitat in brackish waters.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Drainage structure fitted with tidal flap can act as a groyne. Typically no interference.
Built environment design options	Building design elements	××	Building modifications to accommodate inundation not required if inundation is prevented.
	Buoyant / moveable structures	×	Mobile buildings to accommodate inundation not required if inundation is prevented.
	Flood / inundation resilient public infrastructure	✓	Tidal gates may reduce exposure of infrastructure to extreme flood levels.
	Raise land levels	✓	Tidal gates may support raising of land levels surrounding coastal waterways.
Planning options	Strategic planning	×	Hard protection works should not be carried out when the chosen management strategy is to recover coastal space and retreat.
	Statutory planning	×	Hard protection works should not be carried out when the chosen management strategy is to recover coastal space and retreat.
	Emergency planning	✓	Reduction of inundation extent may improve opportunities for emergency access.

5.3.4 Whole of life aspects

Tidal gates need to be responsive to elevated water levels from oceanic and catchment sources. If the gates are closed or a blockage occurs, and catchment based floodwaters are unable to escape, flooding upstream of the gates may occur. Conversely, if they fail to close and inundation from marine sources occurs, flooding consequences could be severe.

Frequent closure may also affect the delivery of sediments to the coast; sedimentation immediately upstream of the gates may necessitate frequent maintenance to retain functionality.

Flap gates may compromise accessibility to and from the waterway. These gates may prevent or limit unrestricted access for fish species and for navigation (including small vessels such as kayaks). Fish ladders can be used to circumvent the problem.

Tidal gates in the form of flaps on small structures are proprietary products that are visually unobtrusive and are easy to install. Larger, bespoke tidal gates, such as those on major waterways, can be technically challenging to design and construct. These larger structures are less aesthetically pleasing, but may be able to be incorporated into existing structures, e.g. the replacement of an existing road bridge incorporates tidal gates.

Depending on the design, the gates can operate over a reasonable design life. Automatic gates can provide adaptability to incremental sea level rise, by increasing closure frequency.

5.3.5 Multi-criteria overview

An overview of tidal gates as an adaptation option to manage inundation is presented in the following table.

Table 16 Multi-criteria overview of tidal gates, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Tidal gates are effective at protecting upstream areas of waterways from oceanic inundation from sea level rise and storm tide, provided land levels or associated structures adjacent to the gates are not breached.
	Flexibility	Can it be modified after implementation?	Yes, but will be expensive, particularly for major infrastructure.
	Reversibility	Is it easy to completely remove?	No, will be expensive, particularly for major infrastructure.
	No regret	Is there any other social or environmental benefit?	Will be site specific. No specific benefits or impacts identified.
	Decision horizon	Can it delay the need for major decisions?	Small tidal gates increase the time available for major decision making, e.g. retreat. Depending on the extent, construction of larger tidal gates may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Tidal gates may affect navigable access to the shore via the waterway. Design of the structure itself may facilitate access along the shoreline.
	Landscape	Does it impact landscape values?	Can have a negative impact on coastal landscape.
	Recreational use	Does it affect recreational use?	Flap gates may affect recreational use around the gate site. Larger gates may only affect recreational use intermittently.
	Property values	Are private property values affected?	Protection increases property values, whilst impacts on landscape can decrease values.
	Impact on ecosystems	Does it impact coastal ecosystems?	Flap gates can have a negative impact on coastal ecosystems. Larger gates for occasional use may have a reduced impact on ecosystems but the construction phase could still be a risk.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Yes. Designed to prevent threats posed by inundation..
Costs	Initial cost	Is the initial cost high?	Costs range from inexpensive for small flap gates on stormwater outlets to very expensive for major infrastructure.

Aspect	Issue		Expected response
	Cost of maintenance	Does it need expensive maintenance?	Maintenance is essential to maintain function.

5.4 Drainage modification

5.4.1 Description

The modification of drainage refers to changes to local drainage lines and structures to reduce inundation extents, particularly due to the combination of catchment-based flooding with elevated tail water levels at the outlet (in this instance, elevated oceanic water levels). It has significant relevance to stormwater drainage, especially in situations where oceanic water levels prevent even moderate rainfall from discharging out of the local stormwater network. This can then cause temporary inundation of landward areas until such time as the oceanic water level drops below the inundation level and stormwater can resume flowing under the influence of gravity. Such issues are very common in low-lying areas immediately landward of dune areas.

Figure 15 Drainage modifications, before (top) and after (bottom), Edgewater (supplied by CoGG)

Modifications to drainage systems may include the use of detention basins in upstream areas to temporarily store stormwater and regulate stormwater outflows whilst tail water levels are high. The provision of larger pipe sizes for an underground network may also be able to be used for temporary stormwater storage in some small catchments. In those extreme situations where upstream flooding is not acceptable, and a barrier system such as a tidal gate is in place, a pumping system may be feasible to force stormwater through the outlet.

Although considered inconvenient by many landowners, where kerb and channel is provided and adjacent land levels are higher than the road, additional capacity for very short term storage of stormwater can be provided within the road itself.

Where unhindered by development, natural discharge into vegetated dune swales (the low area between or landward of sand dunes) allows for the temporary storage of stormwater flows, with gradual reabsorption into groundwater once oceanic water levels subside.

5.4.2 Role in adaptation to inundation

Drainage system modification can reduce inundation extents from oceanic and catchment based sources, where the inundation is spread by the drainage network rather than directly from oceanic overtopping of the coastline.

Whilst modification of the local stormwater drainage may not always avoid inundation occurring, it can reduce the residence time, i.e. the length of time that the area is inundated for.

5.4.3 Interactions with other adaptation options

Some of the methods for the modification of drainage systems to increase capacity and reduce inundation extents rely on other adaptation options for functionality, especially other specific stormwater oriented methods such as tidal gates and wetland restoration.

Table 17 presents an overview of the interactions of this option with other adaptation options.

Table 17 Interactions with drainage modification, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference. Nourishment design needs to accommodate drainage outlets in design.
	Dune construction and restoration	✓	Can be combined to restore/improve drainage and dune stability.
	Riparian corridor restoration	✓	Can be combined to restore/improve drainage and hydrological function.
	Wetland restoration	✓	Can be combined to restore/improve drainage, and hydrological and ecological function.
Primary engineering options	Sea dykes / levees	✓	Must be combined to avoid landward inundation under high rainfall.
	Seawalls / revetments	✓✗	Can be combined to reduce potential for seawall failure due to saturation.
	Tidal gates	✓✗	Can be combined to improve drainage. May limit marine species diversity and habitat in brackish waters.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.

Option type	Option	Interaction	
Built environment design options	Building design elements	✓	Can be combined as part of an integrated accommodate strategy.
	Buoyant / moveable structures	•	Typically no interference.
	Flood / inundation resilient public infrastructure	✓	Can be combined as part of an integrated accommodate strategy.
	Raise land levels	✓×	Can be combined as part of an integrated accommodate strategy, however filling on land may reduce capacity of drainage system and increase inundation elsewhere.
Planning options	Strategic planning	✓	Can be combined as part of an integrated defence system
	Statutory planning	✓	Can be combined as part of an integrated defence system
	Emergency planning	✓	Can reduce need for emergency response and retain emergency access.

5.4.4 Whole of life aspects

Regular maintenance of the stormwater network in areas known to have drainage issues is imperative to retain functionality and to avoid additional localised flooding at high tide under minor rainfall events. As these areas are often reasonably flat, sedimentation within the stormwater network is common as flows may not have sufficient force to scour out sediment deposits within pipes and culverts.

Increased levels of development increase the extents of hard surfaces, resulting in more runoff, and a reduction of opportunities for natural infiltration. Development can also heavily influence drainage layouts and space for accommodating temporary inundation.

Failure of the drainage network could result in increased inundation extents, including areas well seaward of the coastline, and increased inundation depths and residence times.

As sea levels are projected to progressively rise, the effectiveness of existing drainage networks under extreme storm event scenarios will decrease over time unless consideration is given to modifications.

5.4.5 Multi-criteria overview

An overview of drainage modification as an adaptation option to manage inundation is presented in the following table.

Table 18 Multi-criteria overview of drainage modification, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Can be effective at accommodating inundation if coupled with complementary options.
	Flexibility	Can it be modified after implementation?	Yes, but may be expensive.
	Reversibility	Is it easy to completely remove?	No. Whilst possible, it will be expensive to remove.
	No regret	Is there any other social or environmental benefit?	Creation of detention basins can provide additional parkland for recreation.

Aspect	Issue		Expected response
	Decision horizon	Can it delay the need for major decisions?	Minor drainage modification increases the time available for major decision making, e.g. implementation of a sea dyke. Depending on the extent of works, drainage modification may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. If associated with the works (such as an artificial wetland) planting vegetation can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Will be site specific. No specific impacts identified.
	Landscape	Does it impact landscape values?	Will be dependent on works undertaken. Landscape impacts could be positive (e.g. artificial wetland creation) or negative (e.g. concrete lined drain).
	Recreational use	Does it affect recreational use?	Will be site specific. No specific impacts identified.
	Property values	Are private property values affected?	May affect property values (positive and negative). Improved protection of houses from damage/loss due to inundation is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Will be site specific. If done to replicate a natural system can have a positive impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. Reduction in inundation extents may improve emergency access.
Costs	Initial cost	Is the initial cost high?	Construction and restoration works are generally expensive, cost is dependent on the site and the extent of works.
	Cost of maintenance	Does it need expensive maintenance?	While necessary, monitoring and maintenance costs are low to medium, especially in high sedimentation areas.

6. Supportive engineering options

The options discussed in this section of the report are commonly used in coastal environments to stabilise shorelines, and as a consequence have an inadvertent impact on controlling inundation. However, without complementary landside works, such as those discussed in section 4 “Living shoreline options” and section 5 “Primary engineering options” the following options have very little influence on inundation extents. Supportive engineering options to those already highlighted are discussed here to provide context to their value when combined with other inundation adaptation options.

6.1 Artificial reefs

6.1.1 Description

Artificial reefs are used for a variety of purposes, one of which is for coastal protection. An artificial reef for coastal protection purposes comprises a man-made structure placed on the sea bed close to the shoreline to be protected. As waves pass over these permanently submerged structures, the sudden reduction in water depth triggers larger waves to break, which reduces the wave energy that reaches the adjacent shoreline. This has the effect of reducing beach erosion, whilst the calmer wave climate in the lee of the structure also encourages deposition of sediments. An increase in the width of the beach can result (known as a “salient”), but will not cause the height of the dune system backing the beach to extend to elevations greater than those that could occur in the absence of the reef. This is because sand dune formation is governed by the limit of tide and wave penetration, combined with local winds that transport sand particles that are then stabilised by vegetation.

The length of beach to benefit from the artificial reef depends on the length of the reef, and the relative directions of wave approach. In most situations very little benefit is provided to beach areas further up or down coast of the structure. If substantial volumes of sand accumulate in the lee of the structure, erosion of down-drift beaches can eventually occur in response to the loss of sediment supply to these areas.

Artificial reefs are unsuitable for use in areas with large tidal ranges or wide, flat, intertidal slopes. In order to mitigate beach erosion, the structure needs to be positioned close to the shoreline and would therefore be completely isolated for a substantial portion of the tidal cycle.

The design of an artificial reef can also be refined to provide other benefits, such as to provide habitat for marine organisms, and consequently recreational activities such as fishing and diving or snorkelling in calm wave conditions. Artificial reefs have also been used to improve the quality of surfing and swimming opportunities. The design of the reef must be tailored for a specific purpose, as incorrect design can locally increase longshore current speeds, accelerating erosion.

A variety of materials are used for artificial reefs, from sunken vessels; engineered concrete blocks, balls and other shapes; to geotextile bags. Materials are chosen based on the intended function(s) of the reef, availability of materials and funding, and to encourage colonisation by marine organisms.

Figure 16 Shellfish reef, Portarlington (supplied by CoGG)

6.1.2 Role in adaptation to inundation

In isolation, an artificial reef provides very little benefit towards mitigating inundation. The main benefit that it provides is to reduce wave energy directly impacting on adjacent inundation barriers such as coastal dune systems or sea dykes, which in turn reduces the risk of breaching during storm events or elevated water levels.

As sea levels progressively rise, the effectiveness of an artificial reef to trigger wave breaking decreases. Crest levels would need to be raised in response to maintain effectiveness. The overall design would also need to consider whether increases in sea level might also change site specific wave directions.

6.1.3 Interactions with other adaptation options

Artificial reefs offer the most benefit for inundation mitigation if used in conjunction with other options such as the restoration of coastal dunes.

Table 19 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 19 Interactions with artificial reefs, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Can be combined for beach stabilisation and to encourage salient formation.
	Dune construction and restoration	✓	Can be combined as part of an integrated defence system.
	Riparian corridor restoration	•	Typically no interference.
	Wetland restoration	•	Typically no interference.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined, but artificial reefs primarily address erosion rather than inundation.
	Seawalls / revetments	✓	Can be combined as part of an integrated defence system.
	Tidal gates	•	Typically no interference.
	Drainage modification	•	Typically no interference.
Supportive engineering options	Detached breakwaters	•	Typically no interference – these are structures that have the same function so not usually used in conjunction.
	Groynes and artificial headlands	✓	Can be combined under limited circumstances as part of an integrated defence system.
Built environment design options	Building design elements	•	Typically no interference.
	Buoyant / moveable structures	•	Typically no interference.
	Flood / inundation resilient public infrastructure	•	Typically no interference.
	Raise land levels	•	Typically no interference.
Planning options	Strategic planning	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Emergency planning	•	Typically no interference.

6.1.4 Whole of life aspects

The design life of an artificial reef depends on the construction materials. A sunken vessel may provide functionality for upwards of 100 years, whereas a reef constructed of geotextile bags may only last for 20 years.

Reef failure will be realised by a loss of functionality, such as no reduction in wave energy, no colonisation by marine organisms or no surfability. Failure of the reef may be due to the materials used (e.g. deterioration of metal parts of a sunken vessel or anchor/propeller cuts to geotextile bags). Insufficient anchoring, or sinking of reef materials can also be an issue for stability and effectiveness of the structure.

The consequences of failure of a functional structure will be the resumption of wave energy penetrating through to the adjacent beach. Safety risks associated with entrapment usually mean that humans are restricted from entering some or all parts of an artificial reef, e.g. Parks Victoria (2009). The permanent submergence of the structure also can present a navigation hazard unless appropriately marked.

6.1.5 Multi-criteria overview

An overview of artificial reefs as an adaptation option to manage inundation is presented in the following table.

Table 20 Multi-criteria overview of artificial reefs, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Not very useful in isolation. Can be used to reinforce other mitigation options.
	Flexibility	Can it be modified after implementation?	Yes. Structural modifications are possible but expensive.
	Reversibility	Is it easy to completely remove?	Yes, for geotextile bags. Difficult and expensive for other materials, such as a sunken vessel.
	No regret	Is there any other social or environmental benefit?	Provides habitat to support diving and fishing activities. Widens beach for recreational use. May also provide surfing opportunity.
	Decision horizon	Can it delay the need for major decisions?	Installation of an artificial reef may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	No
	Landscape	Does it impact landscape values?	No, as structure is submerged.
	Recreational use	Does it affect recreational use?	Yes. Positive benefits to fishing and diving activities, general beach availability. May improve surfing. Increased caution required around boating.
	Property values	Are private property values affected?	May positively affect property values. Additional protection of houses from damage/loss due to erosion is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a positive impact on coastal ecosystems by creating shelter for marine organisms.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction for coastal protection purposes is generally expensive, and is heavily dependent on location and materials used.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring is required to maintain functionality although maintenance is infrequent if appropriately designed. Maintenance after major storm events may be required.

6.2 Detached breakwaters

6.2.1 Description

A detached breakwater is similar to an artificial reef, in that it is a man-made structure located close to the shoreline. However, the primary purpose of a detached breakwater is to trigger wave breaking, rather than for other recreational purposes. These coastal protection measures are usually placed parallel to the shoreline, and can be long single structures, or more commonly, a series of short structures with a gap between them. They are usually constructed from rock or engineered concrete blocks.

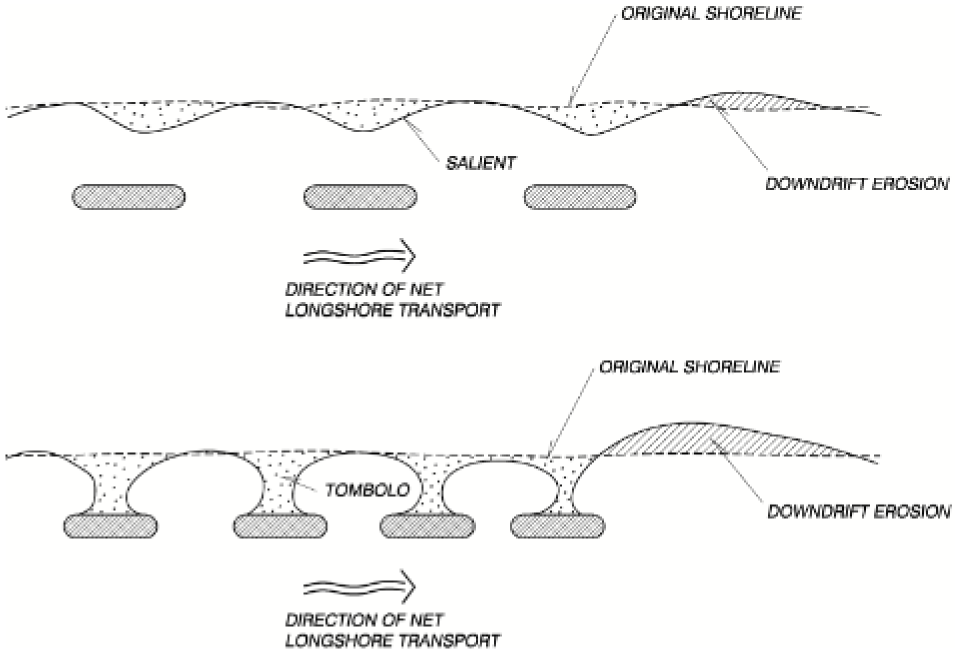

Figure 17 Typical beach configurations with detached nearshore breakwaters (US Army Corps of Engineers, 2002)

Detached breakwaters operate by triggering waves to break as they pass over or onto the structure, thus reducing inshore wave energy and current speeds. The adjacent shoreline is then stabilised and widened through reduced erosion and increased sedimentation.

Unlike artificial reefs, a detached breakwater can be permanently or intermittently submerged. Very shallow detached breakwaters are also known as beach sills; these low profile structures are usually located very close to the shoreline and are often exposed at low tide. They only affect wave breaking during higher tides or elevated water levels. Beach sills have a greater focus on wave breaking rather than salient formation.

The design of the breakwater will influence the beach response, and needs to consider the local wave climate and water depths, required crest elevation for wave breaking, the length of the structure and any gaps, and the distance offshore. The shape of the breakwater can be tailored to the local conditions, considering tidal variability and the way that waves break on the structure to influence wave overtopping.

If there is sufficient sediment transport in the area, structures located close to shore can eventually become connected to the beach via a tombolo. An example of a natural rock reef acting as a detached breakwater that is connected to the shore by a tombolo can be seen at Breamlea. The salient (shoreline bulge) is a direct result of the protection provided to the shoreline by the natural reef. No increase in dune height above normal levels will be achieved as a result of the reef.

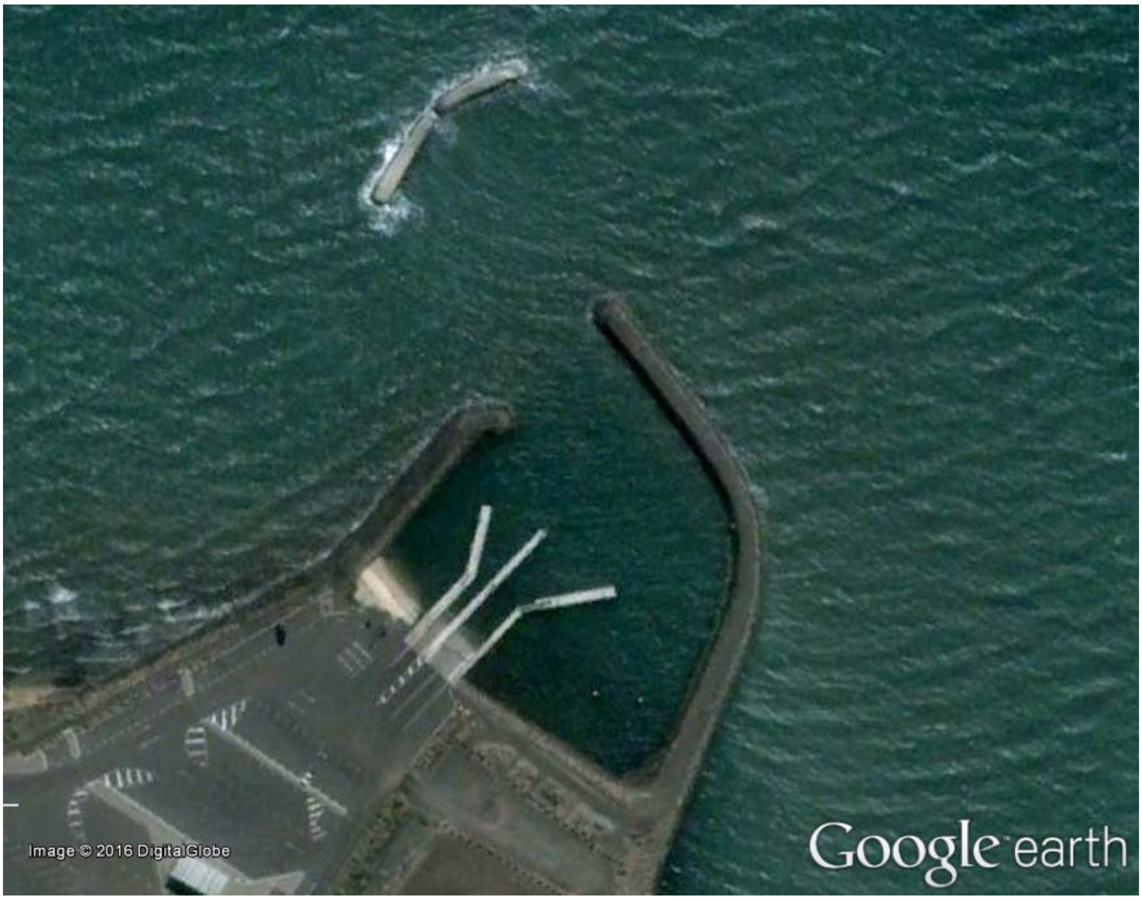

Figure 18 Detached breakwater, Limeburners Point, Geelong (image from Google Earth)

Because of the sediment trapping capability of the breakwater, it can potentially deprive down-drift beaches of sediments, resulting in erosion of those beaches. Recovery of down-drift beaches will only occur once the breakwater no longer traps sediment and natural bypassing can resume, which, depending on the site, may be many decades.

6.2.2 Role in adaptation to inundation

In isolation, a detached breakwater has very little influence on inundation extents. The main benefit that it provides is to reduce wave energy directly impacting on adjacent coastal inundation barriers such as dune systems or sea dykes. This allows the dune to be strengthened, reducing the risk of breaching during storm events or elevated water levels.

As sea levels progressively rise, the effectiveness of a detached breakwater to trigger wave breaking decreases. If not adjusted, the breakwater may only provide the desired functionality for the short to medium term. Crest levels would need to be raised as sea levels rise to maintain effectiveness, however this will also increase the interruption to sediment transport as the salient also responds to rising sea levels. The overall design would also need to consider whether increases in sea level also change site specific wave directions.

Alternatively, a floating breakwater or wave attenuator could be used to trigger wave breaking, regardless of the water depth.

6.2.3 Interactions with other adaptation options

Detached breakwaters will offer most benefit for mitigating inundation if used in conjunction with other options such as the restoration of coastal dunes. Nourishment of down-drift beaches can also be undertaken to proactively manage potential erosion effects from the breakwater.

Table 21 presents an overview of the interactions of this option with other adaptation options.

Table 21 Interactions with detached breakwaters, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Can be combined for beach stabilisation and to encourage salient formation.
	Dune construction and restoration	✓	Can be combined as part of an integrated defence system.
	Riparian corridor restoration	•	Typically no interference.
	Wetland restoration	•	Typically no interference.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined, but detached breakwaters primarily address erosion rather than inundation.
	Seawalls / revetments	✓	Can be combined as part of an integrated defence system.
	Tidal gates	•	Typically no interference.
	Drainage modification	•	Typically no interference.
Supportive engineering options	Artificial reefs	•	Typically no interference – similar structures that have the same function so not usually used on the same section of coast.
	Groynes and artificial headlands	✓	Can be combined under limited circumstances as part of an integrated defence system.
Built environment design options	Building design elements	•	Typically no interference.
	Floating / moveable structures	•	Typically no interference.
	Flood / inundation resilient public infrastructure	•	Typically no interference.
	Raise land levels	•	Typically no interference.
Planning options	Strategic planning	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Emergency planning	•	Typically no interference.

6.2.4 Whole of life aspects

The materials in a rubble mound (rock) detached breakwater can provide functionality for up to approximately 100 years. However, rising sea levels will decrease the functionality of the structure, and an increase in crest level will be necessary to maintain its performance over time. Monitoring of performance and actual water levels and wave heights compared to the design parameters will need to occur on a periodic basis, say every 5 to 10 years.

Breakwater failure will occur when waves are insufficiently attenuated (reduced in size) as they pass the structure, and salient formation may no longer occur. If a tombolo forms unintentionally, that may also be considered as a failure.

Physical failure of the reef may be due to the materials used or the construction method. Rock or concrete armour units of insufficient size or strength may rapidly displace or deteriorate in the harsh marine environment, and especially on open coast beaches. Insufficient anchoring, or sinking of breakwater materials can also be an issue for stability and effectiveness of the structure. Occasional armour unit displacement can be resolved during maintenance works.

The consequences of failure of a functional structure will be the resumption of wave energy penetrating through to the adjacent beach. Intermittent submergence of the structure also can present a navigation hazard unless appropriately marked.

6.2.5 Multi-criteria overview

An overview of detached breakwaters as an adaptation option to manage inundation is presented in the following table.

Table 22 Multi-criteria overview of detached breakwaters, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Not very useful in isolation. Can be used to reinforce other mitigation options.
	Flexibility	Can it be modified after implementation?	Yes. Structural modifications are possible but expensive.
	Reversibility	Is it easy to completely remove?	No, will be expensive.
	No regret	Is there any other social or environmental benefit?	Widens beach for recreational use. May affect fishing/surfing patterns.
	Decision horizon	Can it delay the need for major decisions?	Installation of a detached breakwater may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	No, but a more stable beach may improve access.
	Landscape	Does it impact landscape values?	Possibly, a semi-submerged structure will have visual impacts.
	Recreational use	Does it affect recreational use?	Yes. Positive benefits to general beach availability. Increased caution required around navigation and water based activities.
	Property values	Are private property values affected?	May positively affect property values. Additional protection of houses from damage/loss due to erosion is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can negatively impact coastal ecosystems due to smothering. May have a positive impact on coastal ecosystems by creating shelter for marine organisms.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction for coastal protection purposes is generally expensive, and is heavily dependent on location and materials used.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring is required to maintain functionality although maintenance is infrequent if appropriately designed. Maintenance after major storm events may be required.

6.3 Groynes and artificial headlands

6.3.1 Description

The purpose of a groyne is to interrupt the natural sediment that is transported along the beach. Positioned perpendicular to the shoreline, they provide a natural barrier against which sediment can accumulate. Once the groyne is full, the sediment overtops or extends seaward past the groyne and natural sediment transport resumes. However, in the meantime, the beach immediately down-drift of the groyne will be starved of sediment and erode. There will also be a difference in sand levels on either side of the groyne. The up-drift (or filled) side will have a beach elevation close to that of the groyne crest, whereas the down-drift (eroded) side will be lower until the groyne compartment is completely filled.

Seasonal changes in the direction of longshore transport direction are common in many locations. In these instances the shape of the beach regularly reorients to reflect the dominant wave direction and the groynes continue to function for the opposite transport direction. Where multiple groynes are used on a shoreline (a groyne field), the accumulation/erosion arrangement creates a sawtooth pattern along the shoreline.

An artificial headland also functions as a barrier to sediment transport, but has a notably larger footprint (often wider and higher), which can serve to separate the beach into discreet recreational areas. Sediment supply along the beach does not usually pass over the top of an artificial headland to reach down-drift beaches; sediments either have to bypass the seaward end of the headland or beach nourishment may be needed to manually augment the natural supply.

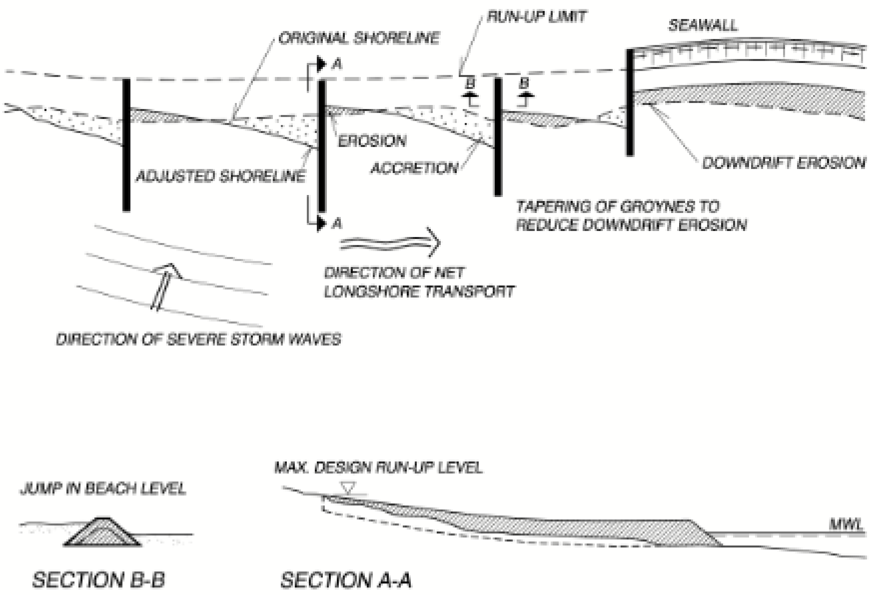

Figure 19 Typical beach configuration with groynes (US Army Corps of Engineers, 2002)

The amount of sand that is trapped is governed by the local sediment transport rates, and the length and height of the groyne. If there is an insufficient supply of sand to a beach area, a groyne will be ineffectual. Erosion of the beach immediately down-drift of the groyne can be offset by “filling” the groyne at the time of construction, so that natural bypassing can occur immediately. In some situations, local seabed scour can occur between groynes as a result of water circulation patterns.

Groynes can be useful to locally build up beach width, providing a buffer to erosion. However, there is a limit to the elevation that beach sediments can be encouraged to accumulate. If groynes are increased in height, it is expected the beach would move seawards rather than upwards into a dune. This occurs mainly because sand dune formation is governed by the limit of tide and wave penetration, combined with local winds that transport sand particles that are then stabilised by vegetation.

Whilst a wider beach and dune means that frequent tidal levels, most wave action and accompanying erosion can be accommodated without impacting on landward properties, groynes do not prevent storm erosion. Accordingly, they will not prevent inundation from extreme events such as storm tides that exceed the dune level.

Historically groynes were constructed from timber, or inadvertently created through the construction of concrete drainage structures crossing the beach. Modern groynes are commonly constructed from rock and/or geotextile bags. Geotextile bags are well suited as temporary structures, as they have a design life of up to 20 years, and are easily opened to release the sand onto the beach in the bags if the groyne is unsuccessful at trapping sediment. Rock groynes typically have a design life of around 50 years.

Artificial headlands are less easy to remove, as these are usually large earth filled structures protected by a rock revetment. More commonly used to enhance public recreation opportunities, these features are typically designed for a 50 to 100 year design life.

6.3.2 Role in adaptation to inundation

Groynes can be useful for widening a beach in areas where there is sufficient natural sediment supply to the beach. However, the sediment trapped will not accumulate to elevations in excess of those that can naturally occur at the beach, and a groyne by itself will not directly mitigate inundation.

Widening a beach increases a buffer for erosion, which may reduce the frequency and severity of wave action reaching coastal dune systems that do act as a barrier to inundation. Groynes therefore have an indirect benefit to inundation management. They are of most value in protecting against inundation when used in conjunction with other adaptation options, such as coastal dune restoration. Beach nourishment works should be implemented as part of any groyne works to minimise adverse impacts from the groynes.

As sea levels progressively rise, groyne crest levels, lengths and spacing between groynes will need to be reassessed to maintain effectiveness. The overall design would also need to consider whether increases in sea level also change site specific wave directions, and the volume of natural sediment supply required to maintain functionality.

6.3.3 Interactions with other adaptation options

As groynes are of limited benefit to inundation management in isolation, they are best used to support other inundation adaptation options.

Table 23 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 23 Interactions with groynes and artificial headlands, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Can be combined for beach stabilisation and to control longshore sediment transport.
	Dune construction and restoration	✓	Can be combined as part of an integrated defence system.
	Riparian corridor restoration	•	Typically no interference.
	Wetland restoration	•	Typically no interference.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined, but groynes and artificial headlands usually address erosion rather than inundation.
	Seawalls / revetments	✓	Can be combined as part of an integrated defence system, however both options usually address erosion rather than inundation.
	Tidal gates	•	Drainage structure fitted with tidal flap can act as a groyne. Typically no interference.
	Drainage modification	•	Typically no interference.
Supportive engineering options	Artificial reefs	✓	Can be combined under limited circumstances as part of an integrated defence system.
	Detached breakwaters	✓	Can be combined under limited circumstances as part of an integrated defence system.
Built environment design options	Building design elements	•	Typically no interference.
	Buoyant / moveable structures	•	Typically no interference.
	Flood / inundation resilient public infrastructure	•	Typically no interference.
	Raise land levels	•	Typically no interference. An artificial headland is effectively a reclamation.
Planning options	Strategic planning	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Emergency planning	•	Typically no interference.

6.3.4 Whole of life aspects

Artificial headlands are major structures, typically with a design life of 100 years. As they tend to be elevated structures, their design generally includes allowance for sea level rise and storm tide. Their construction is robust, and should only require monitoring and maintenance after the passage of severe storm events.

Groynes can be less robust, and depending on the design intent and materials used, have a design life of between 5 to 100 years. As groynes are often designed to allow overtopping by sediments, their efficacy will be reduced as sea levels progressively rise. Their design should therefore be reviewed on a periodic basis, say every 5 to 10 years, and compared to actual changes in water levels, wave conditions and sediment supply.

Major or repeated storm events can rapidly erode the beach, leaving groyne compartments depleted of sand. Groyne failure can occur when there is insufficient longshore sediment supply to the beach to replace lost material, and if beach nourishment is not intended to be used to supplement the sand volumes on the beach. Poor design and construction can also lead to groyne slumping, or excessive scouring under normal design conditions. Major failure can occur during extreme storm events. In areas where a “trial” groyne is considered, the use of geotextiles may be appropriate.

6.3.5 Multi-criteria overview

An overview of groynes and artificial headlands as an adaptation option to manage inundation is presented in the following table.

Table 24 Multi-criteria overview of groynes and artificial headlands, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Not very useful in isolation. Can be used to reinforce other mitigation options.
	Flexibility	Can it be modified after implementation?	Groynes can be modified, artificial headlands are difficult to modify.
	Reversibility	Is it easy to completely remove?	Geotextile groynes can be easily and cheaply removed; rock groynes can be easily removed but are expensive; artificial headlands are difficult and expensive to remove.
	No regret	Is there any other social or environmental benefit?	Widens beach for recreational use. Artificial headlands provide additional passive recreation opportunities.
	Decision horizon	Can it delay the need for major decisions?	An artificial headland is a major decision. Depending on the materials used, a groyne may or may not be a major decision. All works can strongly impact on the natural coastal system.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Planting vegetation on artificial headlands can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Artificial headlands can improve access to the shore or the vicinity of the shore for views.
	Landscape	Does it impact landscape values?	Groynes can have a negative impact on coastal landscapes. Well-designed artificial headlands can have a positive impact on coastal landscapes.
	Recreational use	Does it affect recreational use?	Yes. Positive benefits to general beach availability. Increased caution required around navigation and water based activities around submerged groyne extents.
	Property values	Are private property values affected?	May affect property values (positive and negative). Additional protection of houses from damage/loss due to erosion is the primary positive benefit. Negative impacts on landscape can decrease values.
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a negative impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction can be expensive, and is heavily dependent on form of structure, physical extent and materials used.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring is required to confirm ongoing functionality although maintenance is infrequent if appropriately designed. Maintenance after major storm events may be required.

7. Built environment design options

The options discussed in this section relate to specific adaptation measures that can be applied to structures and infrastructure located within potential inundation areas. Most of the options in this section can be applied on a property level basis.

7.1 Building design elements

7.1.1 Description

There are many locations where existing settlements will be exposed to increasing inundation risks under projected sea level rise. For some communities, abandonment or relocation may not be palatable or possible and there is strong pressure to remain. If fortifications to protect the community from inundation are uneconomical or undesirable from an aesthetic or landscape perspective, building alterations may be a viable alternative.

The design of buildings to improve the way they currently accommodate occasional inundation can be applied to new structures or to retrofit existing buildings.

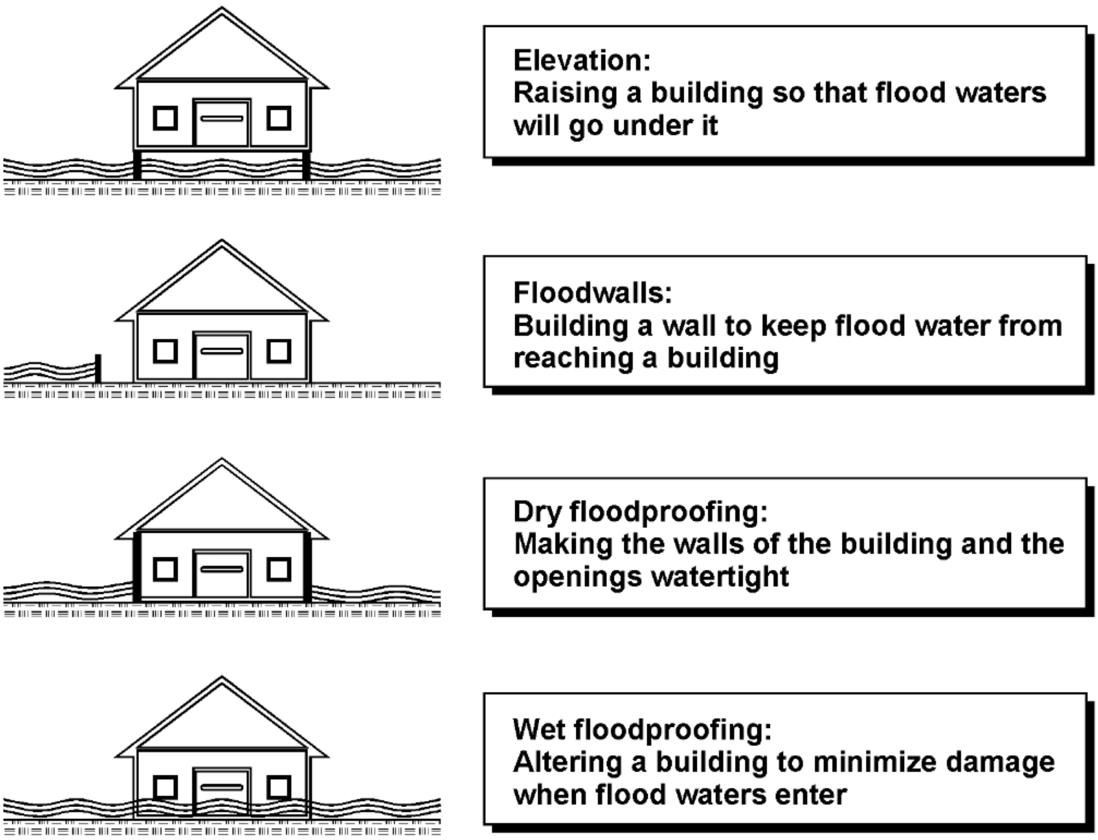

Figure 20 Examples of flood proofing (UNESCO, 1995)

Storm tide events not only bring potentially fast moving flows, but they are also often accompanied by high winds, with wave action penetrating inland, potential directly impacting on buildings. As the storm tide recedes, the flow direction changes to drain to the closest low lying areas.

Structures can be damaged or weakened by the impacts of water flows, waves, and debris carried by wind and water flows; scour can undermine foundations causing uneven settlement or building collapse; and building material deterioration (e.g. corrosion due to saline immersion). In extreme cases, heavy coincident rainfall may trigger landslides in hilly areas.

The changes to be made to a building depend on the inundation characteristics of that location, and the type of building. A building on stumps may be easier to retrofit than a slab on ground style of construction. In addition, there may be unique requirements based on that individual building (e.g. heritage). Consideration needs to be made of rising water levels approaching the floor of the building as well as flows or waves impacting on the walls. Upgrading of foundations to accommodate potential scour, floatation and movement may also be necessary.

Consideration also needs to be given to the ongoing functionality and integrity of services such as electricity, water supply and sewerage to a building during an inundation event. Items able to be penetrated by water such as switches and meters must be located above design inundation levels. Evacuation routes from modified buildings should be considered as part of retrofitting works.

Depending on the location and the style of the building, changes may be required to local planning requirements (such as site coverage or building heights) to allow buildings that meet inundation requirements to remain functional. For example, if building height restrictions limit multi-storey development, a redeveloped dwelling with a higher floor level may take up a greater proportion of the land area to retain the pre-development habitable floor area.

One method of accommodating inundation includes raising buildings so that habitable areas are above design inundation levels. Ground floor levels can be used for non-habitable purposes, such as garaging and storage. Design of these areas is generally very open to allow flows to pass through unimpeded.

Wet flood proofing takes this to the next level, with solid walls designed to align with flow directions, and sufficient gaps in barrier walls to allow flow and debris to pass through the structure. Impacted walls may be designed to break away when subjected to strong flows without affecting the structural integrity of the building. Structural materials should be water resistant and internal linings are non-structural. Lining materials that deteriorate need to be removed following an inundation event, thus providing an opportunity to allow structural elements to completely dry out before new linings are installed (Australian Building Codes Board, 2012).

Methods more aligned with “defend” approaches are floodwalls and dry flood proofing. Floodwalls can be constructed around a building, or incorporated into fencing, with flood proof gates activated across openings on the approach of an inundation event. This is useful in areas subjected to semi-regular inundation, and for heritage properties unsuited to other building modification methods. However, activation of a gate in response to an inundation event may rely on responsible persons such as individual building-owners to be present, and it relies heavily on the satisfactory performance of moving parts for functionality. Regular testing of the activation system is vital for reliable performance.

Dry flood proofing effectively renders a building watertight. Due to the impacts of differential pressure on the wall of a building caused by water flows, this method can only be considered on a case-by-case basis, and requires specific engineering design and materials consideration.

7.1.2 Role in adaptation to inundation

Depending on the methods selected, building modifications provide accommodate/defend adaptation responses to inundation. They are particularly useful in existing developed settlements where retreat is not considered to be feasible.

Building modifications can be implemented by individual building owners over time as buildings are progressively updated or redeveloped. This is useful for balancing costs with increased exposure to storm tide inundation as sea levels progressively rise.

Figure 21 Example moveable flood wall across a driveway (www.spec-net.com.au)

7.1.3 Interactions with other adaptation options

Modifications to buildings can largely be undertaken in isolation of other activities, and the extents of modification can benefit from the implementation of other adaptation options. It is incompatible with retreat adaptation responses.

Table 25 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 25 Interactions with building design elements, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference.
	Dune construction and restoration	•	Typically no interference.
	Riparian corridor restoration	✓	Can be combined as part of an integrated accommodation strategy for adjacent areas.
	Wetland restoration	✓	Can be combined as part of an integrated accommodation strategy for adjacent areas.
Primary engineering options	Sea dykes / levees	✓×	Can be combined as part of a staged defence/accommodate approach.
	Seawalls / revetments	•	Typically no interference.
	Tidal gates	××	Building modifications to accommodate inundation not required if inundation is prevented.
	Drainage modification	✓	Can be combined as part of an integrated accommodate strategy.

Option type	Option	Interaction	
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.
Built environment design options	Buoyant / moveable structures	•	Typically no interference – similar structures that have the same function so not usually used in the same areas. Building modifications more suited to lower exposure areas.
	Flood / inundation resilient public infrastructure	✓✓	Should be combined to support ongoing functionality of community.
	Raise land levels	✓	Can be combined to accommodate inundation from storm tide events and ongoing sea level rise.
Planning options	Strategic planning	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Emergency planning	✓✗	Can reduce need for emergency response, but retain people in high risk areas.

7.1.4 Whole of life aspects

Buildings are constructed with established design life; for dwellings this is usually only around 50 years. However, communities have an expectation that their dwelling in its current form should still be functional, even if it is 100 years old. Undertaking strategic building modifications as existing buildings are updated provides an opportunity to improve the ability of the structure to accommodate infrequent inundation. The cost for undertaking this is borne by the land-owner, and will depend on the design, extent and location of the original building and the required modifications. The economic feasibility of performing this work must be assessed on a case-by-case basis.

Modifications may fail if the design event is exceeded, or due to poor design and construction. Where measures must be deployed prior to an event (e.g. closing a gate in a flood wall), a delay in activation or faulty operation may result in inundation. This may occur when a land owner is not present to manually operate their system.

7.1.5 Multi-criteria overview

An overview of building design elements as an adaptation option to manage inundation is presented in the following table.

Table 26 Multi-criteria overview of building design elements, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Effective up to the designed levels of combined storm tide and sea level rise inundation.
	Flexibility	Can it be modified after implementation?	Yes, but may be expensive.
	Reversibility	Is it easy to completely remove?	It will depend on the measure.
	No regret	Is there any other social or environmental benefit?	Community cohesiveness and resilience may be improved following inundation events where the community has survived intact.
	Decision horizon	Can it delay the need for major decisions?	Modifications are a temporary solution until a major retreat decision is made.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Use of energy efficient materials and other systems can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Temporary interruption only.
	Landscape	Does it impact landscape values?	Temporary interruption only.
	Recreational use	Does it affect recreational use?	Unlikely.
	Property values	Are private property values affected?	May affect property values (positive and negative). Ongoing functionality of buildings during and after an inundation event is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Unlikely.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Accessibility by emergency services should be considered and incorporated into design of modifications.
Costs	Initial cost	Is the initial cost high?	Modifications can expensive for individuals, but can be done at the same time as other building works. No cost to the wider community.
	Cost of maintenance	Does it need expensive maintenance?	Maintenance costs are similar to normal building maintenance costs.

7.2 Buoyant / moveable structures

7.2.1 Description

Buoyant structures are structures that would ordinarily be founded on land, but because of inundation risks or water level variability, are constructed instead as floating structures. Examples of these include houses and bridges. These structures are usually located in areas sheltered from major wave action, although some bridges are exposed to large waves. These bridges then act as a wave attenuator to upstream areas, although they may be temporarily closed during the passage of the storm event. Buoyant structures are well suited to areas fringing estuaries, and support retention of community vibrancy along waterways affected by inundation. Buoyant systems differ from boats in that they do not have propulsion systems (Tam, 2009).

Some buildings may also be able to be located on rails, and are moved landwards to respond to local inundation events. Uses suitable for these structures include beach kiosks, office areas for caravan parks and other seasonal usage.

For buoyant and moveable structures, utilities such as water and electricity are provided through flexible pipes.

7.2.2 Role in adaptation to inundation

Buoyant and moveable structures provide progressive adaptation to inundation risks without requiring design changes as sea levels rise. Buoyant structures respond automatically, whereas moveable systems require warning before a storm tide event to relocate out of the expected inundation zone.

7.2.3 Interactions with other adaptation options

These structures can be used in isolation of other methods, as they can completely accommodate inundation. In exposed areas, some wave protection may be required for buoyant structures to be feasible, especially as they can be overwhelmed by water influx.

Table 27 presents an overview of the interactions of this option with other adaptation options.

Table 27 Interactions with buoyant and moveable structures, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference.
	Dune construction and restoration	✓	Can be combined as part of an integrated defence/accommodate system.
	Riparian corridor restoration	✓	Can be combined as part of an integrated accommodation strategy.
	Wetland restoration	✓	Can be combined as part of an integrated accommodation strategy.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined as part of a staged defence/accommodate approach.
	Seawalls / revetments	•	Typically no interference.
	Tidal gates	✗	Mobile buildings to accommodate inundation not required if inundation is prevented.
	Drainage modification	•	Typically no interference.
Supportive engineering options	Artificial reefs	•	Typically no interference.

Option type	Option	Interaction	
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.
Built environment design options	Building design elements	•	Typically no interference – similar structures that have the same function so not usually used in the same areas. Building modifications more suited to lower exposure areas, but could be used as a portfolio of solutions.
	Flood / inundation resilient public infrastructure	✓✓	Should be combined to support ongoing functionality of community.
	Raise land levels	•	Typically no interference – these are alternatives, and not usually used at the same location at the same time.
Planning options	Strategic planning	✓×	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Statutory planning	✓×	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Emergency planning	✓×	Can reduce need for emergency response, but retain people in high risk areas.

7.2.4 Whole of life aspects

Buoyant and moveable structures have a finite design life, however consideration of changing water levels is implicit in the design. A typical design life for a kiosk may be 20 years, a dwelling 50 years, and a bridge 50 to 100 years. Regular maintenance and testing for functionality is required, particularly for “rare” design events.

Failure of anchorage or buoyancy systems would cause failure of the structure, and may result in dislodgement.

7.2.5 Multi-criteria overview

An overview of buoyant and moveable structures as an adaptation option to manage inundation is presented in the following table.

Table 28 Multi-criteria overview of buoyant and moveable, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Very effective.
	Flexibility	Can it be modified after implementation?	Yes, but may be expensive.
	Reversibility	Is it easy to completely remove?	Yes, but transportation to new location may be difficult and expensive.
	No regret	Is there any other social or environmental benefit?	Structures can be used to provide residential or commercial function in high risk areas.
	Decision horizon	Can it delay the need for major decisions?	Yes. Buoyant structures allow ongoing use of an area event with sea level rise.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Unlikely.

Aspect	Issue		Expected response
	Landscape	Does it impact landscape values?	Landscape impacts are the same as any built environment impacts.
	Recreational use	Does it affect recreational use?	Support for recreational activities on the coast are enhanced.
	Property values	Are private property values affected?	Uncertain. Will depend on land tenure.
	Impact on ecosystems	Does it impact coastal ecosystems?	Will be site specific. No more than any built environment impacts.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. No specific benefits or impacts identified.
Costs	Initial cost	Is the initial cost high?	Construction may be expensive. For private developments there should be no cost to the wider community.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring and maintenance costs are low but necessary. If constant maintenance is required costs will be high and alternative options may be more appropriate.

7.3 Flood / inundation resilient public infrastructure

7.3.1 Description

Numerous public infrastructure assets are located in, or serve, communities at high risk of inundation. Roads, hospitals, water supply etc. may all be threatened by inundation at some point in time. Maintenance of access to this infrastructure during inundation events can be provided through relocation, permanent works, and contingency/emergency works.

Under sea level rise scenarios, infrastructure that may be permanently affected will either be relocated out of the inundation area, or protected from damage. In some locations, relocation out of the inundation area may not be practicable, for example, road access to a hospital. In these situations, alternative works must be undertaken if this infrastructure is to remain functional.

Permanent adaptation options discussed elsewhere in this report include the construction of inundation barriers such as sea dykes, raising land levels for roads and buildings, and upgrading the design of structures to accommodate inundation events. Other measures may include protection for road and railway foundations at risk of scour, and raising pipelines above inundation levels (Andjelkovic, 2001). These approaches, whilst more expensive, remove key infrastructure from high risk areas and require no action to implement once they are in place.

Contingency and emergency works may include the activation of permanent or temporary flood barriers or emergency sandbagging to prevent inundation. These measures may be more appropriate in areas of relatively low risk of inundation, or where failure is not considered to be catastrophic. Where risks are higher, watertight door shields can be installed on access points into buildings vulnerable to inundation.

Selection of the appropriate measure requires consideration of the level of the risk exposure. Flood barriers may also need to be able to cope with debris impacts and minor wave action.

7.3.2 Role in adaptation to inundation

Retaining the functionality of key public infrastructure during a storm tide event is vital for rapid post-event recovery of the community, and can contribute significantly to avoiding health concerns associated with the loss of water and sewerage infrastructure.

The design of new and upgraded infrastructure should incorporate consideration of sea level rise and storm tide implications commensurate with the asset’s functional design life.

7.3.3 Interactions with other adaptation options

Measures for improving the resilience of public infrastructure to inundation align with many of the adaptation options discussed elsewhere in this document. A retreat adaptation response will need to consider alternatives for meeting demand provided by the infrastructure.

Table 29 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 29 Interactions with flood / inundation resilient public infrastructure, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference.
	Dune construction and restoration	•	Typically no interference.
	Riparian corridor restoration	✓	Can be combined as part of an integrated accommodation strategy.
	Wetland restoration	✓	Can be combined as part of an integrated accommodation strategy.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined as part of a staged defence/accommodate approach.
	Seawalls / revetments	•	Typically no interference.
	Tidal gates	✓	Tidal gates may reduce exposure of infrastructure to extreme flood levels.
	Drainage modification	✓	Can be combined as part of an integrated accommodate strategy.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.
Built environment design options	Building design elements	✓✓	Should be combined to support ongoing functionality of community.
	Buoyant / moveable structures	✓✓	Should be combined to support ongoing functionality of community.
	Raise land levels	✓✗	Can be combined as part of a staged defence/accommodate approach.
Planning options	Strategic planning	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Emergency planning	✓✗	Can reduce need for emergency response, but may retain people in high risk areas.

7.3.4 Whole of life aspects

Key public infrastructure typically has a long design life, and so needs to include consideration of extreme storm events and projected sea level rise in its design and location. Permanent mitigation measures can be costly and the practicality of emergency protection versus permanent measures must be considered against the risk of inundation, the implications of inundation on ongoing functionality and cost. As sea levels rise and projections are updated, the design of protection works should be reviewed to assess ongoing suitability.

Emergency response measures usually require trained personnel for deployment. In remote communities or areas where multiple smaller communities may be affected, there may be insufficient resources to support this.

Failure will occur when the level of protection provided is exceeded by the local conditions (water levels, current speeds, debris loads etc.), or if timely protection is unable to be provided. With regard to permanent works, inadequate design or immunity standards and poor construction can also lead to failure during an inundation event.

Maintenance and review timeframes will depend on the protection method selected, and the temporary or permanent nature of the work. Following a storm tide event, a post-event review should be undertaken to assess the effectiveness of the protection implemented, and identify improvements.

7.3.5 Multi-criteria overview

An overview of flood / inundation resilient public infrastructure as an adaptation option to manage inundation is presented in the following table.

Table 30 Multi-criteria overview of flood / inundation resilient public infrastructure, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Works must be effective to retain asset functionality under temporary and permanent inundation scenarios.
	Flexibility	Can it be modified after implementation?	Yes, but may be expensive.
	Reversibility	Is it easy to completely remove?	It will depend on the infrastructure. Temporary works can be removed easily.
	No regret	Is there any other social or environmental benefit?	Infrastructure that provides ongoing functionality can contribute to community cohesiveness during post-event recovery.
	Decision horizon	Can it delay the need for major decisions?	Yes, the works may be able to delay retreat.
	Synergy with mitigation	Does it help reducing emissions?	Initial construction works will contribute carbon emissions. Use of energy efficient materials and other systems can contribute to offsetting carbon emissions. Additional emissions are avoided by not rebuilding.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Unlikely.
	Landscape	Does it impact landscape values?	Will be site specific. No specific benefits or impacts identified.
	Recreational use	Does it affect recreational use?	Will be site specific. Temporary measure unlikely to impact on recreation during emergency periods.
	Property values	Are private property values affected?	May positively affect property values. Protection of buildings from inundation is the primary positive benefit.
	Impact on ecosystems	Does it impact coastal ecosystems?	Possibly. Will be site specific.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Maintenance of infrastructure function is intended to improve disaster and emergency response and management.
Costs	Initial cost	Is the initial cost high?	Construction may be expensive. Community involvement in emergency response measures can reduce costs.
	Cost of maintenance	Does it need expensive maintenance?	Maintenance may be an issue, depending on the location and temporary vs permanent nature of the works.

7.4 Raise land levels

7.4.1 Description

The placement of imported soil to elevate land above natural surface levels is a common approach to improving the usability of land for development. Filling of low-lying areas raises the building surface above inundation levels, and is often used for building platforms and roadways. The method can be used for isolated buildings and access routes, or large scale filling can be used for new urban developments. Fill materials need to be clean and free of large organic particles so that decomposition over time does not lead to uneven settlement.

However, filled areas can have a significant impact on the local drainage of an area. Rainfall, overland and creek flows are re-directed around the filled areas, or fill may block natural drainage paths or substantially reduce natural flood storage. This can lead to localised scouring of fill mounds and worsening of upstream inundation levels. Protection of the edges of the fill with vegetation, geotextiles or armour may be required to prevent undermining, and drainage flows need to be considered in the design. Where this occurs in areas that are regularly inundated, the raising of land is effectively a reclamation.

In rural areas, new or existing buildings can be placed on raised earthen platforms to lift them and their access routes above the flood extent. In urban areas, this method is most cost effective for new developments, as it is difficult and costly to retrofit this option for existing development. Extensive filling for new developments often requires the removal of all established vegetation, as partial burial can severely impact on the survival of many tree species, and timeframes for construction processes can be substantially accelerated.

As sea levels rise, land can be filled progressively. This is appropriate for infrastructure such as roads that may require periodic rebuilding, but may not be cost effective for more permanent structures such as dwellings or commercial buildings. Where multiple properties are at risk of inundation, consideration should also be given to all properties and alternative options that benefit the wider community, rather than approaching adaptation on a property-by property piecemeal fashion. There is also a risk that as fill heights increase, so does the area of land used to contain the batter, or sloped edge of the fill.

The selection of the design fill level should be linked to the design life of the structure it is intended to support, and needs to include an allowance for freeboard.

7.4.2 Role in adaptation to inundation

Placing development on raised land can accommodate storm tide and sea level rise inundation. It can also have benefits for catchment based flooding. However, many Councils require substantial analysis to be completed as part of planning approvals to demonstrate that the filling work will not have any adverse impacts on inundation levels. New development on filled land that was previously subjected to regular inundation is effectively reclamation; seaward edges of the reclamation will need to be protected from scour by armouring. Reclamation work is a “defend” adaption response.

7.4.3 Interactions with other adaptation options

Where reclamation occurs close to the existing shoreline, the armoured edge may eventually function as a seawall. In adaptation terms, raised land levels are used to defend or accommodate inundation, but not to retreat.

Table 31 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 31 Interactions with raising land levels, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	•	Typically no interference.
	Dune construction and restoration	•	Typically no interference, however dunes can be created on the seaward side of raised land.
	Riparian corridor restoration	•	Typically no interference, unless filling occurs in vegetated riparian zone.
	Wetland restoration	•	Typically no interference, unless filling occurs in wetland.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined as part of an integrated defence system.
	Seawalls / revetments	•	Typically no interference, however seawalls can be used to stabilise the seaward side of raised land (e.g. a reclamation).
	Tidal gates	✓	Tidal gates may support raising of land levels surrounding coastal waterways.
	Drainage modification	✓✗	Can be combined as part of an integrated accommodate strategy, however filling on land may reduce capacity of drainage system and increase inundation elsewhere.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference. An artificial headland is effectively a reclamation.
Built environment design options	Building design elements	✓	Can be combined to accommodate inundation from storm tide events and ongoing sea level rise.
	Buoyant / moveable structures	•	Typically no interference –not usually used in the same areas. Land filling more suited to lower exposure areas.
	Flood / inundation resilient public infrastructure	✓✗	Can be combined as part of a staged defence/accommodate approach.
Planning options	Strategic planning	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Statutory planning	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Emergency planning	✓✗	Can reduce need for emergency response and retain emergency access but retain people in high risk areas.

7.4.4 Whole of life aspects

Filling of land to above inundation levels is a long term adaptation solution. Erosion protection works such as armouring of the edge of the fill will have a finite design life, and will need to be routinely monitored and maintained as required. As sea levels progressively rise the design of the fill level will need to be reviewed and assessed for ongoing performance and functionality. Initial design must therefore consider the design life of the infrastructure supported by the fill.

Failure of a filled area can be caused by inappropriate fill materials, particularly high levels of organic particles and very fine sediments such as those found in wetland areas. This material settles unevenly over time and can be syphoned out through any edge protection works. The edge protection works need to be appropriately designed to defend against strong currents, and complementary drainage works need to be constructed at the same time as the filling works to reduce the risk of scour and upstream flooding. Failure can also occur from fill materials unsuited to exposure to marine inundation and groundwater.

7.4.5 Multi-criteria overview

An overview of raising land levels as an adaptation option to manage inundation is presented in the following table.

Table 32 Multi-criteria overview of raising land levels, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Raised land levels can be effective to retain land functionality under temporary and permanent inundation scenarios.
	Flexibility	Can it be modified after implementation?	Yes, but extents are limited by design and development.
	Reversibility	Is it easy to completely remove?	No, especially if it contains infrastructure.
	No regret	Is there any other social or environmental benefit?	Raised land that provides ongoing access can contribute to community cohesiveness, but need to ensure no adverse impacts on terrestrial flooding.
	Decision horizon	Can it delay the need for major decisions?	Reclamation or filling of land is used instead of retreat and may be considered as a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Construction works will contribute carbon emissions. Planting vegetation can contribute to offsetting carbon emissions.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Oceanfront reclamation can affect access, particularly if it is for private purposes.
	Landscape	Does it impact landscape values?	Yes. Source areas for fill may also be affected.
	Recreational use	Does it affect recreational use?	Will be site specific. No specific benefits or impacts identified.
	Property values	Are private property values affected?	May positively affect property values. Protection of buildings and maintenance of access are the primary positive benefits. Values may be negatively affected if flooding is worsened.
	Impact on ecosystems	Does it impact coastal ecosystems?	Yes.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. Benefits include removing habitation to above highest risk areas, but people still potentially surrounded by inundated areas. May also provide safer sites for emergency facilities.
Costs	Initial cost	Is the initial cost high?	Construction works are generally expensive, and cost is heavily dependent on fill material sand sources. On private property there should be no cost to the wider community.
	Cost of maintenance	Does it need expensive maintenance?	Monitoring is required to confirm ongoing functionality although maintenance is infrequent if appropriately designed. Maintenance after major storm events may be required.

8. Planning options

Planning controls can be used to guide suitable adaptation responses to inundation. They may also be needed to support the implementation of certain options. In general, they seek to reduce inundation risks by planning for future development to be located out of the highest risk areas.

It is important to reinforce that the planning options available to individual Councils may be limited by local circumstances, such as geographic area, availability of suitable elevated land, financial capacity and community needs. For these reasons, ongoing and active support and involvement from State and Federal Government in solution development and implementation is vital.

8.1 Strategic planning

8.1.1 Description

Strategic planning manages future growth, supports business development and ensures a sustainable future. Strategic planning inundation options may be used to provide a buffer in which natural coastal processes can occur without impacting on the built environment. There are several mechanisms that can be employed to retain or restore land as development free. In some circumstances, these mechanisms could also be used to acquire land on which to situate coastal protection structures for community-wide benefit, such as seawalls or sea dykes.

Figure 22 Undeveloped buffer between shoreline and dwellings, Beacon Point (supplied by CoGG)

Development setback

A development setback establishes a distance within a property that is subject to additional development regulation. It is a commonly used tool applied through planning schemes; in the coastal management context it is applied to waterfront property boundaries, to avoid loss or damage to infrastructure on the property as a result of coastal and/or hydrological processes associated with erosion or inundation. Ideally, the land within the setback is retained as development free. This has an additional benefit of reducing the need for coastal protection structures, but should they be required, sufficient room is provided for protection works such as seawalls or levees to be constructed on private property rather than on the adjoining public land. Ownership of land affected by the setback remains unchanged.

A coastal setback is usually applied to a section of shoreline rather than to individual properties, to support the continued natural functionality and behaviour of that coastal sector. Suitable for use on open coast and estuarine sites, a setback is commonly used where some level of development has already occurred and further seaward expansion of infrastructure is highly undesirable. The distance of the setback for each coastal sector is unique to that shoreline, and should be based on an assessment of the coastal hazards affecting that area. Setbacks can be established as buffers against coastal recession (erosion) and/or inundation.

Strategic withdrawal

Strategic withdrawal refers to the progressive withdrawal of infrastructure and other services from a high risk area. As services are progressively no longer provided, ongoing usage is discouraged and eventually the area is abandoned by higher intensity uses.

Strategic withdrawal is often triggered by ageing networks or a major storm event causing significant damage to utility infrastructure such as water or electricity supply. The cost of repair or replacement of these services may not be economically feasible, particularly if only a small number of users are expected to use the repaired service and there is a high ongoing risk of damage during future storm events.

In these circumstances, existing development either progressively goes “off the grid”, or progressively abandons the area. Other planning mechanisms such as land buy-back or land use planning may eventually result in formalisation of the reduction in development intensity.

Land buy-back

In some locations, existing development or historical approvals may permit current land owners to undertake development activities that no longer align with community expectations for that area, or that modern, detailed hazard assessments have identified as being at risk of inundation. Land buy-back involves the purchase, usually by government, of land considered inappropriate for development. From a coastal risk perspective, targeted land is usually vulnerable to inundation and/or erosion, or its acquisition contributes to a continuous buffer against coastal hazards for a coastal sector.

Acquisition is usually a voluntary process whereby either the owner offers to sell land to the government, or the government / philanthropic organisation approaches a land owner to purchase the land. Purchase costs are often shared between multiple levels of government. Philanthropic organisations may also acquire the land for alternative purposes (e.g. habitat protection), and then place caveats on the land preventing future development. This type of purchase has a wider benefit in that it also retains the natural coastal function of the land. In extreme situations, the government may compulsorily acquire (resume) the land.

Coastal land acquired by government through a buy-back scheme generally becomes part of the coastal reserves system.

Land swap

Land swap involves the exchange of land for mutually beneficial outcomes. It usually is applied to individual properties, but has also been used to relocate small communities. Land has commonly been swapped historically with government to provide environmental benefits in exchange for increased development rights or opportunities for commercial expansion.

For coastal risk management purposes, land subject to coastal hazards may be swapped for land with similar or improved development potential out of the hazard area. That land located outside of the high hazard area may be specifically acquired for the purposes of the land swap, or may be existing publicly held land with no particular assigned usage. High hazard land targeted by government using this mechanism then usually becomes part of the coastal reserves system after any infrastructure has been removed or re-purposed.

In order to be successful, the land swap needs to be advantageous for both parties.

Land-use planning

Changing land use can be a useful way of managing potential future development in high risk coastal areas. This can include rezoning or the use of overlays to reduce potential development intensities, or consciously not changing zonings to retain existing low intensities or low-risk activities. Land-use planning is a routine responsibility of local government, and is reviewed on regular planning cycles. Usually land use is changed to increase development intensities, particularly for residential or commercial purposes. Development pressures such as expansion of coastal villages into surrounding coastal and rural areas can be considered by decision makers with input from the community in light of the coastal hazards (and any other planning aspects), before land use is formally changed.

Changes to land use can be staged to permit temporary usage in the short to medium term whilst risks may be considered to be at acceptable levels. As risks are reassessed in the future, land use can be further reviewed.

8.1.2 Role in adaptation to inundation

Development setbacks can be used to confine infrastructure to areas above adopted inundation extents. Land use planning can restrict usage of the land to be compatible with the nature of the hazard, for example, land subject to occasional storm tide inundation may be suitable for grazing purposes. Both of these options apply to public and privately owned land.

Land buy-back and land swap generally place the land under public control, where it can be managed as part of the wider public estate, such as for coastal protection purposes. Purchases by philanthropic organisations retain the land in private ownership but generally contain additional safeguards to prevent future development. Permanent development on land acquired is generally not supported. Strategic withdrawal is most commonly associated with low-lying areas considered to be highly vulnerable to inundation.

The removal, restriction or withdrawal of development from all of these areas will allow natural inundation processes to continue to occur without placing communities or significant infrastructure at risk.

8.1.3 Interactions with other adaptation options

Most of the planning options can be readily combined with other options, particularly as there can be variability in inundation extents over time. Retaining or restoring land as development free can delay the need for physical infrastructure which in the future may become the last line of defence.

Table 33 presents an overview of the interactions of this option with other adaptation options.

Table 33 Interactions with strategic planning, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Can be combined to maximise buffer integrity and functionality.
	Dune construction and restoration	✓	Can be combined to maximise buffer integrity and functionality.
	Riparian corridor restoration	✓	Can be combined to maximise buffer integrity and functionality.
	Wetland restoration	✓	Can be combined to maximise buffer functionality.
Primary engineering options	Sea dykes / levees	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Seawalls / revetments	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Tidal gates	✓	Can be combined to maximise buffer integrity and functionality.
	Drainage modification	✓	Can be combined as part of an integrated defence system
Supportive engineering options	Artificial reefs	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Detached breakwaters	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Groynes and artificial headlands	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
Built environment design options	Building design elements	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Buoyant / moveable structures	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Flood / inundation resilient public infrastructure	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Raise land levels	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
Planning options	Statutory planning	✓	Can be combined as part of staged retreat.
	Emergency planning	✓	Removes people and infrastructure from highest risk areas.

8.1.4 Whole of life aspects

Strategic planning mechanisms require periodic review in light of updates to science to confirm ongoing functionality of land identified as a buffer to inundation. The assessments of land extents identified must be site specific, technically sound and robust, particularly for future climate change scenarios. Reviews should take place every 5 to 10 years.

Implementation of these options requires policy support for transparency and to inform discussion on any legal or compliance issues relating to the selection of land. In some locations, affected stakeholders may be resistant to the abandonment of existing uses.

If inundation extents are well understood and erosion rates do not increase significantly over the next 30 to 50 years, these mechanisms pose a relatively low risk of failure. As part of any abandonment of existing uses, physical removal of services such as water and electricity supply will be required for safety.

8.1.5 Multi-criteria overview

An overview of strategic planning mechanisms as an adaptation option to manage inundation is presented in the following table.

Table 34 Multi-criteria overview of strategic planning mechanisms, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	An appropriately sized buffer can accommodate extreme sea levels.
	Flexibility	Can it be modified after implementation?	Yes.
	Reversibility	Is it easy to completely remove?	Yes.
	No regret	Is there any other social or environmental benefit?	Yes, space for ecosystem restoration. Contributes to maintenance of public access along and/or to the shoreline.
	Decision horizon	Can it delay the need for major decisions?	These options are major decisions. Setbacks can delay the need for retreat alternatives.
	Synergy with mitigation	Does it help reducing emissions?	Yes, can contribute to offsetting carbon emissions if coupled with ecosystem restoration.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Strategic planning can improve access to and along the shoreline.
	Landscape	Does it impact landscape values?	Coastal landscape values are improved.
	Recreational use	Does it affect recreational use?	Possibly. Restoration of land into public ownership may increase recreational opportunities. Recreational use of private land may be restricted through no infrastructure provision.
	Property values	Are private property values affected?	May affect property values (positive and negative).
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a positive impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. Benefits include removing habitation from within highest risk areas.
Costs	Initial cost	Is the initial cost high?	Setbacks are generally inexpensive, but other mechanisms can be extremely expensive. Site specific study costs need to be included.
	Cost of maintenance	Does it need expensive maintenance?	No. Similar to normal open space management costs.

8.2 Statutory planning

8.2.1 Description

Statutory planning refers to the consideration of individual development proposals as required by legislation. This may be against the local government planning scheme that contains provisions on how land may be used, or against State policies and other approved plans or strategies. Each application is considered on its merits and either approved, approved with conditions, or refused.

As part of the assessment process, the suitability of the proposed development on the subject land should be considered. Where ongoing usage for that proposal is considered to be inappropriate, a number of mechanisms may be available to allow the development to proceed for the short-to-medium term only, or subject to ongoing review of suitability.

A major drawback of statutory planning is that the majority of mechanisms only apply if a change to the existing usage of the land is proposed. Existing development is largely unaffected.

Non-permanent land tenure

In many locations along the coast, private individuals occupy or manage land owned by the Crown (the State of Victoria) under lease arrangements. The activities that can be carried out on the land usually form part of the lease agreement, and range from low intensity uses such as grazing through to commercial premises. Some leases have been in place for decades. At the expiry of the lease, lessees can apply to renew or relinquish the lease, or may even apply to have the land tenure converted to freehold ownership. If ongoing usage is requested, the lease and/or tenure is reassessed for its suitability to continue.

As our knowledge of coastal hazard risk areas increases, it may become apparent that some locations will become increasingly unsuitable for ongoing occupation for particular purposes. For example, an area that is not inundated by an extreme storm tide event at present may be more vulnerable to future inundation as a result of sea level rise and increased storm frequencies. Alternatively, an area that is already inundated under very high tide conditions may be more severely or frequently affected in the future.

In these instances, it may be prudent to either not renew the lease, or to renew the lease for a timeframe that permits ongoing occupation of the land whilst risk levels are still relatively low. Low intensity uses that do not place human life at risk may still be permissible on this land despite the hazards. At lease expiry the risks can again be reviewed and reassessed.

Time-limited approval

Time-limited approvals allow for the lawful use of land to be terminated after a set period of time. Lawful use can only resume once a new approval is granted or the existing approval is renewed.

A key issue with these approvals is that the approval may expire even though the hazard may not have yet occurred (Macintosh, Foerster, & McDonald, 2013). To manage this, identification of the expiry date for the approval must be linked to a robust and site specific assessment of the coastal hazards. The time frame involved should include sufficient allowance for the hazard to be reviewed, and the relative risk to the site re-assessed, before the site is realistically exposed to the hazards on a frequent basis. Renewal of the approval can then be considered in the context of projected hazards from that point onwards.

Ongoing usage of the land depends on the local adaptation strategy. Under a “defend” strategy, the land owner may be required to construct or contribute to coastal protection works such as a seawall. An “accommodate” response may be to undertake building modifications, whereas a “retreat” strategy may entail landward relocation of infrastructure out of the hazard zone or abandonment of the site. In addition, Council can require that dwellings be readily moved (e.g. on rails).

Contingent approval

Contingent approvals allow for the lawful use of land to be stopped or altered. Usually, the approval is linked to the occurrence of a particular set of circumstances, such a threshold water level being reached, or erosion progressing to within a set distance of infrastructure on the land. The circumstances become a condition of the approval, and if they occur, the approval is revoked. Alternatively, the right to use the land for that purpose expires, and continued “use becomes illegal unless the approval is renewed or a new approval is granted” (Macintosh, Foerster, & McDonald, 2013). Approvals relating to the ongoing usage of the land must be considered in the context of the local adaptation strategy as discussed in “Time-limited approvals”.

Contingent approvals are useful for permitting usage of the land until a hazard eventuates. They are especially useful for short to medium term uses, and allow for mitigation costs to be delayed (Macintosh, Foerster, & McDonald, 2013). However, they may still provide an expectation to some landowners, particularly those who purchase the property subsequent to approval being granted, that continued usage of the site for that purpose is permanent.

Rolling easement

Titus (2011), in the context of adaptation to coastal climate change, defines a rolling easement as “a legally enforceable expectation that the shore or human access along the shore can migrate inland instead of being squeezed between an advancing sea and a fixed property line or physical structure. The term refers to a broad collection of legal options, many of which do not involve easements. Usually, a rolling easement would be either (a) a law that prohibits shore protection or (b) a property right to ensure that wetlands, beaches, barrier islands, or access along the shore moves inland with the natural retreat of the shore.”

The prohibition of shore protection refers to measures that do not permit coastal protection structures such as seawalls or levees to be built. As sea levels progressively rise, the available “dry” beach will eventually disappear. In areas where private property closely adjoins the coastal margin, loss of the dry beach may sever public access. The rolling easement provides the concept of that width of land that should be made available for either accommodating natural coastal processes, or ensuring that the community benefit to access is not lost under rising sea levels. This concept is useful, particularly for wetlands, as the boundaries of wetlands migrate at different rates: the position of the seaward boundary is heavily influenced by wave action whereas landward boundary migration is dictated heavily by land elevation.

The rolling easement can be implemented through conditions on approvals (including those discussed in this document), planning scheme zones and regulations or local laws. Clarification of the rolling easement concept in legislation would likely be required to further support implementation.

Non-regulatory approaches suggested by Titus (2011) include:

- The right to public access regardless of land ownership
- Covenants and easements binding owners to avoidance of shore protection structures

- Ambulatory property boundaries (boundaries that are linked to tidal extents so that the boundary migrates inland over time)
- Compensatory provisions such as transferrable development rights (rights that are lost on inundated land are transferred to nearby properties not affected by coastal hazards.

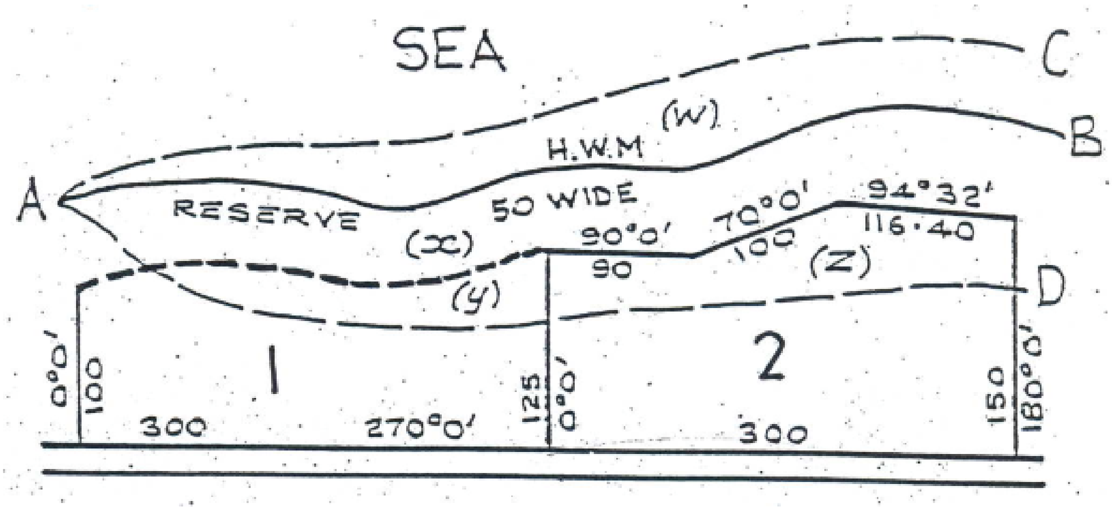

Figure 23 Example ambulatory boundary (NPPL Public Land Policy Section, 1993)

8.2.2 Role in adaptation to inundation

Statutory planning tools are very useful for permitting the functional usage of land vulnerable to future coastal hazards until such time that the risks outweigh the benefit and ongoing use for the approved purpose become untenable. This is especially relevant to projected progressive increases in sea level.

Contingent approvals also give flexibility to the timing or staging of major infrastructure decisions by allowing natural coastal processes to occur unhindered before "defence" responses are required to be implemented.

These tools ultimately still provide scope for the eventual removal or withdrawal of development from high risk inundation areas.

8.2.3 Interactions with other adaptation options

Most of the planning options can be readily combined with other options, particularly as there can be variability in inundation extents over time. Uncertainty with climate change projections, available funding and community attitudes may result in a management approach that combines physical and planning options to maximise short to medium term usage of coastal areas.

Table 35 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 35 Interactions with statutory planning, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Can be combined to maximise buffer integrity and functionality.
	Dune construction and restoration	✓	Can be combined to maximise buffer integrity and functionality.
	Riparian corridor restoration	✓	Can be combined to maximise buffer integrity and functionality.
	Wetland restoration	✓	Can be combined to maximise buffer functionality.

Option type	Option	Interaction	
Primary engineering options	Sea dykes / levees	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Seawalls / revetments	✓✗	Can be combined as part of an staged defence system, but unsuitable for retreat.
	Tidal gates	✓	Can be combined to maximise buffer integrity and functionality.
	Drainage modification	✓	Can be combined as part of an integrated defence system
Supportive engineering options	Artificial reefs	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Detached breakwaters	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
	Groynes and artificial headlands	✓✗	Can be combined as part of an integrated defence system, but unsuitable for retreat.
Built environment design options	Building design elements	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Buoyant / moveable structures	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Flood / inundation resilient public infrastructure	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
	Raise land levels	✓✗	Can be combined as part of a staged accommodation strategy, but unsuitable for retreat.
Planning options	Strategic planning	✓	Can be combined as part of staged retreat.
	Emergency planning	✓	Removes people and infrastructure from short-term highest risk areas.

8.2.4 Whole of life aspects

As for strategic planning, statutory planning requires contemporary assessments that are site specific, technically sound and robust, to identify land extents vulnerable to inundation, particularly for future climate change scenarios. Updated assessments using the most recent credible scientific information and assessment techniques should be undertaken every 5 to 10 years, depending on how well actual water level changes align with modelled changes over time.

Implementation of these options requires strong policy support. Some of the concepts involved have not been applied widely in Australia, and there may be education required to assist the community to better understand these options and the implications of their use.

If inundation extents are well understood and erosion rates do not increase significantly over the next 30 to 50 years, these mechanisms pose a relatively low risk of failure. If there is great uncertainty in predictions of sea level rise, approvals are best linked to the occurrence of a particular event, such as inundation to within x m of a dwelling. As part of any abandonment of existing uses or infrastructure, physical removal of services such as water and electricity supply will be required for safety.

8.2.5 Multi-criteria overview

An overview of statutory planning mechanisms as an adaptation option to manage inundation is presented in the following table.

Table 36 Multi-criteria overview of statutory planning mechanisms, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	An appropriately sized buffer can accommodate extreme sea levels. Effectiveness is reduced in heavily developed areas.
	Flexibility	Can it be modified after implementation?	Yes.
	Reversibility	Is it easy to completely remove?	Yes.
	No regret	Is there any other social or environmental benefit?	Yes, space for ecosystem restoration. Contributes to maintenance of public access along and/or to the shoreline.
	Decision horizon	Can it delay the need for major decisions?	Yes. Statutory planning mechanisms can delay the need for retreat alternatives. Implementation of a rolling easement is a major decision.
	Synergy with mitigation	Does it help reducing emissions?	Yes, can contribute to offsetting carbon emissions if coupled with ecosystem restoration.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Statutory planning can improve access to and along the shoreline.
	Landscape	Does it impact landscape values?	Coastal landscape values are improved.
	Recreational use	Does it affect recreational use?	Possibly. Restoration of land into public ownership may increase recreational opportunities. Recreational use of private land may be restricted through no infrastructure provision.
	Property values	Are private property values affected?	May affect property values (positive and negative).
	Impact on ecosystems	Does it impact coastal ecosystems?	Can have a positive impact on coastal ecosystems.
	Emergency procedures	Is there any benefit for disaster and emergency procedures?	Will be site specific. Benefits include removing habitation from within highest risk areas.
Costs	Initial cost	Is the initial cost high?	Tools apply to the non-development of high hazard parts of the land. Most are inexpensive to implement, but some landowners may have concerns over the value of unrealised development potential. Site specific study costs need to be included.
	Cost of maintenance	Does it need expensive maintenance?	No. Similar to normal open space management costs, and all on privately managed land.

8.3 Emergency planning

8.3.1 Description

As sea levels continue to rise, and during storm tide events, there is a risk that dwellings or communities may be permanently or temporarily isolated from major access routes. This then can become problematic for emergency services personnel to reach people in times of personal or community crisis.

Emergency planning refers to planning undertaken to identify accessibility issues for coastal communities, and includes consideration of evacuation and recovery measures. The selection of adaptation options must be undertaken in consideration of how emergency responses can be provided and managed.

Where large communities are temporarily isolated, evacuation to higher ground within the community may be an acceptable response. However, if road access is to be retained at all times, consideration must be given to physical works to prevent inundation, or development of alternative access routes.

Depending on the locality, the designated evacuation shelter may also be at risk of inundation. Planning to relocate or identify alternative facilities on higher ground should therefore be undertaken before the shelter is rendered non-functional. If the adaptation strategy for a community is to accommodate, assets used in emergency planning must also accommodate coastal hazards.

Management of other basic services during an inundation event also needs to be considered in emergency planning. These include electricity, water supply and sewerage. Elevated water levels may affect the ability of the sewerage system to operate, causing back flooding into dwellings with commensurate health risks if water levels are sustained for long periods.

Figure 24 Flooding at Eastern Beach, 27 January 2016 (ABC, 2016)

Should provision of emergency services be extremely problematic, there may be sufficient justification to pursue a retreat strategy. Alternatively, an inability to provide emergency response to an area may encourage retreat by market forces, although this is not a deterrent to many members of the wider community.

8.3.2 Role in adaptation to inundation

Emergency planning provides a means to determine the suitability of conventional adaptation options for a particular area. It also assists in identifying which areas require defend, accommodate or retreat strategies.

The nature of the inundation risk (storm tide vs sea level rise) influences how emergency access, particularly by road, can be provided. Roads designed to cope with periodic slow moving tidal inundation (i.e. sea level rise) may be able to continue to be used when inundated, whereas during a storm tide event the potential damage extent to an inundated road may necessitate road closure.

8.3.3 Interactions with other adaptation options

Emergency planning is not strictly an adaptation option, but it must be considered to inform selection of appropriate adaptation options, and also influence the appropriate adaptation strategy. It is also reactive, and the response depends upon which adaptation option is adopted.

Table 37 presents an overview of the interactions of this option with other adaptation options covered in this document.

Table 37 Interactions with emergency planning, adapted from GU/GHD (2012)

Option type	Option	Interaction	
Living shoreline options	Beach nourishment	✓	Can maximise buffer integrity and functionality to reduce need for emergency response and retain emergency access.
	Dune construction and restoration	✓	Can maximise buffer integrity and functionality to reduce need for emergency response and retain emergency access.
	Riparian corridor restoration	✓	Can maximise buffer integrity and functionality to reduce need for emergency response and retain emergency access.
	Wetland restoration	✓	Can maximise buffer integrity and functionality to reduce need for emergency response.
Primary engineering options	Sea dykes / levees	✓	Can reduce need for emergency response and retain emergency access.
	Seawalls / revetments	✓	Can reduce need for emergency response and retain emergency access.
	Tidal gates	✓	Can reduce need for emergency response and retain emergency access.
	Drainage modification	✓	Can reduce need for emergency response and retain emergency access.
Supportive engineering options	Artificial reefs	•	Typically no interference.
	Detached breakwaters	•	Typically no interference.
	Groynes and artificial headlands	•	Typically no interference.
Built environment design options	Building design elements	✓✗	Can reduce need for emergency response, but retain people in high risk areas.
	Buoyant / moveable structures	✓✗	Can reduce need for emergency response, but retain people in high risk areas.

Option type	Option	Interaction	
	Flood / inundation resilient public infrastructure	✓✗	Can reduce need for emergency response, but may retain people in high risk areas.
	Raise land levels	✓✗	Can reduce need for emergency response and retain emergency access but retain people in high risk areas.
Planning options	Strategic planning	✓	Can reduce need for emergency response.
	Statutory planning	✓	Can reduce need for emergency response.

8.3.4 Whole of life aspects

Review of emergency planning should be undertaken as part of planning scheme reviews, and be reconsidered whenever a new assessment that affects the previous inundation extents is undertaken. Emergency planning should also be considered in development applications, and a holistic review of a particular area undertaken on a regular basis, such as annually. This is particularly important for rapidly expanding communities with large urban subdivisions.

Consideration also needs to be made on the indirect impacts of inundation on emergency access, such as on the operation of power, water supply and sewerage systems. Failure of these systems may have additional negative impacts on the community.

8.3.5 Multi-criteria overview

An overview of emergency planning as an adaptation option to manage inundation is presented in the following table.

Table 38 Multi-criteria overview of statutory planning mechanisms, adapted from GU/GHD (2012)

Aspect	Issue		Expected response
Climate uncertainty	Effectiveness	How effective is it for inundation adaptation?	Not very. Emergency planning is an element that must be considered in the selection of adaptation strategies and options.
	Flexibility	Can it be modified after implementation?	Yes.
	Reversibility	Is it easy to completely remove?	No. New arrangements will need to be made.
	No regret	Is there any other social or environmental benefit?	Yes, removal of people from high risk areas..
	Decision horizon	Can it delay the need for major decisions?	No. It may accelerate the need for major decisions.
	Synergy with mitigation	Does it help reducing emissions?	No.
Social and environmental impacts	Accessibility	Does it affect access to the shore?	Access to the shore may be compromised by options to support emergency access.
	Landscape	Does it impact landscape values?	Will depend on options chosen to support emergency access.
	Recreational use	Does it affect recreational use?	Possibly. Will depend on options chosen to support emergency access.
	Property values	Are private property values affected?	May affect property values (positive and negative).
	Impact on ecosystems	Does it impact coastal ecosystems?	Will depend on options chosen to support emergency access.
	Emergency procedures	Is there any benefit for disaster and	Yes.

Aspect	Issue		Expected response
		emergency procedures?	
Costs	Initial cost	Is the initial cost high?	Planning costs are low. Option implementation may be high.
	Cost of maintenance	Does it need expensive maintenance?	No.

9. Legal and administrative framework

The following sections outline the policy direction the relevant planning schemes provide in relation to coastal land in the Geelong region. Both the Greater Geelong Planning Scheme and Queenscliffe Planning Scheme are applicable.

9.1 State Planning Policy Framework (SPPF)

The SPPF seeks to ensure that the objectives of planning in Victoria (as set out in Section 4 of the *Planning and Environment Act 1987*) are fostered through appropriate land use and development planning policies and practices which integrate relevant environmental, social and economic factors in the interests of nett community benefit and sustainable development. The relevant State Planning Policies are identified in Table 39.

9.2 Strategies – Local Planning Policy Framework (LPPF)

The LPPF consists of a Council's Municipal Strategic Statement (MSS) and Local Planning Policies. Local Planning Policies are tools to implement the objectives and strategies of the MSS. The MSS is a concise statement of the key strategic planning, land use and development objectives for the municipality and the strategies and actions for achieving the objectives. Relevant provisions of both Councils' MSS and local planning policies are outlined below.

9.2.1 City of Greater Geelong

Municipal Strategic Statement (MSS)

Clause 21.05-4 Coastal environments

The objectives of Clause 21.05-4 are "*to protect, maintain and enhance the coast, estuaries and marine environment*" and "*to respect and manage coastal processes*".

Relevant strategies to achieve these objectives include:

- Focus urban coastal development within existing urban settlements.
- Prevent lineal urban sprawl along the coast.
- Avoid the loss of, and wherever possible increase, public access to the foreshore environment.
- Restrict development on primary dunes.
- Ensure the potential for existence of acid sulphate soils adjacent to coastal and wetland locations is considered.
- Setback future land use and development from coastal areas, estuaries and coastal wetlands to provide a buffer which is adequate to accommodate coastal recession and the landward migration of coastal wetland vegetation communities such as mangroves and salt marshes.

Clause 21.05-5 Climate change

The objective of Clause 21.05-5 is "*to plan for and adapt to the impacts of climate change*". To achieve this objective, "*avoid land use and development within areas considered at risk of coastal erosion and inundation from flooding, storm surge and rising sea levels*".

Local Planning Policies

No local planning policies are considered directly relevant to this project.

Table 39 Relevant State Planning Policies

Clause	Objective	Relevant Strategies	Applicability
11.05-5 Coastal Settlement	To plan for sustainable coastal development.	Avoid development on ridgelines, primary coastal dune systems and low lying coastal areas	Development and coastal land
12.01-1 Protection of Biodiversity	To assist the protection and conservation of Victoria's biodiversity, including important habitat for Victoria's flora and fauna and other strategically valuable biodiversity sites.	Use state-wide biodiversity information to identify high value biodiversity and consider the impact of land use and development on these values. Ensure strategic planning: Avoid and minimises significant impacts, including cumulative impacts, of land use and development on Victoria's biodiversity. Consider impacts of any change in land-use or development that may affect the biodiversity value of adjoining national parks and conservation reserves or nationally and internationally significant sites including wetlands and wetland wildlife habitat designated under the Convention on Wetlands of International Importance (the Ramsar Convention), and sites utilised by species designated under the Japan-Australia Migratory Birds Agreement (JAMBA) or the China-Australia Migratory Birds Agreement (CAMBA). Assist in the protection and management of sites containing high value biodiversity. Ensure that decision making takes into account the impacts of land use and development on Victoria's high value biodiversity.	Biodiversity and vegetation
12.01-2 Native Vegetation Management	To ensure that permitted clearing of native vegetation results in no net loss in the contribution made by native vegetation to Victoria's biodiversity.	Apply the risk-based approach to managing native vegetation as set out in Permitted clearing of native vegetation – Biodiversity assessment guidelines (Department of Environment and Primary Industries, September 2013). These are: Avoid the removal of native vegetation that makes a significant contribution to Victoria's biodiversity. Minimise impacts on Victoria's biodiversity. Where native vegetation is permitted to be removed, ensure that an offset is provided in a manner that makes a contribution to Victoria's biodiversity that is equivalent to the contribution made by the native vegetation to be removed.	Biodiversity and vegetation

Clause	Objective	Relevant Strategies	Applicability
12.02-1 Protection of Coastal Areas	To recognise and enhance the value of the coastal areas to the community and ensure sustainable use of natural coastal resources.	Coordinated land use and planning with the requirements of the Coastal Management Act 1995 to: Provide clear direction for the future sustainable use of the coast, including the marine environment, for recreation, conservation, tourism, commerce and similar uses in appropriate areas. Protect and maintain areas of environmental significance. Identify suitable areas and opportunities for improved facilities. Apply the hierarchy of principles for coastal planning and management as set out in the Victorian Coastal Strategy 2014, which are: • Principle 1: Ensure the protection of significant environmental and cultural values. • Principle 2: Undertake integrated planning and provide clear direction for the future. • Principle 3: Ensure the sustainable use of natural coastal resources. • Principle 4: Ensure development on the coast is located within existing modified and resilient environments where the demand for development is evident and any impacts can be managed sustainably.	Development and coastal land
12.02-2 Appropriate Development of Coastal Areas	To ensure development conserves, protects and seeks to enhance coastal biodiversity and ecological values.	Ensure development is sensitively sited and designed and respects the character of coastal settlements. Encourage revegetation of cleared land abutting coastal reserves. Maintain the natural drainage patterns, water quality and biodiversity within and adjacent to coastal estuaries, wetlands and waterways. Avoid disturbance of coastal acid sulphate soils.	Development and coastal land
12.02-3 Coastal Crown Land	To achieve development that provides an environmental, social and economic balance.	Ensure that use and development on or adjacent to coastal foreshore Crown land: Maintain safe, equitable public access and improves public benefit whilst protecting local environmental and social values. Demonstrate need and coastal dependency. Is located within a defined activity or recreation node.	Development and coastal Crown land
12.02-5 Bays	To improve the environmental health of the bays and their catchments.	Reduce major environmental pressures associated with urban growth and development within catchments of Port Phillip Bay and Western Port by: Requiring growth area planning to protect significant natural assets. Protect coastal and foreshore environments by: Requiring coastal planning and management to be consistent with the Victorian Coastal Strategy 2014.	Foreshore environment and development

Clause	Objective	Relevant Strategies	Applicability
12.04-1 Environmentally Sensitive Areas	To protect and conserve environmentally sensitive areas.	Protect environmentally sensitive areas with significant recreational value such as … Port Phillip Bays and their foreshores … the coastal areas and their foreshores … from development which would diminish their environmental conservation or recreation values.	Foreshore environment and development
13.01-1 Coastal Inundation and Erosion	To plan for and manage the potential coastal impacts of climate change.	In planning for possible sea level rise, an increase of 0.2 metres over current 1 in 100 year flood levels by 2040 may be used for new development in close proximity to existing development (urban infill). Plan for possible sea level rise of 0.8 metres by 2100, and allow for the combined effects of tides, storm surges, coastal processes and local conditions such as topography and geology when assessing risks and coastal impacts associated with climate change. Consider the risks associated with climate change in planning and management decision-making processes. For new greenfield development outside of town boundaries, plan for not less than 0.8 metre sea level rise by 2100. Ensure that land subject to coastal hazards are identified and appropriately managed to ensure that future development is not at risk. Ensure that development or protective works seeking to respond to coastal hazard risks avoids detrimental impacts on coastal processes. Avoid development in identified coastal hazard areas susceptible to inundation (both river and coastal), erosion, landslip/landslide, acid sulphate soils, bushfire and geotechnical risk.	Climate change and sea level rise
13.03-1 Salinity	To minimise the impact of salinity and rising watertables on land uses, buildings and infrastructure in rural and urban areas and areas of environmental significance and reduce salt loads in rivers.	Identify areas subject to salinity in the preparation of planning schemes and land use planning decisions. Promote vegetation retention and replanting in aquifer recharge areas contributing to groundwater salinity problems. Prevent inappropriate development in areas affected by groundwater salinity.	Salinity

9.2.2 Borough of Queenscliffe

Municipal Strategic Statement (MSS)

Clause 21.02 Municipal Profile

The Municipal Profile identifies a number of issues which require coordinated cross border planning between Queenscliffe and the City of Greater Geelong. The protection and improvement of coastal assets and the need to identify and implement shared land use strategies for its preservation is identified as a key focus.

Clause 21.03 Key Influences

The relevant key influences on land use planning identified for the Borough of Queenscliffe are as follows:

The natural environment

"*The high quality and international significance of its natural environment is a key feature of the Borough, which deserves protection for its own sake. The Borough as a major custodian of the natural heritage has an important role to play in protecting the environment and also in supporting community initiated environment and conservation action. The environment is also a significant tourism attraction, as such the protection and enhancement of this asset is important for the economic survival of the Borough.*

Almost all of the Borough falls within the Swan Bay Catchment, with the Borough forming the southern end of Swan Bay. Development within the Borough must not have a detrimental impact on the international environmental significance of Swan Bay".

Commonwealth Land

"*The Borough contains sites of environmental and heritage significance in Commonwealth ownership. As Commonwealth Land is not able to be zoned under the Planning Scheme it is important to establish agreements and protocols with Commonwealth agencies to ensure that land is used and developed in accordance with the objectives of this Planning Scheme. The planning scheme must also be immediately amended to include Commonwealth Land should it change ownership*".

Clause 21.05-2 Environment

The Borough contains natural environment areas of international significance – Swan Bay is protected under the RAMSAR, CAMBA (China-Australia Migratory Birds Agreement) and JAMBA (Japan-Australia Migratory Birds Agreement) treaties, and areas of Register of Natural Estate, and species endangered and listed under the Flora and Fauna Guarantee Act.

Objectives under Clause 21.05-2 include:

- Preserve and maintain the ecology of environmentally significant areas.
- Preserve the biodiversity of flora and fauna.
- Protect the natural environment from inappropriate use and development.
- Encourage development that complements natural environment values.

The relevant strategies for achieving the objectives are to:

- protect environmentally and/or ecologically significant sites recognised in treaties and legislation from adverse development impacts.

- identify and encourage the protection, maintenance and enhancement of other environmentally and/or ecologically significant sites.
- protect cliff, dune and foreshore areas from inappropriate development and subdivision.
- protect and restore significant and remnant native vegetation, particularly tea tree, moonah and coastal heath.
- encourage the retention of other existing vegetation.
- ensure that all development and use adjacent to significant natural areas is developed in a manner which minimises adverse impacts on those areas.
- identify suitable locations along the foreshore to provide for appropriate tourism service development.
- encourage and participate in a regional approach to the conservation of areas of environmental and/or ecological significance.

Local Planning Policies

Clause 22.04-3 Foreshore Areas

Objectives of this policy aim to protect the distinguishing elements of the character of the Foreshore Areas including protecting the prevailing native coastal dune landscape within the Port Philip bay area which, in conjunction with the undulating landform, conceals 1 and 2 storey buildings from view along the foreshore.

One policy of Clause 22.04-3 requires the '*retention of existing native coastal vegetation on the land wherever possible*'.

9.3 Other legislation/considerations

In addition to obtaining planning approval under the *Planning and Environment Act 1987*, the following approvals, requirements and legislation may apply to the remediation, development and management of bayside, coastal, estuary and foreshore areas:

- Aboriginal cultural heritage considerations under the *Aboriginal Heritage Act 2006.*
- Sites of significance:
  - RAMSAR – Port Phillip Bay (Western Shoreline and Bellarine Peninsula) RAMSAR site.
  - Protected and threatened species listed under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999.*
  - A permit to take protected flora under the *Flora Fauna Guarantee Act 1988.*
- Considerations of Corangamite Catchment Management Authority (CCMA).
- The Victorian Coastal Strategy 2014 – Victorian Coastal Council.
- Consent under the *Coastal Management Plan Act 1995.*
- Consent and considerations of the relevant Public Land Manager for works on coastal Crown Land.
- Considerations of the relevant Committees of Management under the *Crown Land (Reserves) Act 1978* – Bellarine Bayside Coast Committee and Barwon Coast Committee of Management.

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