# Coastal Hazards - Adaptations

Part 1

Local Government Association of Tasmania

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SGS Economics & Planning

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This report has been prepared by:

**SGS Economics and Planning Pty Ltd**

ACN 007 437 729

Level 5 171 Latrobe Street

MELBOURNE VIC 3000

P: + 61 3 8616 0331

F: + 61 3 8616 0332

E: sgsvic@sgsep.com.au

W: www.sgsep.com.au

Offices in Brisbane, Canberra, Hobart, Melbourne, Sydney

SGS

Economics & Planning

**Figures**

# 1 Options to address hazards and protect assets

SGS Economics and Planning (SGS) are assisting the Local Government Association of Tasmania working with Tasmanian Climate Change Office and the Tasmanian Planning Commission to develop future pathways for climate change adaptation in four coastal areas in Tasmania: Lauderdale (Clarence City Council), St Helens/Georges Bay (Break O'Day LGA), Port Sorell (Latrobe LGA) and Kingston Beach (Kingborough LGA).

This section of the study develops an extensive range of adaptation options covering protection, accommodation, avoidance and retreat in the face of possible coastal hazards. In part this paper seeks to increase awareness of the wide range of options to manage the risk and respond to coastal hazards arising from climate change and protect assets in affected areas. These include responses that avoid the risk allowing room for natural processes, work to minimise risk but allow modest modification to the environment or major interventions that protect property but seek to deflect or resist natural processes in order to protect communities and properties.

Each option listed is assessed in terms of:

- risk addressed;
- suitability or hazard level;
- general impacts and outcomes if adopted;
- modes of failure in an extreme event exceeding design specification or with long term continued sea level rise;
- complimentary options (either favourable or essential) or incompatible options;
- indicative cost;
- the extent to which it is individual asset based or collective action based; and
- any obvious implications of using this option (e.g. impact on coastal values).

This compilation does not make any recommendations about what choices are suitable in a particular location and makes no specific reference to conditions at the four project sites or even Tasmanian conditions in general. In that sense it is and is intended to be generic.

The completed list of adaptation options has been used to inform a range of future adaptation pathways for each of the four participating communities. The strategic options assessment will lay out possible futures that range from early planned retreat allowing maximum play to natural processes to protection of property to the maximum extent practical.

The assessment will be framed in such a way as to encourage each community to make choices that provide or protect total community value. The completed list of adaption options will also assist each community to understand the costs in terms of investment in adaptation or bearing the damages from acceptable levels of risk as well as to compare the outcomes of different pathways under a range of scenarios.

# 2 Works to Address Erosion Risks

Works to address erosion risk may be designed to reduce the hazard (ie rate or extent of erosion) or to make structures less vulnerable to the effects of erosion.

## 2.1 Works to reduce coastal erosion

This section presents a number of potential options for removing or minimising erosion risks. The options are generally the only effective approach to protecting existing structures from erosion where the structure cannot withstand undermining or other effects of erosion of the shoreline. However, they may also provide protection for new development in affected areas, if there is confidence that the erosion control works will be effective and maintained for the lifetime of new assets being built.

The options identified in this section are generally based on collective action to mitigate erosion hazards. The methods described in this section are generally not practical or cost effective for individual properties although shore hardening approaches might be used as a last ditch effort by a property owner whose property is on the brink of loss (if permitted). However, in the case of very large or isolated properties, the treatments described may be used by a single property owner.

The feasible approaches to reducing the rate or extent of erosion vary according to the context: the kind of shore being eroded (sandy beach, clay/mud or soft rock), the degree and character of exposure to wave action and currents, the sediment budget and interaction with sediment drift along shores and the dynamics introduced by river entries or other water flows across the coast.

The following treatment of options is not exhaustive but provides some of the main characteristics of different approaches to managing erosion. The first group of approaches deal with sandy beaches and offer a range of interventions that involve introducing and managing sand or capturing and holding sediment derived from long shore sediment movement. The second group looks at how shore armouring and hardening can be used to prevent erosion on a variety of coast types, or in some cases, shift erosion from one location to another.

| **Interventions to Manage Sediment Flows** | **Shore Armouring and Hardening** |
|---|---|
| Sand dune stabilisation with vegetation | Coastal Hardening |
| Beach nourishment | Seawalls |
| Groynes | Revetment |
| Artificial Headlands | Training Walls |
| Offshore Breakwaters and Reefs | |

Works to reduce the rate or extent of erosion can be expensive. However, they often provide the only socially and economically acceptable means of reducing risk to **existing** properties exposed to erosion hazards. The investment in these works needs to be realistic in respect of the value of property being protected, impacts the works may have on the environment and the changes that these works inevitably bring to the coastlines where they are applied and the values the community places on these coastlines in the original condition.

Works designed to reduce coastal erosion may not provide a guarantee against future erosion but can substantially reduce the risk. Works generally will need ongoing maintenance and if the maintenance is not kept up, their effectiveness can be greatly reduced or lost altogether.

This section does not deal with erosion arising from terrestrial causes: land slip and land instability on steep unconsolidated or weak soils or caused by water mobilisation of slopes. In some instances these occur near the coast, and undermining by coastal erosion may be a contributing factor. Stabilisation of the toe of such slips may contribute to stabilisation of the slope but this is not addressed here.

### 2.1.1 Sand Dune Stabilisation with Vegetation

**Figure 1 Dune stabilisation using appropriate local species**

Source: Scottish Natural Heritage http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.2.shtml

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| Description and Risks Addressed | Intact dune vegetation will normally trap windblown sand and raise the height of dunes. Stabilising dunes with vegetation is intended to reduce erosion of the dune (lowering the height) and the movement of the sand into other areas.<br><br>Higher, more intact dunes can reduce the probability of wave run-up overtopping dunes and reaching property behind in a |

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| | storm. Dunes that have been trampled and had their tops eroded offer less protection from wave-run up.<br><br>Restoring dune vegetation can be used to stabilise sandy areas that have been disturbed by foot traffic or construction activities, and, in areas of high wind to protect roads, buildings, sewers and valued areas like wetlands and watercourses from encroachment by blowing sand[1]. |
| Suitability (Hazard Level) | By trapping and holding sand, dune vegetation can add to the bulk of the dunes, increasing the amount of available sand to resist erosion during a storm. However, it does not add any additional sand to the local sand supply and has a limited effect on long term erosion of a sandy coast subject to recession.<br><br>Dune vegetation will not stop erosion of the dune face from wave action (except in very sheltered estuaries). Even a well vegetated dune will be undermined and collapse when the face is eroded.<br><br>Only certain plant species may be used to stabilise dunes. When possible, sand dune stabilisation should be applied before serious dune/sand erosion problems occur. |
| Modes of Failure | Dune vegetation is most often lost by trampling (people, livestock, pets, vehicles), particularly at beach entry points and disturbance associated with construction. The use of traditional residential landscaping treatments (mowing 'lawns' or other non-dune vegetation) and cutting down coastal shrubs to enhance views can reduce the effectiveness of sand capture or resistance to waves that do overtop the dune, either by reducing dune height or by making the dune less resistant to water flowing over the surface permitting faster surface erosion. This can increase the risk to property immediately behind the dune. If a significant breach occurs in the dune in a low, poorly vegetated section, more property will be affected.<br><br>A beach that is subject to long term erosion/recession will still be undermined at the dune face in a storm unless other works are used to increase the sand supply to the dune face. |
| Complimentary Options | Community education of the value of intact dune vegetation |

[1]http://books.google.com.au/books?id=iaAj8rTILYUC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

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| | and the importance of using only designated access points is an essential component of maintaining the effectiveness of dune vegetation.<br><br>Fences can also be constructed so as to minimise the amount of disturbance on the dunes by trampling. Wooden pathways or bridges can be built for access to the beach[2].<br><br>Planning laws may need to be reviewed to ensure that residential or other construction activity does not disturb the natural processes which govern the dunes.<br><br>Dune vegetation will not prevent progressive erosion/recession where this has been a historical trend, or enhanced erosion due to sea level rise without other approaches that bring additional sand into the beach/dune system or resist sand loss by hardening. |
| Indicative Cost | Sand dune stabilisation costs of the order of $150 per linear meter of dune.<br><br>Community groups such as Coast Care may organise volunteers to undertake the work[3]. This may reduce the cost but also increase the community engagement and ownership of the works contributing to making them last longer.<br><br>Well established dune vegetation should require only modest levels of maintenance if not disturbed. However, future work can be required if the vegetation is subject to trampling, fire, invasive weeds or the death of older shrubs that lead to large exposed areas of sand.<br><br>Revegetation may also be required after a major storm or if dune bulk is increased by dune nourishment (exposed fresh sand). |
| Implications | Dune vegetation can retain the natural character of a sandy shoreline and enhance its attractiveness while protecting the property behind.<br><br>Maintenance of dune vegetation typically requires the cooperation and engagement of the community, if only to |

[2] http://www.docstoc.com/docs/80279801/Coastal-Dune-Vegetation

[3] http://books.google.com.au/books?id=iaAj8rTILYUC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q&f=false

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| | reduce losses due to trampling, mowing and clearing for views. This is particularly the case where private property extends onto the foredune.<br><br>In some locations a strong vegetation community may reduce coastal views substantially and be resisted by residents.<br>A healthy vegetation cover can reduce the risk of erosion by waves that do overtop the dune in a storm, potentially reducing the risk of a dune breach in a heavy storm.<br><br>However, even a robust and healthy vegetation cover on a high dune may not be sufficient to resist long term erosion/recession where this is occurring. |

### 2.1.2 Beach nourishment

**Figure 2 Before and after photos of beach restoration efforts. Florida Coastline. USA**

Source: http://en.wikipedia.org/wiki/Beach_nourishment

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| Description and Risks Addressed | Beach nourishment can reduce or offset the effects of beach erosion/recession and may increase beach amenity by building a wider beach[4]. It does this by bringing additional sand into the local sand budget for the beach and dunes. |
| Suitability (Hazard Level) | The effectiveness of beach nourishment depends on why erosion takes place at the site. If the site is eroding progressively, as a result of offshore conditions, such as a locally steeper shoreline or a convergence of wave energy, the |

[4] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

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| | artificially placed fill will also be subjected to the same conditions and will not perform well[5].<br><br>The design of the beach nourishment program will then be concerned with how much sand to place, how often it needs to be replenished and where it can be obtained. It may be constrained by the availability of sand and the cost of bringing it to and placing it on the beach.<br><br>Artificial nourishment in most areas becomes a beach maintenance solution, based on annual cost/benefit figures. |
| General Impacts and Outcomes | Nourishment retains the beach with minimal modification to its character. Nourishment that introduces new sand does not promote erosion in downdrift locations of the beach. Beach nourishment programs have few detrimental effects (this is part of their attraction) provided that an adequate supply of suitable sand is available and that it can be obtained without undue consequences[6]. However, sand of different characteristics (eg grain size) can change the character of the beach (slope, mobility, supported fauna and 'feel' of the beach) or the duration between periods of replenishment.<br><br>Potential negative consequences of beach nourishment include:<br><br>• Disturbance of the indigenous biota inhabiting the sub aerial beach habitats, which may in turn affect the foraging patterns of the species that feed on those organisms; and<br><br>• Disruption to species that use sub aerial beach habitats or adjacent areas for nesting, nursing and breeding[7].<br><br>These consequences can generally be managed by selection of sand source and control of operations. |
| Modes of Failure | Nourishment does not stop the process driving erosion where there is progressive erosion. In these conditions, sand from the beach and dunes will generally wash away over time and need to be replaced. Even where this occurs, the impacts of erosion on property are deferred and may be lessened compared with taking no action at all. |

[5] http://books.google.com/books?id=iaAj8rTILYUC&printsec=frontcover#v=onepage&q&f=false

[6] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

[7] http://www.nap.edu/openbook.php?record_id=4984&page=110

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| | If an insufficient sand bulk is maintained, the safety margin for protection of property may be too small. If a major storm removes most of the sand, it may not be possible or practical to replace the sand before the next major storm, resulting in property loss.<br><br>When beach and dune nourishment cease to be practical alternatives due to cost or shortage of sand, it may be possible to reinforce some structures that are appropriate to maintain in the shoreline against undermining (eg piles). In general this may invoke consideration of retreat.<br><br>Where there are significant hind dunes, allowing the shoreline to retreat can bring additional sand into the coastal sand budget and temporarily reduce the rate nourishment required from external sources. |
| Complimentary Options | The rate of loss of sand may be diminished by other measures that affect long shore drift (groynes, offshore reefs, etc).<br><br>Dune revegetation is essential where dune height and bulk is built up to prevent the dune height from being reduced by wind or trampling. |
| Indicative Cost | An indicative cost of beach nourishment is $15 per cubic metre but potentially ranging from $5 to $50 per cubic metre. An additional cost of about $150 per m of beach would be incurred for vegetating the enlarged dunes.<br><br>The actual cubic metres of sand needed is highly dependent on the required beach widening and the wave climate of the beach.<br><br>For an exposed open coast beach, about 500 $m^3/m$ would be needed to widen the beach by 20 m, or offset recession due to 0.4 m sea level rise, which equates to approximately $7.5M/km.<br><br>For a semi sheltered beach (eg Roches Beach), this would reduce to 120 $m^3/m$, or approximately $1.8M/km.<br><br>An indicative lifetime may be a few years to decades, but detailed assessment is required for each beach. The life may be extended by complimentary options which help to retain the sand. |

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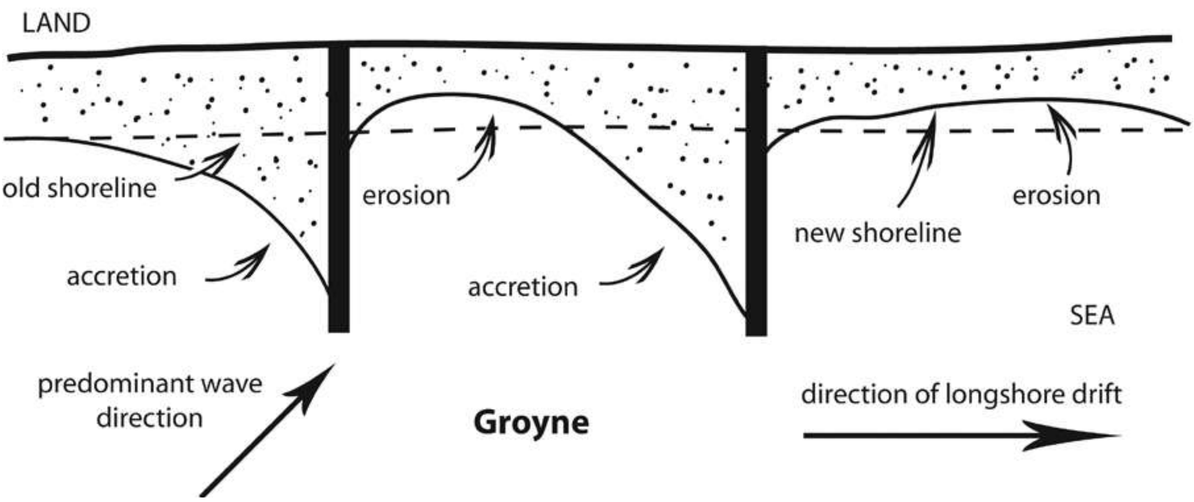
| Implications | The main drawback of beach nourishment is that further nourishment is likely to be needed in the future[8]. However, even allowing for this, the cost may not be greatly different from other alternatives.<br><br>Beach nourishment may be constrained where there is a limited suitable available sand supply, or where the impacts of taking the sand are severe and cannot be remediated.<br><br>The main advantage is that it generally maintains the character and amenity of the beach and leaves no permanent structures that may need to be cleared if damaged or ineffective. |

### 2.1.3 Groynes

The following works describe approaches that influence sediment transport along a coast. Where there is significant movement along the short, these works may help to hold sand in a location where erosion is occurring. This can reduce the rate of erosion in the treated area, potentially even over long periods of time. However, by affecting the amount of sand transported along the coast, these approaches may have effects on areas 'downstream' by reducing the amount of sand available. Unless carefully designed and constructed, structural works, by reason of their location within the active beach zone, may have a number of unforeseen detrimental effects on amenity[9].

**Figure 3 The effects of a groyne on sediment flow, deposition and erosion. Adapted from Sediment Budgeting (O'Keeffe 1978)**




Source: Tasmanian Coastal Works Manual

[8] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html
[9] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

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| Description and Risks Addressed | Groynes can provide coastal protection from beach erosion and increase amenity by capturing more sand from longshore drift and thus building a wider beach[10]. This can counter erosion process to a greater or lesser extent depending on the design of the groyne and the characteristics of the coast and longshore drift in the affected area.<br><br>Groynes may be constructed from rock or other hard bulk materials, sheet piles or from large geotextile sand bags. The size and construction of the groynes needs to be tailored to local conditions both to be effective in trapping or holding sand and to have sufficient resistance to damage from storms. |
| Suitability (Hazard Level) | When erosion is a result of a steep beach and foreshore, causing a net offshore motion of sand, groynes may not help. Artificially filling the groynes also may not work, or may be much less effective when there is a possibility of large temporary offshore transport rates or when there are large fluctuations in mean water level, such as in areas of large storm surge.<br><br>Groynes are most effective in areas where erosion is a result of or accelerated by predominantly alongshore sediment transport. The incident wave angles cannot be too large for groynes to be effective, otherwise they will need to either be very long, or very closely spaced. Protection from groynes is much less effective when there are large long-term water level fluctuations such as on the Great Lakes USA. |
| General Impacts and Outcomes | Erosion of the surrounding shore by a groyne field may occur depending on the rate of sediment bypassing. A filled groyne system creates little erosion. When the groyne field is not filled, long, high groynes will stop or reduce longshore sediment transport, and cause downdrift erosion by preventing sediment supply to surrounding areas. Shorter, lower groynes will cause less erosion but will still affect the surrounding shore, until they are filled to capacity.<br><br>Groynes also generate offshore currents. These currents move sediment offshore and can be a hazard to bathers. More complex shapes can reduce these currents. |

[10] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

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| | Downdrift of the groynes, the sediment gradation may become finer and the shore may become less stable. This process of local decrease in grain size can cause additional erosion downdrift of a groyne field and increase the extent to the downdrift erosion out of proportion to the groyne sizes[11].<br><br>Groynes are generally highly visible, although they may be designed to be just at the high tide level reducing visibility for part of the time. Nonetheless, many people regard groynes as visually intrusive, adversely affecting the character of the beach. Conversely, when sufficiently elevated, they are also very popular for walking and fishing, and often produce surf breaks where the wave climate is sufficient. |
| Modes of Failure | Cross shore sediment transport can rapidly add or remove sediment from the groyne field. When offshore sediment motion resulting from high water levels and storm surge empties a groyne field of sand and removes the accretion volumes collected updrift of the groynes, downdrift erosion will begin to take place.<br><br>If the offshore movement of sand is severe the shore will erode far enough that the groynes will flank, and the shore behind the groynes will be eroded.<br><br>Groynes may be physically damaged in a severe storm. This may eventuate due to the storm exceeding the original design parameters, degradation of the structure, or an underdesigned structure arising from budget limitations. This would then require repair and maintenance works to maintain their effectiveness and reduce hazards to beach users.<br><br>Groynes constructed from geotextile bags can be easily removed and the beach restored to its original condition if found to be ineffective or have unacceptable adverse effects. However, groynes from geotextile bags will have a shorter lifetime than groynes built from rocks or concrete.<br><br>With continued sea level rise, the groynes may become less effective if they are not raised and the beach renourished. As the scale of the groynes increases, the cost will also grow.<br><br>Should a groyne field 'fail' it may not result in the immediate loss of property along a beach front. There may be a period of |

[11] http://books.google.com/books?id=iaAj8rTILYUC&printsec=frontcover#v=onepage&q&f=false

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| | time between the failure of the groyne field and the resulting erosion of the dunes and property behind during which time either repairs can be made or retreat from property can occur. |
| Complimentary Options | Erosion tends to occur along the section of beach downdrift of the groyne field. This can be minimised by initially filling the groyne embayment with sand as part of a beach nourishment program[12].<br><br>Beach nourishment will also assist beaches to reach their desired volume sooner, reducing risk to property from erosion in the initial period after construction.<br><br>Dune vegetation should also be maintained as groynes may have only a small impact on wave runup. |
| Indicative Cost | Costs are highly dependent on the required length and wave climate. Typical groyne spacing is two to 4 times the groyne length subject to detailed modelling, and may vary from one to 14 times. An indicative cost for groynes is about $5000 per m with typical length about 100 m. Well designed and constructed structures should have a long lifetime, with minimal maintenance except where sea level rise necessitates raising the level of protection[13]. |
| Implications | When used in appropriate situations, groynes are generally cost-effective coastal defence measures, requiring little maintenance, and are one of the most common coastal defence structures. However, groynes are increasingly viewed as detrimental to the aesthetics of the coastline[14]. |

[12] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html
[13] SGS Economics and Planning (2009). *Climate Change Impacts On Clarence Coastal Areas – Final Report.* Retrieved on November 7 from http://www.ccc.tas.gov.au/webdata/resources/files/CCICCA-Final-Report-A415375.pdf
[14] http://en.wikipedia.org/wiki/Coastal_management

### 2.1.4 Artificial Headlands

**Figure 4 Artificial Headlands, Byron Bay, NSW**

Source: Google Maps

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| Risks Addressed | Artificial headlands act as groynes that extend into the water to restrict longshore transport or stabilise the beach between two hard points in a similar manner to natural headlands. They assist rapidly eroding dunes with important backshore assets at discrete intervals along shore[15]. |
| Suitability (Hazard Level) | On the open coast, they require large, expensive structures. Consequently, their use has been restricted to areas with less severe wave climates[16]. |
| General Impacts and Outcomes | Artificial headlands stabilise discrete lengths of the dune face while allowing the intervening stretches to erode naturally, forming an increasingly embayed shoreline. As the shoreline becomes more indented so the wave energy will be dissipated over a longer frontage and ultimately a more stable plan shape can develop. |
| Modes of Failure | The modes of failure are essentially the same as for groynes. |
| Complimentary Options | Generally avoidance of development and retreat of any existing development on adjacent areas where erosion is not being controlled will be required. |

[15] http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.9.shtml
[16] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

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| | Beach nourishment between the headlands. |
| Indicative Cost | Artificial Headlands are rock structures built along the toe of eroding dunes to protect strategic points, allowing natural processes to continue along the remaining frontage. This is significantly cheaper than protecting a whole frontage and can provide temporary or long term protection to specific assets at risk.<br><br>The cost per meter to establish is similar to groynes, but may need to extend further into the water, plus minor works for unprotected frontages.[17]<br><br>Armour size and costs are a function of how far seaward the headland will be, and therefore how large the waves will be which impact it.<br><br>Temporary headlands can be formed of gabions or sand bags, but life expectancy will normally be between 1 and 5 years[18], though durable geotextiles have a life expectancy of approximately 20 years. |
| Implications | Even though this form of defence is intended to give only partial protection to the dunes the impacts on shoreline processes and landscape will still be high, and may be unacceptable in environmentally sensitive areas. Erosion may well continue along the unprotected frontages, and, without ongoing management, the structures may be outflanked allowing erosion of the protected frontage as well.<br><br>On frontages affected by longshore transport the headlands may reduce drift rates, resulting in the erosion of downdrift stretches of coast, but helping to stabilise the updrift shore.<br><br>As with all fixed dune defences, the headlands will interfere with the natural dynamic interchange of material between beach and dune. They will also influence the longshore transfer of sand, modify dune habitats, disrupt the natural landform and potentially result in localised dune face scour at their terminal ends[19]. |

[17] http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.9.shtml

[18] http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.9.shtml

[19] http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.9.shtml

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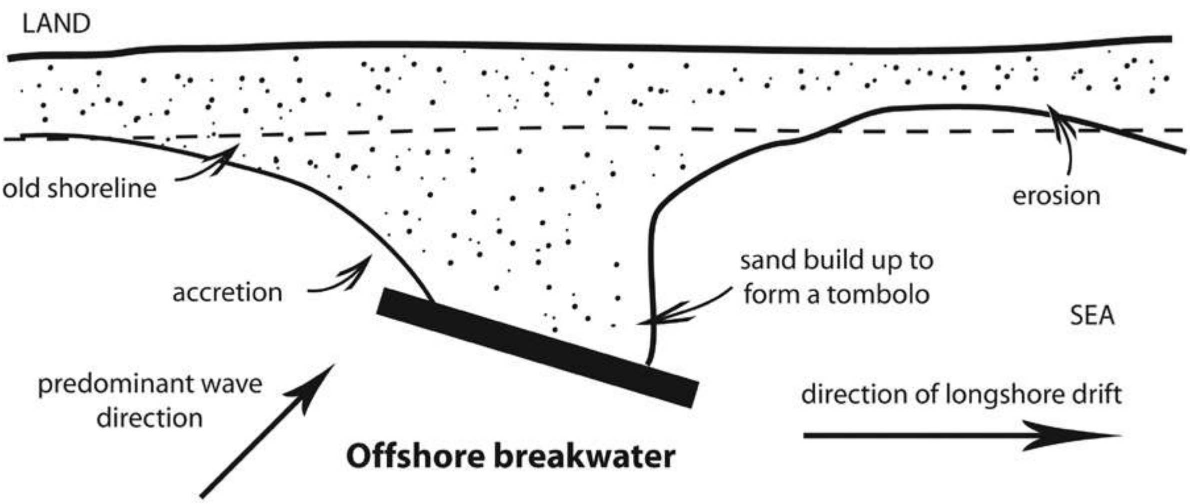
| | Without additional sand nourishment, artificial headlands will transfer erosion from one location to another. |

### 2.1.5 Offshore Breakwaters and Reefs

**Figure 5 An offshore breakwater encourages deposition on the beach. Sometimes sediment is deposited all the way out to the breakwater, forming a coastal feature known as a tombolo. Adapted from Sediment Budgeting (O'Keefe, 1978)**




Source: Tasmanian Coastal Works Manual

**Figure 6 An offshore breakwater at Semaphore Park, Adelaide SA**

Source: Google Maps

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| Risks Addressed | Offshore breakwaters reduce the intensity of wave action in inshore waters and thereby reduce the rate of coastal erosion[20]. They can lead to greater sand retention, even reversing erosion effects in the short to medium term. |
| Suitability (Hazard Level) | Offshore breakwaters may stabilise an existing beach. A trade off can be made between the size, length and crest elevation of breakwaters and the resulting level of transmitted wave energy versus resulting beach shape, erosion and consequent need for periodic renourishment.<br><br>Most offshore breakwaters are built with a low crest elevation to minimise cost, maximise water circulation in their lee, and reduce their visual impact.<br><br>Offshore breakwaters are quite effective in stabilising shorelines, but, particularly on exposed coasts having higher waves, their capital cost can be quite high. The structural aspects of their design are reasonably well understood theoretically, but their functional layout, length, gap width, distance offshore, and crest elevation are generally based on empirical evidence or detailed modelling. |
| General Impacts and Outcomes | One or more breakwaters, with intervening gaps, may be built parallel or nearly to shore in water depths of a few to 6-10 m to stabilize a shoreline. They function by intercepting a large portion of the incident wave energy and thereby decrease the offshore and alongshore transport capacity of waves.<br><br>Where significant alongshore transport occurs, offshore breakwaters will trap a portion of that transport to augment the original beach. If the original beach is inadequate and the potential for trapping a significant volume of sand from alongshore transport does not exist, the area in the lee of the breakwater can be filled with sand[21].<br><br>They can also be a hazard to navigation and swimming. |
| Modes of Failure | The base of the breakwater can be undercut resulting in it collapsing. An inadequately designed or undersized breakwater may be damaged in a severe storm and require rebuilding. However, if it has been effective in developing a |

[20] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

[21]http://papers.risingsea.net/downloads/Challenge_for_this_generation_Barth_and_Titus_chapter6.pdf

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| | sand deposit shoreward, property may not be immediately affected by such a failure. However, the breakwater would probably need to be reinstated before the next major storm if the damage is extensive.<br><br>With sea level rise, over time the breakwater will need to be increased in height to remain effective. Effectiveness is likely to decline gradually over time, not catastrophically, as long as it remains in place.<br><br>Without additional sand nourishment, the redistribution of sand and consequent change in planform means that some parts of the shoreline will become more eroded than they were prior to the offshore structure. |
| Complimentary Options | Offshore structures incorporating surfing amenity (surfing reefs).<br><br>Beach/fill and /or shoreline structures might be constructed landward of the breakwaters to keep the shore from being inundated if the unmodified beach and dune does not provide sufficient protection even with the breakwater.<br><br>Dune vegetation would still be desirable to reduce damage to and lowering of dune height. |
| Indicative Cost | Breakwaters and offshore reefs are more feasible for protection of sheltered areas not exposed to open coast wave conditions[22]. On the open coast they generally need to be constructed from the water, which results in difficult construction and large amounts of down time. In lower energy locations, they may be constructed from the land by building sand bunds and/or sheet pile coffer dams.<br><br>Open coast locations may cost in the range of $10,000 to $50,000 per m, while semi-sheltered locations may cost $5,000 to $10,000 per m. Typical lengths are 100 to 200 m, meaning costs range from $1 million to $10 million each on the open coast, to $500,000 to $2 million each in semi-sheltered locations. Low energy locations would be much cheaper than this. Incorporating surfing amenity may mean less steep sides, which will further increase material volumes and costs. |

[22] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

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| Implications | By changing the physical structure of the beach, breakwaters and offshore reefs can affect current coastal recreation activities such as boating, surfing, fishing, sailboarding, etc. However, if designed to do so they may even enhance some recreational activities through the changed conditions |

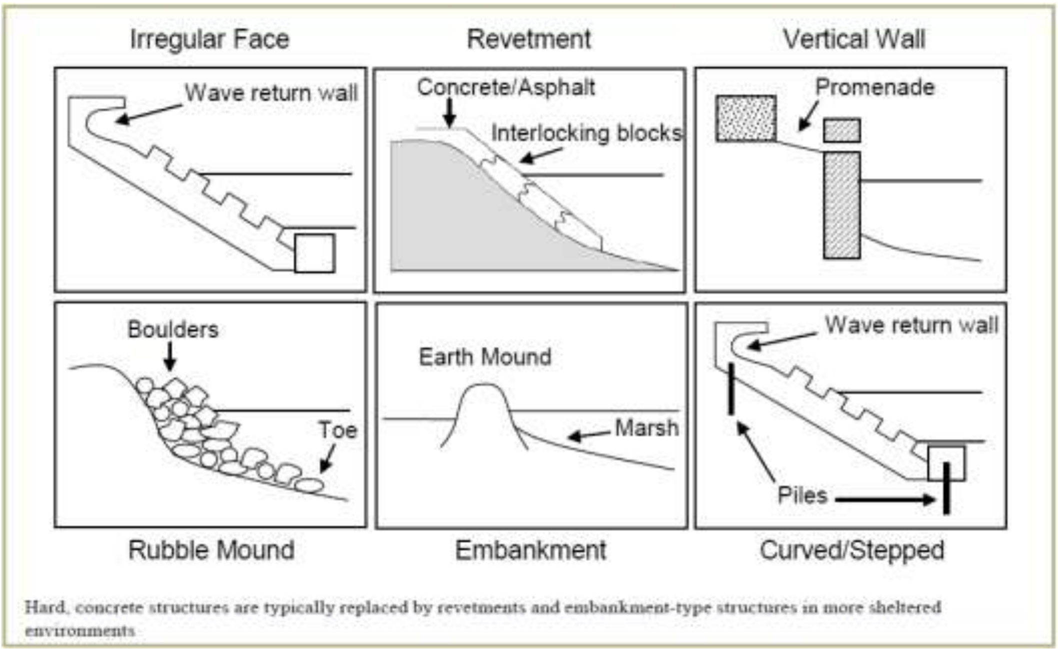
### 2.1.6 Coastal Hardening

Whereas the previous sections describe approaches that use sand and sediment to provide a form of protection of the shoreline from erosion, an alternative where this is not possible or cost effective would be a manmade structure designed to either prevent erosion or protect shore based structures from the effects of coastal wave and current action. Examples include seawalls, revetments, bulkheads, retaining walls, sloped boulder revetments, and sloped geotextile revetments, geotextile dune scour protection. All these options effectively mimic natural rocky shorelines.

A hardened shoreline is very different from a sandy beach. With the beach gone, access to the water’s edge becomes hindered by the rock and concrete structures. However, such structures may be made attractive and provide valued coastal features if thoughtfully designed while providing protection to property from erosion.

The following sections describe a few of the many variations of coastal hardening that are possible along with some of the implications of these choices. Other variations share many similar characteristics or features.

**Figure 7 Variation in Design Type of Seawalls**




Source: Adapted from French, 2001, at http://climatetechwiki.org/content/seawalls

### 2.1.7 Seawalls and Revetments

**Figure 8 The Seawall at Kingston Beach Tasmania**

Source: John Harkin TPAC

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| Risks Addressed | A seawall is a structure that is designed primarily to resist wave action along high value coastal property, and may also be used as a landscaping feature or to allow boats to be anchored at the shore. Its scale is highly dependent on the wave climate and expected range of water levels.<br><br>Seawalls may be either gravity- or pile-supported structures. Common construction materials are rock, concrete or sand filled geotextile containers. Seawalls can have a variety of face shapes: sloped, stepped, or curved to deflect incoming waves seaward.<br><br>A properly designed and constructed seawall will protect properties and areas of the foreshore from the impacts of beach erosion and coastline recession hazards[23]. |
| Suitability (Hazard Level) | A shoreline without a beach of any consequence is more likely |

[23] http://en.wikipedia.org/wiki/Coastal_management#Sea_walls

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| | to be stabilised by construction of a structure at the land-water interface such as seawalls, revetments, or bulkheads rather than an offshore breakwater.<br><br>A seawall is a protection wall, built along the shore. It is generally used where further shore erosion will result in excessive damage, for example, when roads or buildings are about to fall into the water. It may also be used as the face of an area being reclaimed from the sea by filling, where the fill would otherwise be subject to erosion.<br><br>Seawalls range from steel sheet pile walls to monolithic concrete barriers, to rubble mound structures, to brick or block walls to gabions (wire baskets filled with rocks).<br><br>They may be located at the top of the shore out of reach of the water at low water. Sometimes they may be partly or even fully covered with beach sand if there has been a period of sand accumulation since the wall was built. At high tide and during storms they will be exposed to direct wave action. Since seawalls are usually built as a last resort on eroding coasts, most seawalls are continually under stress from waves. |
| General Impacts and Outcomes | A sea wall at the back of an eroding beach may reduce further erosion of the sand behind the wall but will not stop the erosion of the beach. Where the beach is subject to long term erosion, loss of the beach eventually even at low tide is likely.<br><br>The wave action reflected off the seawall can promote deep scour holes immediately offshore of the seawall. The disturbed flows and scour areas can be dangerous and the scour may even excavate the supporting sand from under the structure, compromising the stability of the wall.<br><br>Very high water levels will cause waves to overtop the seawall resulting in erosion at the back of the structure. Trapping water behind the seawall may cause drainage problems resulting in erosion and structural instability.<br><br>Areas with long-term water level fluctuations, such as the Great Lakes USA are potentially vulnerable to cycles with periods of destruction of seawalls, followed by periods of lower water, when many new seawalls are built that are quite sound (until the next cycle of high water). |

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| | They can be dangerous during times of high water and storms. People on or near the structure may be injured or swept out to sea.<br><br>For near-vertical structures, there will be much overtopping, sending salt water spray inland, resulting in accelerated corrosion[24].<br><br>In many tourist areas, seawalls have been replaced by offshore breakwaters, artificial nourishment or both[25]. |
| Modes of Failure | Sea walls typically fail by undermining of the seaward face or by water undermining the rear face, either from overtopping waves or land based runoff.<br><br>Rock revetments may fail due to wave action breaking the rocks or waves moving the rocks reducing their effectiveness. Sea walls and revetmen<br>ts often require restoration or maintenance after particularly heavy storms.<br><br>If erosion is allowed to progress behind the sea wall, the wall may become ineffective, standing free of the shore face as an intrusive but ineffective element on the shore. Some shorelines are now cluttered by the remnants of old, no longer functioning sea walls while erosion continues behind them.<br><br>**Figure 9 Failed sea wall at Port Fairy Victoria, offshore, below water level**<br><br><br><br>Source: Google Maps |

[24] http://en.wikipedia.org/wiki/Coastal_management#Sea_walls

[25] http://en.wikipedia.org/wiki/Coastal_management#Sea_walls

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| | Erosion and scouring at the end of a seawall or other shore hardening is common. If unmanaged it can lead to failure of the end of the wall as well as accelerated erosion of the adjacent coastline.<br><br>With sea level rise, coastal sea walls will need to be increased in height periodically. This will only be practical if the foundations of the wall have been built sufficiently robustly to allow the extra load. Otherwise the wall will need to be rebuilt from scratch.<br><br>Many sea walls fail due to inadequate design and unwillingness to invest in a structure of suitable capability. |
| Complimentary Options | If located in the active beach zone, seawalls mat act as artificial headlands.<br><br>The ends of a seawall are difficult to design. To prevent undermining and flanking of the seawall at its ends, the structure needs to be built well back into the existing shore.<br><br>The difficulty in designing the ends of the structures and preventing erosion damage to adjacent properties shows the need for integrated shore protection design. Sea walls should be integral with the system in which they are placed, taking into account their own structural integrity and their environmental impacts.<br><br>Beach nourishment may be used to retain some useable beach in front of the revetment as a public amenity, while not being depended upon for protection against coastal erosion. |
| Indicative Cost | Costs are highly dependent on the size of waves impacting the seawall and the range of expected water levels. Reinforced concrete seawalls on the open coast cost approximately $20,000 per m, while rock rubble seawalls cost approximately $10,000 per m.<br><br>On semi-sheltered coasts, rock rubble seawalls cost approximately $2,000 to $5,000 per m.<br><br>On low energy estuarine shorelines with a small water level range, seawalls may be constructed from timber sleepers or concrete blocks at a cost of $100 to $1,000 per m. |
| Implications | The recreational use and scenic appeal of the beach may be |

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| | reduced by seawalls, especially if their presence facilitates the loss of sand in front of the wall and/or delays beach rebuilding after storms[26].<br><br>Shorelines protected by seawalls usually lose most of their natural character and environmental functions. Seawalls form a physical barrier to cross-shore movement of people and wildlife[27].<br><br>Coasts protected by seawalls have a dramatically different character than beaches or other natural shorelines. However, if developed as a promenade with facilities for boating or other amenities, they may still attract residents and visitors and be appealing – but generally to a different group for different types of activity than natural coastlines. |

**Figure 10 Rock revetment that is aesthetically pleasing and provides intertidal habitat on a low energy estuarine shore at Bobbin Head, Cowan Creek, Hawkesbury River, NSW. Copywright Daniel Wiecek, DECCW**

Source: Tasmanian Coastal Works Manual

[26] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html
[27] http://books.google.com/books?id=iaAj8rTILYUC&printsec=frontcover#v=onepage&q&f=false

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| Risks Addressed | A revetment is a facing of erosion resistant material, such as stone or concrete, that is built to protect a scarp, embankment, or other shoreline feature against erosion. Revetments are used to increase the stability of eroding foreshores. |
| Suitability (Hazard Level) | Revetments can sustain considerable damage without totally failing, but take up more foreshore space than more vertical seawalls. Rock revetments can be suitable for high wave energy environments, but the potential for scouring in the upper reaches should be considered carefully. |
| General Impacts and Outcomes | Revetments may provide more opportunities to create habitat for marine and coastal wildlife and vegetation than vertical sea walls. They cause less wave reflection than seawalls and survive storms for longer, but generally require regular maintenance to keep their generally structural integrity[28]. |
| Modes of Failure | Because revetments are permeable, they become susceptible to scouring behind the wall caused by poor seepage control and/or waves surging over the top.<br><br>If extreme, this can lead to the collapse of the revetment. Good design and careful consideration of coastal processes including sea level rise can overcome this risk[29].<br><br>As with sea walls, revetments would need to be built up from time to time as sea levels rise. |
| Complimentary Options | Beach nourishment may be used to retain some useable beach in front of the revetment as a public amenity, while not being depended upon for protection against coastal erosion. The sand may also reduce the stress on the revetment from wave action reducing maintenance of the rocks. |
| Indicative Cost | They are costly to install and require regular maintenance. They must be designed by a coastal engineer in consultation with a coastal geomorphologist; otherwise they may be |

[28] Department of Primary Industries, Parks, Water and Environment (2010)*Tasmanian Coastal Works Manual* http://www.environment.tas.gov.au/index.aspx?base=9877

[29] Department of Primary Industries, Parks, Water and Environment (2010)*Tasmanian Coastal Works Manual* http://www.environment.tas.gov.au/index.aspx?base=9877

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| | subject to failure or create erosion problems further along the foreshore[30]. |
| Implications | As with sea walls, revetments modify the coastal environment and may lead to the loss of a useable beach. Revetments are generally less easily developed as promenades or accommodating to boat access or other recreational use, although these may be possible in some settings. |

Other approaches that may be used which may be considered to be variations on those described above. These include:

- **Bulkheads** are retaining walls whose primary purpose is to hold or prevent the backfill from sliding while providing protection against light-to-moderate wave action. They are used to protect eroding bluffs by retaining soil at the toe, thereby increasing stability, or by protecting the toe from erosion and undercutting. They are also used for reclamation projects, where a fill is needed seaward of the existing shore, and for marinas and other structures where deep water is needed directly at the shore[31].
- **Terminal protection behind sand dunes**: where sand dunes are expected to be subject to long term erosion or even periodic extreme events that may affect property, a hardened face may be built at the back of the dunes so that if the dunes are eroded away, there is a hard last line of defence to limit immediate damage to property from undermining. The protection could take any of a number of forms from large geotextile bags, geotextile sheets, steel sheet piles or a concrete wall or rock mass wall.  It is unlikely that the structure would last more than a single storm if exposed and some form of follow up work would be essential once exposed to ensure its future effectiveness.
- **Armouring** is another hardening method which involves large rocks piled or placed at the foot of dunes or cliffs with native stones of the beach. This is generally used in areas prone to erosion to absorb the wave energy and hold beach material. Although it may be effective, this solution is unpopular due to the fact that it is unsightly. Rock armour has a limited lifespan, it is not effective in storm conditions, and it reduces the recreational value of a beach[32].

[30] Department of Primary Industries, Parks, Water and Environment (2010)*Tasmanian Coastal Works Manual* http://www.environment.tas.gov.au/index.aspx?base=9877

[31] http://140.194.76.129/publications/eng-manuals/em1110-2-1614/basdoc.pdf

[32] http://en.wikipedia.org/wiki/Coastal_management

### 2.1.8 Training Walls

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| Risks Addressed | Rock or concrete walls built to constrain a river or creek discharging across a sandy coastline. The walls help to stabilise and deepen the channel which benefits navigation, flood management, river erosion and water quality but can cause coastal erosion due to the interruption of longshore drift. One solution is the installation of a sand bypassing system to pump sand under and around the entrance training walls[33].<br><br>Properly designed and constructed training walls can stabilise a coastal entrance, improve navigation and help mitigate estuarine flooding[34]. |
| Suitability (Hazard Level) | The construction of river entrance training walls is generally aimed at improving navigability of the river mouth where waves and shifting sand shoals otherwise cause shallow and dangerous conditions[35].<br><br>Another objective has at times been to stabilise land configuration to allow development adjacent to the river mouth. The more hydraulically efficient entrance can reduce flood levels upstream in rivers. |
| General Impacts and Outcomes | Training walls can markedly alter patterns of erosion and deposition, both within the estuary and on the coastline either side of the entrance. They can also have a marked effect on the tidal range of the estuary and thereby estuarine ecology[36] due to the more hydraulically efficient entrance.<br><br>For the beaches around training walls, the training walls act in a similar manner to groynes.<br><br>Where they are located on coastlines with significant net longshore sand transport, they potentially impact on the adjacent shorelines by interrupting the natural flow of sand along the coast, at least temporarily. The updrift shoreline and, over time, the bar area accrete by trapping the longshore transport. This may require continued dredging to keep the |

[33] http://en.wikipedia.org/wiki/Coastal_management

[34] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

[35] http://www.coastalconference.com/2009/papers2009/Dean%20Patterson%20Full%20paper.pdf

[36] http://www.environment.gov.au/archive/coasts/publications/nswmanual/index.html

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| | channel clear.<br><br>Correspondingly, the downdrift shoreline erodes because the supply there is reduced while the transport away continues, although there may be a localised area of accretion immediately downdrift adjacent to the structure. Where there is gross sand transport back and forth but little or no net transport, the training walls may cause accretion in the immediate vicinity with erosion further away on both sides[37]. |
| Modes of Failure | Training walls may fail due to erosion and undermining of the walls, or due to damage in a storm.<br><br>In many cases the channel fills with sediment, requiring either maintenance dredging, extension of the training walls or a sand trap/bypass plant.<br><br>The training wall would need to be raised from time to time as sea levels rise.<br><br>If the river system is prone to be mobile and have the potential to break out to the coast at alternate locations (particularly if the existing channel has substantially silted and clogged), this could negate the value of the training wall, however, generally the entrance will follow the hydraulically efficient path of the training wall. |
| Complimentary Options | Nourishment, dredging, groynes, sand bypass plants and relocation of outfalls are common with the establishment of training walls.<br><br>Most creeks, rivers and lakes in developed areas have bridges near their mouths. The armoured abutments of these bridges acts as a training wall. |
| Indicative Cost | Training wall costs are highly dependent on the wave climate and water depth to which they extend. The volume of material required is approximately proportional to the square of the water depth, while the mass of the required armour is approximately proportional to the cube of the design wave height.<br><br>Typical costs range from $20,000 to $50,000 per m on |

[37] http://www.coastalconference.com/2009/papers2009/Dean%20Patterson%20Full%20paper.pdf

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| | exposed coasts. On semi-sheltered coasts, this can reduce to \$10,000 to \$20,000 per m. In low energy estuaries, costs can be \$1,000 to \$10,000 per m. The costs for a pair of training walls for a large coastal river on an open coast can range from \$20 to \$50 million.<br><br>The Nerang (Gold Coast Seaway) and Tweed River bypass projects involved capital costs of \$16 million and 23 million respectively, together with annual pumping costs of \$700,000 to \$3 million per year for bypassing approximately 500,000 to 700,000 cubic metres per year. There are no Tasmanian sites likely to require works of this scale.<br><br>Typical bypassing costs using small plant such as the "sandshifter" can be undertaken for \$5 to \$15 per cubic metre. |
| Implications | Training walls required a substantial investment and the benefits in terms of navigation or other use need to be substantial to justify the capital cost and ongoing maintenance. The impacts on adjacent areas may also be substantial. The coastal impacts can be offset with a sand bypass system, however, ecological impacts on the estuary are an artefact of the more efficient entrance, |

## 2.2 Works to defend individual assets from erosion hazards

The works described in section 1.1 were designed to address the erosion hazard by reducing the rate or severity of erosion processes. In some cases these may be effective for a sustained period of time, protecting the property on the coast where these works are introduced for extended periods.

In some cases, there may not be effective options for managing erosion, or the community may not choose to adopt them, or funding may not be available for them. In this case, any new structures in the identified hazard zone may be exposed directly to the erosion hazard over its lifetime.

It is possible to build structures that are resistant to the effects of coastal erosion. Many shore based and nearshore structures are built in areas where erosion of varying degrees of severity would be expected to cause soil instability that would undermine structures built in a conventional way in inland sites. This is common for ports and harbour structures, as well as seaside developments that seek to be as close as possible to the shore to provide a high level of amenity and attractiveness to users.

A number of approaches are described in this section that would allow structures to be resistant to erosion hazards even where there are not general efforts to slow or restrict erosion processes.

### 2.2.1 Piles and Excavation to Rock

**Figure 11 A piled coastal structure not structurally affected by shoreline erosion (NSW)**

Source: WRL

**Figure 12 Piled foundations are used for this waterside home on the Thames, as they allow the house to move slightly and water to travel underneath should any flooding occur.**

Source: http://www.homebuilding.co.uk/feature/foundations

**Figure 13 Woolloomooloo Pier, Sydney, built on piles (old commercial wharf converted to apartments)**

Source: http://www.hotels.com/ho173172/blue-sydney-a-taj-hotel-woolloomooloo-australia/

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| Risks Addressed | There are two forms of erosion resistant foundations:<br>**Excavation to rock** requires that erodible soils be cleared and the foundation be excavated to suitable rock and then prepared. Some rock foundations, primarily shales, require a protective covering such as reinforced concrete to protect them from deterioration after being exposed and before concrete placement, unless the final excavation can be performed close enough in time to the placement of the structural base slab.<br><br>**Piles** may be bored, driven or screwed into the ground to a sufficient depth to ensure load bearing and stability even after expected erosion has occurred. A common and generally cost effective approach in sandy soils is to use hollow steel piles which are then filled with concrete. The piles then get topped with a ground beam to build off.<br><br>A variation between the two is to use mass concrete columns usually to bedrock in excavated shafts. |
| Suitability (Hazard Level) | Both excavations to rock and piled foundations are suitable making structures resistant to erosion hazards. However, excavation to rock depends on a suitable stable rock base being at a reasonable depth below the structure. If on lower lying ocean coastal areas, the structure may also be exposed to substantial wave impact after surrounding soils are eroded and need to be built strongly enough to withstand this.<br><br>Piled foundations can be used even on unconsolidated soils provided they are driven deep enough to ensure stability after expected erosion. However, if built at the top of an unstable or erosion prone slope, the degree of piling required to ensure stability may be excessive. By having an open structure, piles may allow water to travel underneath should any flooding occur. The structure may move slightly and should be designed accordingly.<br><br>These adaptations could only be considered for new properties as it would be prohibitively expensive to change the foundations of existing buildings. |
| General Impacts and Outcomes | Erosion resistant foundations provide great flexibility about locating structures in coastal areas safely. However, allowing such structures to be built requires consideration of how these structures will be serviced with utilities and accessed by roads.<br><br>Structures that survive after a beach or surrounding land has been eroded may create unattractive shorelines, reducing the amenity for other residents of coastal users. Examples of this outcome are shown below: |

**Figure 14a&b Houses on an eroding beach at Kitty Hawk, North Carolina, once situated on top of a dune**

*From: Titus Rolling Easements Primer, US EPA, June 2011*[38]

**Figure 15 House in Texas – used to be on land**

*From: Titus Rolling Easements Primer, US EPA, June 2011*[39]

[38] www.epa.gov/cre/downloads/rollingeasementsprimer.pdf

[39] www.epa.gov/cre/downloads/rollingeasementsprimer.pdf

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| Modes of Failure | Many structures eventually fail as they reach the end of their service life, typically in a storm.<br><br>Structures may become unserviceable or unusable as they become isolated from shore services and may then be abandoned if not demolished.<br><br>The unsightly intrusion or perceived risk to public safety may lead to a demolition order of the structure.<br><br>Structures that fail in a storm may create hazards for others at sea or along the beach. If the occupants are present during the storm, they may be at risk of injury or death and attempts at rescue may endanger emergency service workers. | |
| Complimentary Options | While individual structures may be resistant to erosion hazard, it is still desirable to retain beaches for their amenity value and to avoid the form of isolated structure shown in Figures 11 and 12.<br><br>Road access and services would need to be available for the structure to be of service to the occupant.<br><br>For structures that are exposed, an emergency response plan would be desirable. | |
| Indicative Cost | Excavation to rock | Highly dependent on depth to rock, condition of rock below site; costs includes excavation and masonry sub-structure. The cost premium may be modest if rock is near the surface, only a few % of total construction cost, but where bedrock is deep or excavation conditions difficult, this can rise to very high levels. It would generally not be used once piles are cheaper if they are viable. |
| | Piling | There is a minimum setup cost so piles would be relatively more expensive for smaller dwellings than for more substantial ones. The depth, spacing and type of piles selected will vary significantly with soil conditions. Using piles for foundations could add from 10% to 40% to the total construction cost of a dwelling. |
| Implications | These options are generally required at the design and planning stage, and cannot be readily retrofitted. Where site conditions permit and suitably constructed, both options can potentially provide foundations of a high strength and stability which will remain solid given a certain amount of erosion of the surrounding soils. However, they may result in a structure left 'stranded', with no easy access from non-eroded adjacent areas in an extreme case. | |

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| | While principally adopted to address erosion, both alternatives may be used to elevate the structure to address inundation risk as well, and additional elevation will increase costs by relatively modest amounts, that is, once committed to piles the marginal cost of additional height is low. |

# 3 Works to Address Inundation Hazards

Section 3 addresses works that can address inundation hazards. As with section 2, the first part, Section 3.1 deals with approaches that in general apply to groups of properties providing collective protection. 3.2 describes adaptations that can allow individual dwellings to withstand inundation hazards with limited or reduced costs and risks.

## 3.1 Collective works to reduce flood hazard

### 3.1.1 Dykes and levees

**Figure 16 Example of a Sea Dyke**

Source: http://climatetechwiki.org/content/sea-dikes

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| Description | Dykes and levees provide a barrier that keeps flood waters from inundating adjacent land. They are generally earth embankments, but may also consist of or be reinforced by masonry walls, sheet piles, surface hardening or other enhancements where flow rates, space limitations or other conditions require. |
| Suitability | Dykes and levees are generally aimed at preventing flood peaks from inundating adjacent land. If the outer face is |

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| | hardened, they may also resist erosion from storms or fast river flows. They can be quite effective where the flood flow is well contained and temporary and they are designed conservatively so they do not fail in an extreme event (ie not structurally sound or not high enough). |
| General Impacts and Outcomes | As sea levels rise, the level of the dyke or levee would have to increase. If regular high tide is above the level of the land being protected, then water tables are likely to be near the surface if not above.<br><br>While dykes may be used to protect land that is below mean sea level, this will require all rain and incoming stormwater to be pumped from the area to prevent flooding. Water may also move through soils, raising water tables to near or above the surface, requiring almost constant pumping. With rising sea levels, this situation only becomes more severe over time. It would be highly desirable to have independent back up power for the pumps as power failures are relatively more frequent during storms when operation of the pumps is most essential.<br><br>The height of the dykes would need to be increased to accommodate sea level rise as well.<br><br>The elevated barrier may act as a visual and psychological barrier between the community and the shore, changing the character of the area. Alternatively, a road along the top of the dyke may be regarded as an enhancement for some. |
| Modes of Failure | If overtopped, erosion of the top of the levee or dyke can lead to rapidly increasing flows. If the overtopping occurs early in the flood event, substantial water may enter the protected area and flood to a substantial depth.<br><br>If the wall fails entirely in one section, flooding may approach levels that occur in the absence of the dyke or levee.<br>If the barrier is only designed to limit penetration of peak events, and land levels behind the barrier are kept above normal high tides and minor storm height levels, then the consequences of a failure would be reduced. |
| Complimentary Options | General filling of land. The development of a dyke or levee could be used to protect against extreme events and provide a hardened boundary to resist erosion, with the land gradually filled behind it to reduce the need to pump out stormwater and reduce the consequences of a catastrophic failure (breach |

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| | or overtopping).<br><br>Elevating the floor levels of new structures above the expected flood level either prior to elevating land levels or instead would reduce the level of damage in the event of a dyke breach or overtopping. Making structures flood resistant as described in later sections would provide some resistance to flood damage even if not elevated.<br><br>It may also be desirable to raise major roads and high value structures above the general ground level behind the protection barrier to provide safety in the event of a breach or overtopping.<br><br>In the event of overtopping, having sacrificial undeveloped low lying areas to accept much of the spill water can reduce damage to higher value areas. |
| Costs | The costs for these treatments vary enormously, depending on the initial site conditions, degree of wave exposure, specific erosion dynamics, the outcome sought, etc.<br><br>The protection may extend over the length of the low lying shore between naturally higher points, or it may encompass only the developed portion of low lying land.<br><br>While generally most cost effective to surround a collection of property with a single dyke, individual properties could, in principle adopt the same approach if they have sufficient surrounding land, as shown below. This is more likely to apply to rural residential properties.<br><br>**Figure 17 House surrounded by own dyke, Mississippi floodplain**<br><br> |

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| | Source: http://thinkprogress.org/romm/ |
| Implications | If dykes are built higher with sea level rise, and the land behind is not raised, then the community is committed to continuing to build the dyke higher over time unless the area is abandoned.<br><br>In the event of a storm that overtops or breaches the dyke, the cost and risk of re-establishing may be sufficient to cause abandonment of the area. |

### 3.1.2 Flood barriers (eg. Thames Barrage)

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| Description | A flood barrier, surge barrier or storm surge barrier is a specific type of floodgate, designed to prevent a storm surge or spring tide from flooding the protected area behind the barrier. A surge barrier is almost always part of a larger flood protection system consisting of floodwalls, levees (also known as dykes) and other constructions and natural geographical features.<br><br>Surge barriers allow water to pass under normal circumstances, but when a storm surge is expected the barrier can be closed. The means of closing can consist of various forms of gates.<br><br>Examples of flood barriers are<br>- Delta works in the Netherlands;<br>- Thames Barrier;<br>- New Orleans (under construction);<br>- Eider Barrage[40];<br>- Venice (Mose project proposal). |
| Suitability | Usually used where an open passage is required to a bay, river mouth or canal for ships and pleasure craft, and where the opening is relatively narrow and capable of being 'closed'. This has no application on open coastlines.<br><br>A barrier may be appropriate to close off the Lauderdale canal from direct access to the sea. At present it allows the water from Ralphs Bay to flow freely into the canal an adjacent areas, even though South Arm Road is high enough to act as a |

40 http://en.wikipedia.org/wiki/Flood_barrier

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| | major impediment to inflows from the Bay. However, it would not be worth putting a barrier here if there was not some assurance that water could not also enter from Roches Beach or through storm sewer outlets and other connections to the sea. Further, the gates would need to be raised as sea levels rise, along with all of the other barriers that enclose the affected area. |
| General Impacts and Outcomes | Flood barriers are generally complex and costly to construct but may provide protection from a large area behind the barrier.<br><br>Some barriers may be large and visually intrusive structures. |
| Modes of Failure | Barriers will eventually fail by being overtopped in the long run unless raised as sea levels rise above their maximum design height. They can also fail if the other parts of the barrier system are not raised and the barriers is outflanked.<br><br>Barriers can also be subject to failure to close or close completely during a storm surge, either due to a mechanical failure or a failure of the control system or operator.<br><br>In locations where there is water traffic, failure to reopen afterward may block sea traffic.<br><br>The structures may be subject to physical failure due to storm damage.<br><br>If normal sea levels rise above level of land being protected and the barrier can no longer be opened without flooding the land, it becomes part of a permanent wall or dyke. |
| Complimentary Options | As noted above, flood barriers are usually part of a wider barrier system of dykes and levees.<br><br>The complementary options would be the same as for dykes and levees. |
| Costs | The costs will vary dramatically according to the span of any barrier, the height of storm tide that needs to be accommodated and the degree to which the channel must quickly and reliably open for shipping. |
| Implications | Flood barriers have mostly been used to protect relatively large heavily developed areas. They are likely to have a |

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| | limited future against continuing sea level rise. |

### 3.1.3 Prevention of water back up into stormwater mains

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| Description | Many stormwater mains empty into the sea with outflows at or near sea surface level. When a coastal storm surge occurs, rainfall runoff not only cannot get out, but sea water can enter storm water systems. Sea water can emerge in low lying areas that otherwise are protected from the storm surge by dunes, elevated roads or other barriers.<br><br>Where the rainfall outflow is restricted by elevated sea surface levels the 'backed up' stormwater may contribute to inundation at surface levels higher than the sea surface.<br><br>Prevention of sea water entry can be achieved through application of fittings available for stormwater outlets that prevent the entry of sea water, but which only slightly restrict the outflow of stormwater e.g. http://www.tideflex.com/tf/index.php These valves may be subject to blocking by debris, reducing their effectiveness at blocking sea water entry and also restricting outflow.<br><br>**Figure 18 St Helens road inundated at surface levels (~2.8m AHD) above the concurrent sea surface level (~1.1mAHD) due to restricted outflow.**<br><br><br>Source: Leigh Stevens (BO'Day Council) |

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| | To prevent stormwater flooding caused by surge elevated coastal sea surface levels that slow the rate of drainage, the stormwater systems will require designs suitable for increased capacities or alternately open systems (such as drainage channels or improved air valves). |
| Suitability | The ingress prevention solutions only provide a benefit where storm water mains provide a linkage allowing transferred sea water inundation to low lying land that otherwise would be protected from the surge.<br><br>Stormwater flooding impact minimisation may require alternate system designs where existing stormwater capacity is at the upper limit for outflows under assumed 'normal' sea surface conditions. |
| General Impacts and Outcomes | The ingress prevention approach provides a benefit in limited geographic specific situations.<br>Enhanced capacity systems or alternative designs accommodating elevated sea surfaces provide a benefit only during coincident rainfall/stormwater flooding and elevated sea surface events (for example during the peak of a surge tide) with limited or negligible impact at low tide or 'normal' sea surface levels. |
| Modes of Failure | There are a variety of designs with different operating characteristics. Some fittings may fail to seal if fouled by debris. Others may restrict outflow of stormwater and increase flood risk from rainfall. |
| Complimentary Options | This can be used with most other options where applicable. Storm water detention basins are particularly complimentary because they allow for stormwater to be stored without flooding nuisance or damage to infrastructure (see 3.1.4 below). |
| Costs | Costs depend on the size and number of the stormwater pipes that can benefit from the treatment. Indicative costs, installed, are $8,000 for a self closing flood gate installed on a 1200mm storm water pipe. |
| Implications | These fittings can make a modest contribution to flood hazard reduction in specific circumstances. |

### 3.1.4 Detention/retention basins and improved management of rainfall runoff

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| Description | The function of detention basins is to provide temporary storage of stormwater runoff at or near the initial point of flooding. This technique reduces the amount of flooding during large rainfall surges and following the surge is slowly redistributed into the drainage system.<br>The function of retention basins is to store water for re-use or to be re-distibuted to the environment by evaporation, groundwater injection or soakage into the soil[41].<br><br>While designed to address rainfall and runoff, not direct flooding from the sea, in coastal areas subject to rising coastal water levels, stormwater drainage may become less effective where the ends of pipes are submerged below sea level. High storm surge levels from the sea may even enter stormwater pipes and cause flooding by eliminating opportunities for rainwater to drain. Detention and retention basins may accommodate some portion of the runoff and reduce peak flood levels. Detention basins are generally more effective than retention basins for extreme events because they empty soon after filling and are thus fully effective for storms that follow in quick succession. |
| Suitability | As such systems are mainly to reduce the volume of water flowing at a given point in time (i.e. reduce the outflow of water from the system) the suitability of the facility is only to those areas that need to mitigate peak flows sporadically. Furthermore, these basins are designed to be one facet of an integrated water system and would not be used in isolation. |
| General Impacts and Outcomes | Basins can lower the peak volumes of water throughout a drainage system, when integrated with the rest of a storm water system.<br><br>Detention and retention basins require a relatively large area in a suitable point in the drainage pattern. It may be difficult to find such a site or it be relatively costly land if near a town centre or similar. Alternatively, the basin may be useable as an open space or amenity for the community. Such dual use |

[41] http://redac.eng.usm.my/EAD/EAD512/MSMA.pdf, http://www.brandman.com/TMSC-EIR/docs/Appendices/G_Technical_Report_on_Drainage_and_Flooding.pdf

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| | may affect the effectiveness of the basin. |
| Modes of Failure | The volume of the water catchment in the basin is a function of the local flood intensities. It is relatively costly to design for rare events. Basins would normally be designed with a spillway to allow for extreme events that might otherwise destroy the dam wall causing a catastrophic flood from the basin. In-ground basins may simply be allowed to overflow once their capacity was reached.<br><br>If rainfall intensities increase with climate change, the effectiveness of any improvements may decline over time. |
| Complimentary Options | Improved rainwater management would not be used in isolation, but would function as one aspect of a water network that has been designed to allow for rising sea levels. Provided the water drainage system is well designed and operates efficiently the drainage system will be a key component of managing flood risk overall. |
| Costs | Highly site specific, potentially high land cost/opportunity cost. Generally cheaper and more effective when established in the upper part of the catchment. |
| Implications | This approach addresses rainfall more than coastal flooding from storm surges. However, experience demonstrates that rising sea levels and associated storm surges also require a response in the stormwater drainage system in many locations. Detention basins at outfalls will be inevitable if tide gates are installed on outfalls. |

### 3.1.5 Raise land levels

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| Description | Raising the land level of developed low lying land above the expected sea storm surge level is one of the most secure and sustainable responses to rising sea levels. For any new development or major re-development in inundation hazard affected areas, this could be a requirement controlled by the Planning Scheme.<br><br>While building new structures with floor levels above expected flood heights would reduce damage, raising the land levels in general further reduces risks and maintains access and use of the property across the areas even during storm events with high sea levels. |

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| | Raising the ground level also means that most services would be above flood levels. Issues of high water tables would also not generally arise.<br><br>Typically the edge of the raised land would need some protection from erosion. This may be an existing sand dune system maintained by beach nourishment or by a sea wall, dyke or other erosion resistant face along a shore with no beach or dunes. This edge may change the character of the shoreline. |
| Suitability | Raising the land level on a coastal plain to avoid coastal inundation need not restrict rainwater runoff if due allowance is made for stormwater detention and drainage. Raising land levels in flood plains may have a significant effect of raising the river flood levels during extreme rainfall events. This is particularly significant in areas where rainfall intensity is expected to increase with climate change and rising sea levels will raise outflow levels.<br><br>One approach could be to excavate soil from the main drainage channel as the source of fill, taking care to maintain or even increase the volume capacity and cross section of flow.<br><br>It is possible to be selective about areas raised for development and occupation, areas excavated for fill that become channels or lagoons, and areas left or filled to levels suitable for evolution into wetlands or wading bird habitat.<br><br>For existing structures, it may be possible to raise the structure and rebuild the foundation underneath if the structure is of high value and lifting costs are acceptable. More often, it would be more cost effective not to reinvest in older structures for a period of time and rebuild when the building structure and fabric have reached the end of their normal service life. This approach would be problematic in areas where there are heritage structures on low lying land that cannot be lifted.<br><br>The approach can be most readily applied for green field development in low lying areas, but once developed would face the same issues of having to lift existing structures when a further increase in levels is required for ongoing sea level rise. |

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| General Impacts and Outcomes | While raising land above the storm surge height can avoid inundation, it represents a complete obliteration of the existing flora and fauna in the filled area and may also have significant impacts at the source of the fill material. For areas that are already heavily developed and urbanised, the loss in existing environmental values may be limited, especially if new plantings of native plants are encouraged. However, there may be a significant loss of mature trees or pockets of valuable habitat affected by the filling.<br><br>The impact of filling will depend in part on how it is done. If the filling is done in stages, or property by property rather than on a widespread scale, some flora and fauna may recolonise the filled area from adjacent areas. Older trees may remain in unfilled areas while newly planted trees in filled areas mature. However, such a patchwork filling approach may create problems with drainage unless some considerable thought and planning is put in place to anticipate and manage this issue.<br><br>Where a new area is being developed on low lying land, a more widespread approach to filling would likely be adopted. This approach would allow for the slopes and drainage lines to be well planned.<br><br>It is unlikely to be cost effective to fill areas that are not intended for reasonably intense development.<br><br>Land may be filled repeatedly as sea levels rise, typically with each redevelopment of a structure or renewal of roads, keeping fill levels above expected inundation levels. However, such an approach may have the effect of making the area feel quite 'transient' and disrupted if rapidly rising sea levels made filling a frequent or even constant activity in the area. |
| Modes of Failure | The main way in which raising land levels will fail is if the land is not raised as high as the highest flood experienced. In this case there may be a flood, but it is unlikely to be deep.<br><br>Failure can also occur due to erosion at the perimeter. Depending on the extensiveness of the filled area and whether there is any development on or near the perimeter, this may or may not be a major issue.<br><br>In coastal areas the low lying land is often unconsolidated silt |

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| | that will consolidate slowly when fill is placed on top or fail at the shoreline due to lack of support and alternate wetting drying of tides.<br><br>If the fill has been poorly placed and compacted or is un suitable material, filled areas may be subject to significant settling. In back yards and open spaces this is not a great concern, but would be a significant issue for roads and structures and may increase maintenance on infrastructure.<br><br>If the land ownership becomes quite fragmented with many different aged structures, ongoing attempts to top up the fill as sea levels rise may become increasingly difficult. A patchwork of fill may also lead to overland flow problems where higher ground obstructed drainage from lower ground . |
| Complimentary Options | Dykes or levees may be used as short term approaches to hold back storm or tide extremes in the period before existing developed areas are filled before redevelopment (or lifting of existing structures).<br><br>An alternative to lifting structures below the expected flood level that have substantial remaining service life would be to waterproof lower levels and services where possible to minimise any flood damage until redevelopment. A variety of technologies have been used to achieve this depending on the form of construction, flood depths anticipated etc[42]. |
| Costs | The cost of raising land levels will depend on the availability and cost of suitable fill. Sometimes fill material may be available for free. Costs of placing and grading may be quite modest, with higher costs for the load bearing area under the structure where consolidation and suitable material is required. An indicative cost to raise land level by up to 1 m may be $10 - $30/m$^2$, perhaps 10% of the market value of land in many areas. Additional costs may be incurred under foundations or for edges that may face erosion from flood water.<br><br>For existing development there would be additional cost if these structures have to be lifted. In general, one would time the raising of the land to coincide with the redevelopment of a structure or normal rebuilding cycle for roads or other |

42 SGS Economics and Planning (2009). *Climate Change Impacts On Clarence Coastal Areas – Final Report.* Retrieved on 7 November from http://www.ccc.tas.gov.au/webdata/resources/files/CCICCA-Final-Report-A415375.pdf

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| | infrastructure. In practice, this is unlikely to be achieved exactly so some cost for lifting existing development and infrastructure is likely to be incurred.<br><br>In general the cost of raising land used for agricultural purposes will be too high to justify in Tasmania. Fill required to raise agricultural land will need to be compatible with the intended or ongoing agricultural use and may therefore be at a higher costs than less productive fill options. It may be possible to preserve productivity by utilising material from lower levels or other sites that would be otherwise lost to inundation.<br><br>Agricultural land that is flooded by sea water will require restoration to be useable. Frequent flooding would make even this expenditure unviable, leaving agricultural land to revert to tidal areas as sea levels rise. |
| Implications | Raising land levels could provide an effective way to continue to occupy an area expected to be prone to inundation hazard with sea level rise.  However, the process would need to be continually repeated if sea level rise continues. The heavy modification of the landscape would dramatically alter the character of the area increasingly so with higher sea levels.<br>It is likely that eventually the fill option would become unsustainable due to increasing issues with edge erosion and rising costs while the shoreline is increasingly artificial, losing most of its natural values. If the area is then abandoned it is less likely to be in a catastrophic way that with a failing dyke and the occupied area well below sea level. |

## 3.2 Individual Asset Measures to reduce risk from coastal flood hazards

Section 3.1 discussed a number of measures that reduce the area exposed to or likelihood of coastal inundation hazards over a broad area. If such approaches are not adopted, individual assets in the inundation hazard zone will be exposed to the hazard. This section discusses approaches that can be used to minimise the risks of this hazard while occupying the hazard zone.

The first sections address responses for existing structures. The later sections address the potential for new structures to respond to inundation hazards.

The options for existing dwelling primarily attempt to exclude flood waters from entering the structure, an approach that can be used by a wide variety of structures. The one variation from this is to lift the structure and place it on higher foundations, but this is very difficult to do for many structures.

### 3.2.1 Flood skirts

**Figure 19 Example of the level of a flood skirt**

Source: http://www.whitehorsedc.gov.uk/Images/flood_product_guide_lowres_tcm4-217.pdf

**Figure 20 Example of other flood protective products such as an air brick cover.**

Source: Unknown

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| Risk Addressed | According to one source, there are currently over 150 temporary flood protection products on the market in the UK, many patented. These systems typically attempt to seal one or more elements of the building (doors, windows, vent openings etc.) or to assist in making the outer building fabric impermeable to flood water by sealing from the foundation up.<br><br>Many consist of continuous plastic sheeting with various support structures across doors and other openings that seal |

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| | the base of the building. Some have joins that are claimed to be durable and water tight while quick to deploy. At least one system has an unobtrusive storage arrangement for the sheeting around the base of the building when not in use[43].<br><br>These waterproof barriers are variations on plastic sheeting and sandbags that may be quicker to deploy and more effective (better seal). While not yet widely available or proven in Australia it is likely that such products will become more widely known. |
| Suitability (Hazard Level) | Flood skirt is light weight and it is claimed that rapid deployment by one person is possible. It provides a minimum of protection against inundation hazards. It is suitable for new and existing properties. |
| General Impacts and Outcomes | This approach can protect individual buildings or assets.<br><br>Effectiveness depends in part on the capacity of structure to withstand water pressure from the flood so may not apply to light weight forms of construction (garden sheds). |
| Modes of Failure | Failure to deploy due to absence during a flood or too short notice to respond.<br><br>Flood height exceeds height of protection provided.<br><br>Barrier fails (tear, cut, puncture, seal failure, etc.) possibly by being snagged from floating debris. This would allow water to enter but potentially less than if the building is unprotected.<br><br>Flood height sufficient to cause structural failure of building being protected. Few buildings can stand much more than 600 mm of water on external walls before structurally failing from the pressure. |
| Complimentary Options | While flood skirts exclude flood water from entering structural openings, drain pipes need to be sealed against flood water backing up and overflowing within the building.<br><br>Flood skirts and other building sealing arrangements could be |

[43] http://www.freepatentsonline.com/4425744.html

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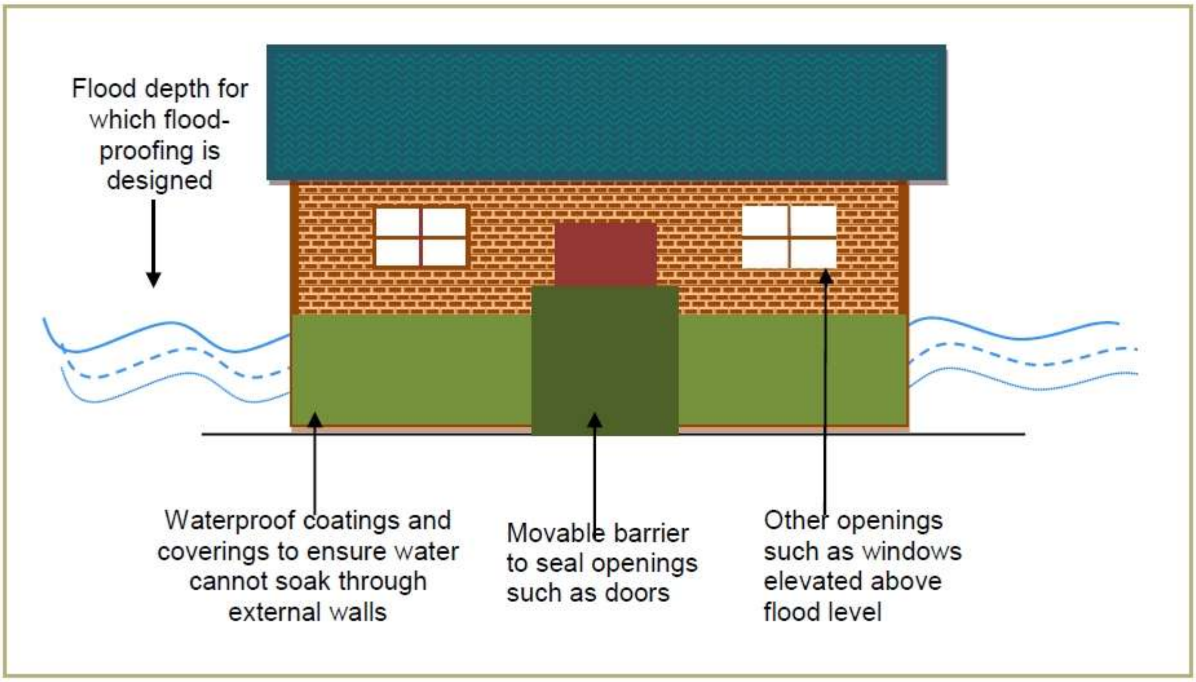
| | used in conjunction with dykes and levees as an additional backup protection in the event of failure.<br><br>Even if dwellings and other structures are protected, there will be a need to ensure access to these structures. It would still be desirable to lift roads or otherwise ensure access during floods.<br><br>Emergency planning for households in inundation areas would be desirable in the event of failure of the flood skirts or floods that exceed their capacity to cope.<br><br>In general one would not depend on flood skirts as the primary form of inundation hazard risk management for new development. |
| Costs | Cost of one product estimated to be about $1,300 per metre of building perimeter (adjusted from UK prices and exchange rates but may cost more delivered to Australia). Price and availability in Australia has not been determined.<br>If the system becomes more widely used, costs may decline. However, for a dwelling with a ground floor perimeter of about 40m, the cost as estimated would be a substantial $52,000 or about 20%-30% of the construction cost of a 'typical' dwelling.<br><br>Seals designed to protect individual elements also are available. For example seals for doors are available for about $600 per door[44]. |
| Implications | Flood skirts are designed to 'wrap' around a property preventing floodwater from seeping through the building fabric as well as through openings. Other products include air brick covers and protection against flooding caused backflow from drains can be prevented by fitting non-return valves and bungs to drainage systems. |

[44] Chrichton, D. (2003) *Temporary local flood protection in the United Kingdom*

### 3.2.2 Flood barriers

**Figure 21 Example of a Flood Barrier System**




Source: http://climatetechwiki.org/content/flood-proofing

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| Risk Addressed | Numerous flood barrier products exist made from a range of materials including aluminium and timber. These can be attached to the property or a free standing mechanism. |
| Suitability (Hazard Level) | Barriers can be attached to property or detached. Those barriers not dependent on the strength of the walls of the property are especially suitable for:<br>- Deeper or fast moving waters, for example river banks.<br>- Temporary buildings, caravans.<br><br>Combined with pumps and generators, the water can be kept well away from the property. |
| General Impacts and Outcomes | Barriers of this kind can deflect withstand modest flooding of perhaps up to about 600 mm over the area deployed. They could be used for single dwellings of groups of dwellings, or to protect an area with a singly low entry point against flood flows entering.<br><br>The barriers require a suitable surface on which to form a seal against water entry. This may not always be available. |

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| Modes of Failure | Failure to deploy the barrier in time.<br><br>Flood height exceeds height of protection provided.<br><br>Barrier fails (tear, cut, puncture, seal failure, etc.) |
| Complimentary Options | While flood barriers can exclude flood water from entering an area, storm sewers and other drain pipes need to be sealed against flood water backing up and overflowing within the area.<br><br>Flood barriers could be used in conjunction with dykes and levees as an additional backup protection in the event of failure.<br><br>Even if dwellings some areas are protected, there will be a need to ensure access to these areas. It would still be desirable to lift roads or otherwise ensure access during floods.<br><br>Emergency planning for households in inundation areas would be desirable in the event of failure of the flood barriers or floods that exceed their capacity to cope.<br><br>In general one would not depend on flood barriers as the primary form of inundation hazard risk management for new development. |
| Costs | Typical cost is approximately $29,800 for a free standing flood barrier. (length?) |
| Implications | Self-standing systems are bulky and heavy and require at least two fit people and over an hour for deployment and longer for removal. They also require adequate notice to be deployed in time.<br><br>Space is required around the property, so the barrier can be located far enough away from the walls to allow the pumps to be used.<br><br>Failure or overtopping could be disastrous, with a sudden rush of water hitting the property. Large storage space is needed for some systems while not in use.<br><br>Those flood barriers which are attached to the houses are not |

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| | usually suitable for floods deeper than 1m above floor level as the building structure may not take the differential water pressure. Door and window barriers are not suitable for walls with vulnerable cladding or coatings. The free standing barriers should withstand impacts from floating debris.<br><br>If poorly placed, the barrier may reduce the flow channel, raising flood levels for adjacent properties. |

### 3.2.3 Lifting existing dwellings

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| Risk Addressed | Existing structures may be lifted to raise their floor levels above expected flood levels. In general this is easiest for structures with timber framed floors and walls and light weight cladding such as weatherboards or sheeting. However it has been done for brick veneer buildings as well and techniques are available for lifting some slab on ground structures. |
| Suitability (Hazard Level) | Buildings in areas subject to inundation hazards that are capable of being lifted may be able to avoid flooding above floor levels and incur minimal damage in a flood. |
| General Impacts and Outcomes | While the structure and contents may be protected from flooding, access may still be an issue during a flood. |
| Modes of Failure | The flood height exceeds the level to which the floor is raised either due to a particularly extreme event or ongoing sea level rise.<br><br>The foundation is not secure, especially against floating debris or high flow rates. |
| Complimentary Options | Raising buildings could be used in conjunction with dykes and levees as an additional backup protection in the event of failure.<br><br>Even if dwellings are raised, there will be a need to ensure access. It would still be desirable to lift roads or otherwise ensure access during floods.<br><br>Emergency planning for households in inundation areas would be desirable in the event of floods that exceed the design level. |

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| | The principle of elevated floor levels could be applied to new construction or major renovations in the inundation hazard areas. |
| Costs | Highly variable according to size and construction of structure and the soil conditions affecting the new foundation options. |
| Implications | Probably applicable only to a limited portion of existing dwellings. |

The following sections apply primarily to new construction. Some of the approaches described may be applicable to extensive renovations of existing structures.

The first of these approaches describe ways of elevating dwellings or other structures. These share a number of common features:

- Property by property response does not ensure overall level of risk management.
- Solution works up to a point but 'safe' level fixed at the time of construction. This should ideally provide sufficient risk management for the service life of the structure or permit risks to continue to be managed after the sea level rise makes inundation above floor level a significant risk.
- Doesn't address access issues in a flood. Property may avoid (most) damage in a flood but access is not assured and there may be consequential losses (eg unable to access employment, health care, etc.)

Dwellings elevated by whatever means will generally benefit from being used in conjunction with:

- Raising roads, driveways, footpaths and other access;
- Raising the surrounding land;
- Flood proofing infrastructure and services;
- Emergency planning.

Most forms of construction that raise the dwelling will have the following issues:

- Raising the dwelling where access is not raised or ramped may create difficulty for access by frail or disabled people
- Raised dwellings have less immediate access to outdoor areas such as patios unless surrounding ground areas are also raised. This will add to the total cost and still may reduce amenity.
- Timber framed floors that are subjected to flooding are more likely to be damaged than concrete floors. They also have less thermal mass and may affect the comfort and durability of the dwelling.
- Raised dwellings in flood flow areas will impede flooding, reducing discharge rates and increasing flood levels to upstream properties. Raised dwellings along low flow ocean, bay or lake shoreline frontages should have minimal effects on other properties.

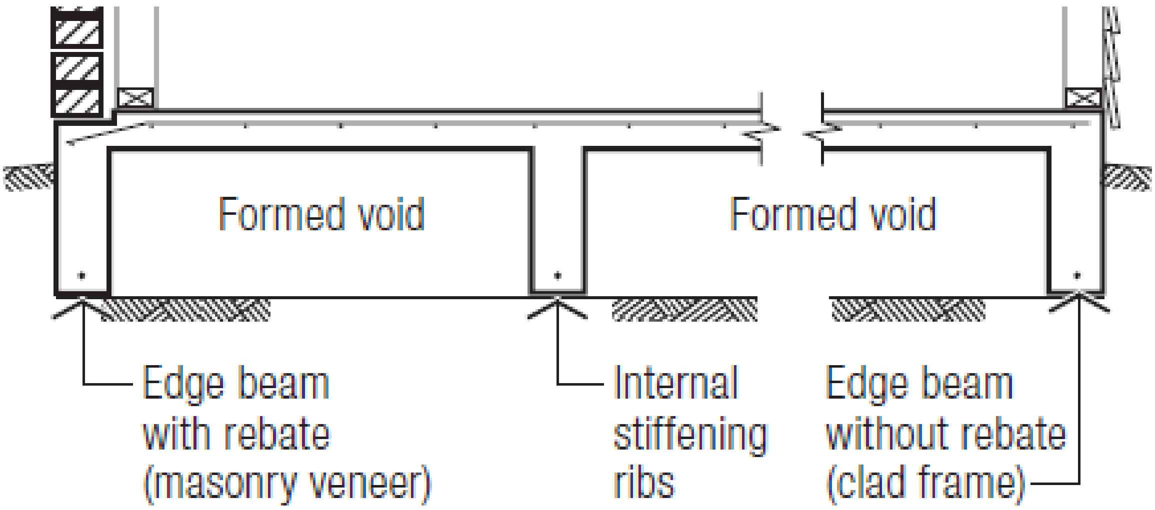
- If there is a development height limit specified from ground level, not the lower floor level, raising the floor may limit the capacity to build in some locations. For example, even where two stories are permitted in principle, if the ground floor level needs to be raised too high to avoid flooding, a second storey may not fit within the specified height limit.
- Difference in floor and roof heights along a road may have unacceptable aesthetic impacts
- While elevated structures may be suitable for dwellings, they are generally less suitable for commercial premises due to more difficult access.

### 3.2.4 Elevated substructure – type 1 (raised slab or floor)

**Figure 22 Example of a suspended concrete slab prepared for pouring**

Source: Building Guidelines

**Figure 23 Raised slab via waffle**




Source: Cement Concrete and Aggregates Australia (2003) Guide to Residential Floors

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| Risks Addressed | Raising the slab or floor of a dwelling will reduce the probability of the dwelling flooding, prevent ponding against the walls, and improve the drainage around the house[45].<br><br>There are a number of options for raising a slab. The most common are raising the slab via earth fill or via waffle fill.<br><br>A waffle raft is a stiffened raft with closely spaced ribs constructed on the ground and with slab panels suspended between the ribs. As the footing system is cast on the surface using forms, rather than trenched into the foundation, site preparation is minimised and reduced concrete and reinforcement is required. Waffle rafts can be designed to be supported on piers/piles, but it is more common to lay directly on the grade which limits the height they can achieve. If suspended on piles, etc the cost is substantially higher.<br><br>Concrete slabs may also be suspended so that they are not in direct contact with the ground.<br><br>It is also standard for all timber floors to be suspended and the height can be set to the desired level by raising the piers and perimeter skirt. | |
| Suitability (Hazard Level) | These floor structures allow for a certain amount of inundation protection depending on the level to which they are raised. These foundations do not offer protection from an erosion hazard such as an eroding dune or unstable slope. | |
| General Impacts and Outcomes | Not suitable in areas where flood waters have significant flow rate.<br><br>If many dwellings are built in this way it will reduce the flood water capacity of flood plains. | |
| Modes of Failure | Flood height is greater than floor elevation.<br><br>Scouring of the edges and undermining. | |
| Costs | Raised slab | Crushed rock filling (needs to extend |

45 Hawkesbury-Nepean Floodplain Management Steering Committee (2006) 'Reducing Vulnerability Of Buildings To Flood Damage; Guidance On Building In Flood Prone Areas'

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| | via earth fill | beyond exterior walls to provided foundation stability), requires edge treatment for landscaping, aesthetics.<br>Cost roughly proportional to depth. For 0.5 m fill total construction cost is likely to be increased by 5%-10% and for 1.0 m fill by 10%-20%.<br><br>Compacted Sand: This is not suitable in areas subject to significant flows during flooding unless enclosed with a hard facing or backing onto a rising slope. Requires a greater extent of fill beyond the exterior walls to ensure foundation stability than crushed rock that may partly offset cost savings per m2 to place and consolidate. Costs would increase by 3%-6% for 0.5 m fill and 9%-12% for 1.0 m fill.<br><br>The filling would be the main additional cost but some additional costs may include:<br>• Edge treatment for erosion control or aesthetics<br>• Landscaping<br>• Raising adjacent areas for access<br><br>In some instances clean fill may be obtained and consolidated for a lower cost than those cited, particularly where the fill is used for land surrounding the structure, access roads, etc. |

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| | Raised slab via waffle | The additional cost would involve the concrete used for the close grid of reinforced ribs, which support the slab panels. However as the footing system is cast on the surface using polystyrene or other lightweight forms, rather than trenched into the foundation, site preparation is minimised and reduced concrete reinforcement is required. Waffle rafts can also be designed to be supported on piers[46].<br><br>Waffle slabs can be quite economical for low lifts, adding about 2%-10% to total cost depending on the lift. However the height of the lift is generally limited to less than 1 m above grade without adding significantly further to costs. |
| | Suspended concrete slab | Suspended slab require a load bearing structure and foundations, generally with a perimeter wall on a foundation and some supporting interior walls. The void created may provide some additional useable (albeit potentially floodprone) space.<br><br>Suspended slabs can be cast in-situ, but can also consist of composite concrete/steel and precast. Prefabricated slabs may be significantly lower in price where available.<br><br>Suspended slabs will typically increase total construction costs by 10%-15% compared to slab on ground, but have the advantage of being built to the height required and potentially adding some useable storage space, particularly where flooding is not expected in the short term. While an expensive initial step from slab on ground, the marginal cost to raise further is less. |
| | Timber floor | Timber floors are usually constructed on piers or stumps and foundations, and need to be elevated above the ground to provide |

[46] Cement Concrete and Aggregates Australia (2003) *Guide to Residential Floors*

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| | | adequate ventilation. They are often set high enough to provide underfloor access for wiring and plumbing. They may be the most economical form of construction on some sloping sites where cut and fill is not viable. The height can be increased readily by raising the piers at modest cost. However, generally garages and parking are not similarly elevated, except by filling adjacent areas. This may add further to the overall cost. A timber frame floor can be expected to cost 2%-4% more than a slab on ground construction and the marginal cost of additional elevation is relatively low. |
| Implications | This type of dwelling adaptation does not permit water to flow through the base of the dwelling. | |

### 3.2.5 Elevated substructure – type 2 (stilt houses)

**Figure 24 Elevated dwellings in Galveston, on the Gulf of Mexico, USA.**

Source: http://www.capeweather.com/ftopicp-9553.html

In this example the dwellings are raised very high as protection against hurricane storm surges in the Gulf of Mexico. In the case study areas the required height would be considerably lower than that shown in the picture.

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| Risks Addressed | Dwellings would be raised on legs above the expected storm surge or flood levels for the design period. This may be in the form of extended piles where there is also erosion or |

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| | significant flood flows or simple piers where flow rates are lower and the soils are non-erodible.<br><br>'Pole homes' are a variation of stilt houses. They are typically supported by a number of load bearing columns set into the ground and encased in a concrete footing. Walls are generally non-load bearing and therefore would be constructed from light weight materials. |
| Suitability (Hazard Level) | In a severe storm, an elevated 'open' foundation will allow floodwaters to wash underneath the first floor without putting excessive load on the structure. In the US these foundations are required for homes in coastal flood zones that are rated for 'velocity wave action'. This typically only includes the first row of homes on the beach[47].<br><br>Where poor soil conditions are found, deep foundations may be needed to provide the required bearing capacity and to limit settlement. Examples if deep foundation systems include driven piles. Deep foundation systems provide a certain amount of protection from erosion as discussed above. |
| General Impacts and Outcomes | The use of homes elevated in this way has many similar characteristics to those on raised enclosed foundations in terms of protection from flooding but not addressing access issues. In some respects access issues are likely to be worse as the open structure is usually there to accommodate flows. Elevating roads and access (driveways, footpaths) may inhibit flows or be damaged by them, making their use in high flow areas undesirable or impractical. |
| Modes of Failure | Flood levels higher than the design floor heights.<br>Floating debris or rocks driven by flood water damaging the substructure, potentially bringing down the building. |
| Costs | In construction sites where settlement or scour in flooding conditions is not a problem, shallow foundations provide the most economical foundation systems. Where poor soil conditions are found or significant flows expected, deep foundations or piles may be needed to provide the required bearing capacity and to limit settlement. Deep foundations |

[47] http://www.coastalcontractor.net/cgi-bin/article.pl?id=1

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| | would require additional excavation and treatment. It may be more economical to use piles than to excavate.<br><br>Costs are quite variable for this form of construction, somewhat as per piles discussed earlier. However, if the principle requirement is to achieve higher elevation not to address poor soil conditions, piling depths may be less. Thus we estimate a range of from 10%-30% more than slab on ground for this form of construction. |
| Implications | Properties on stilts or poles are generally lighter weight to reduce the load on the piles/piers, although piles may be as robust as required for the building design at a higher expense. Where light weight structures are used they may be more susceptible to damage from high winds and poorer thermal performance.<br><br>Properties on stilts or poles will rarely have provision for parking and access raised to the same extent. During a flood event, residents may be safe within their dwelling but isolated until the flood subsides.<br><br>In locations where there is significant flows or wave action, and there is some potential for large water borne debris, stilts will need to be able to withstand impact or accumulation of debris creating flow resistance and the additional loads this may place on the structure. |

### 3.2.6 Elevated substructure – type 3 (Non-inhabited ground floor)

**Figure 25 An example from a wide range of 'coastal home' designs offered, South Carolina, USA.**

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| Risks Addressed | One of the most commonly used foundations with raised floor systems are pier-and-beam foundations. These are generally constructed of reinforced masonry (brick or concrete block) supported by individual, reinforced-concrete pad footings or by continuous, reinforced-concrete spread footings. Spacing of piers in the range of 2.4m to 3.6m is common[48].<br><br>By elevating the first inhabited floor to a full floor height, the lower (ground level) space created can be useful for under cover parking, storage of non-critical or waterproof items, etc. The non-inhabited ground floor of such a dwelling may be the full building footprint or partial building footprint. Access to the dwelling will generally be enclosed within the lower uninhabited space, providing additional privacy and security to the access. |
| Suitability (Hazard Level) | These types of elevated structures can be built to have as little resistance to flood waters as necessary e.g. minimal ground floor structure. |

[48] http://www.raisedfloorlivingpro.com/footings.shtml

| | |
|---|---|
| General Impacts and Outcomes | Similar to those identified for other raised structures. |
| Modes of Failure | Flood levels higher than the design floor heights, however, by being a full storey higher than the ground there is likely to be an extended margin of safety for the inhabited floor level. |
| Costs | It becomes difficult to ascribe additional costs just to the elevation of the inhabited floor. Some functions may be achieved in the lower level that would otherwise occur within the dwelling (eg laundry, storage). Further the elevated form of construction is likely to lead to significant changes to the design concept compared to either a slab on ground or a modestly elevated dwelling. Outdoor patios would more likely become decks, etc. The additional elevation may in some cases add value if it enhances views.<br><br>Thus it is hard to ascribe a meaningful percentage increase in cost to dwellings with a non-inhabited ground floor. |
| Implications | If non-inhabited ground floor is built to the full building footprint the building may increase resistance to flow, causing damage or elevating surrounding floodwaters.<br><br>The openness of pier foundations creates natural venting of the crawlspace.<br><br>Where there is a building height restriction the non-inhabitable character of the lower floor reduces the total potential useable floor area that can be developed.<br><br>If flood risk is sometime in the future, the ground floor (if high enough elevation for current day risk) may be inhabited until sea level rise makes it no longer suitable. |

### 3.2.7 Modular homes and moveable dwellings

**Figure 26 Examples of modular homes on raised foundations**

Source: Modular Home Builder http://modcoach.blogspot.com/

**Figure 27 Examples of moveable houses**

Source left:
http://www.madeinchina.com/showroom/richardzyb/productdetailKbdQchFCPPky/China-Movable-House-02-.html
Source right: http://www.kellyhicks.com/EBAY/EBAY.htm

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| Risk Addressed | Modular homes are sectional prefabricated houses that consist of multiple modules or sections which are manufactured in a plant and then delivered to site. Movable homes are similar but generally designed as a single unit and somewhat smaller.<br><br>Modular buildings and moveable homes are relatively low cost but generally less durable than conventional construction.<br><br>These homes can be assembled on top of multiple foundation surfaces, such as crawl space, stilts, full basements or slab on ground. Exterior wall surfaces and roof systems can be finalized in the plant or on-site. |
| Suitability (Hazard Level) | Modular and moveable homes can be designed to be suitable for inundation hazards. Modular homes can also be designed to be 'waterproof' (see below).<br><br>However, by their character of being transportable, they are necessarily light weight and are not able to withstand any flow or wave impacts even a small depth above floor level.<br><br>These homes may be relocated back from an erosion scarp or taken off site should erosion come to close or within the stable foundation zone of the structure.<br><br>They can be readily lifted to higher levels if required to adjust for increased future sea levels. |
| Modes of Failure | Flood level exceeds floor elevation.<br><br>May be washed of the foundations in an extreme flood.<br><br>Damage to supporting piers or foundations from debris. |
| Costs | It is estimated that modular construction costs 5%-25% less than traditional homes built on-site. Foundation costs are generally also modest as the structure is light weight.<br><br>However, they depreciate faster than conventional dwellings. The choice of design and fitout are also usually more restricted making them not directly comparable with conventional dwellings. However they may be particularly suitable for |

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| | temporary 'holiday' accommodation. |
| Implications | Modular homes would generally be most suitable when the land value is low, or the length of expected occupancy before failure is short (eg near an advancing erosion scarp).<br><br>If the dwelling is to be moved, sewage and utility connection points must also be moved. |

### 3.2.8 Water resistant and waterproof construction

| | |
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| Risk Addressed | **Water resistant construction** at a minimum eliminates readily damaged furnishings and finishes from flood prone levels (solid masonry construction with sealed surfaces, no plasterboard or carpet, minimal timber use and this treated to seal all surfaces, wiring from the ceiling down only, no low power points, any curtains or other fabrics designed to be raised). This minimises flood damage to the structure and finishes. Contents would generally need to be moved from the flood prone area or at least lifted. The design would also allow the water to flow out afterwards for easier cleanup.<br><br>**Waterproof construction** goes further by designing to exclude flood water from lower levels through tight sealing of exterior openings, drainage and sanitary plumbing that can be sealed against water entry, sealable air vents, etc. This may protect contents as well, at least up to design levels. |
| Suitability (Hazard Level) | Water resistant and waterproof construction are suitable for inundation. |
| General Impacts and Outcomes | Still faced with clean up costs for water resistant construction. |
| Modes of Failure | Lack of warning or opportunity to clear contents leads to damage. |
| Complimentary Options | Not defined. |

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| Costs | Adopting a waterproof form of construction may not add significantly to the cost of a dwelling compared to conventional construction, However, it will restrict design options significantly and typically has rather utilitarian finishes that do not appeal to many homeowners.<br><br>Making lower levels water proof is more demanding and not always effective. Costs vary greatly by design, with some of the contributing elements described in the previous section. |
| Implications | For flood resistant construction protection of household contents requires a high degree of preparedness if flood waters are expected to flow through the property. There will still be significant cost and inconvenience for clean up and it will take time to dry the area thoroughly before re-occupation. |

### 3.2.9 Waterproof lower levels

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| Description | At its simplest, wet flood-proofing involves moving valuable objects to higher ground in order to avoid the effects of flooding. Since this can be undertaken at negligible cost, wet flood-proofing is highly achievable on a local level provided sufficient warning time is provided.<br><br>Wet flood-proofing measures typically include structural measures, such as properly anchoring structures against flood flows, using flood resistant materials below the expected flood depth, protection of mechanical and utility equipment and use of openings or breakaway walls to allow passage flood waters without causing major structural damage[49].<br><br>Dry flood-proofing measures include sealing walls with waterproof coatings, impermeable membranes or supplemental layers of masonry or concrete and equipping doors, windows and other openings below the flood elevation with permanent or removable shields. Installation of backflow valves on sewer lines and drains is also likely to be required.<br><br>A dry flood-proofed structure is made watertight below the expected flood level in order to prevent floodwaters from entering in the first place. Making the structure watertight requires sealing the walls with waterproof coatings, impermeable membranes, or a supplemental layer of masonry or concrete, installing watertight shields on openings and fitting measures to prevent sewer backup[50]. |
| Suitability | Flood-proofing can be applied in residential and non-residential buildings and the principles of flood-proof design can also be applied to other important infrastructure such as electricity substations and sewage treatment works. Obviously, the decision to choose wet or dry flood-proofing should be influenced by the use of the structure being protected and the compatibility with flood waters.<br><br>In the United States homeowners are instructed to move all |

[49] http://climatetechwiki.org/content/flood-proofing

[50] http://climatetechwiki.org/content/flood-proofing

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| | wiring at least one foot above the 100-year flood level. All outlets, switches, light sockets and junction boxes, as well as the main breaker or fuse box and electric motors, should be out of danger of getting wet[51]. |
| General Impacts and Outcomes | Not defined. |
| Modes of Failure | Not defined. |
| Complimentary Options | Not defined. |
| Costs | US cost estimates for these measures are presented below and are in 2009 $US<br><br>Component / Cost / Per<br>Sprayed on cement wall covered / \$55.10 / Linear metre of<br>Waterproof membrane wall covered / \$18.70 / Linear metre of<br>Asphalt wall covered / \$39.36 / Linear metre of<br>Drainage line around perimeter of the house / \$101.68 / Linear metre<br>Plumbing check valve / \$1060 / Each<br>Sump and sump pump / \$1710 / Lump sum<br>Metal flood shield shield surface / \$1230 / Linear metre of<br>Wood flood shield shield surface / \$383.76 / Linear metre of<br><br>Costs are relevant for flood proofing of approximately 0.9 m[52]. |
| Implications | The costs of dry flood-proofing a structure will depend on the following factors (FEMA, 2007)<br>• The size of the structure;<br>• The height of the flood protection elevation;<br>• Types of sealant and shield materials used;<br>• Number of openings that have to be covered by shields; and<br>• Plumbing measures required to prevent water back-up.<br><br>At the community level, flood-proofing costs will depend on the number of properties in the flood hazard zone and associated costs such as flood hazard mapping and modelling |

[51] http://www.bhs.idaho.gov/Pages/Preparedness/Hazards/PDF/protecting_home_book_508compliant.pdf
[52] http://climatetechwiki.org/content/flood-proofing

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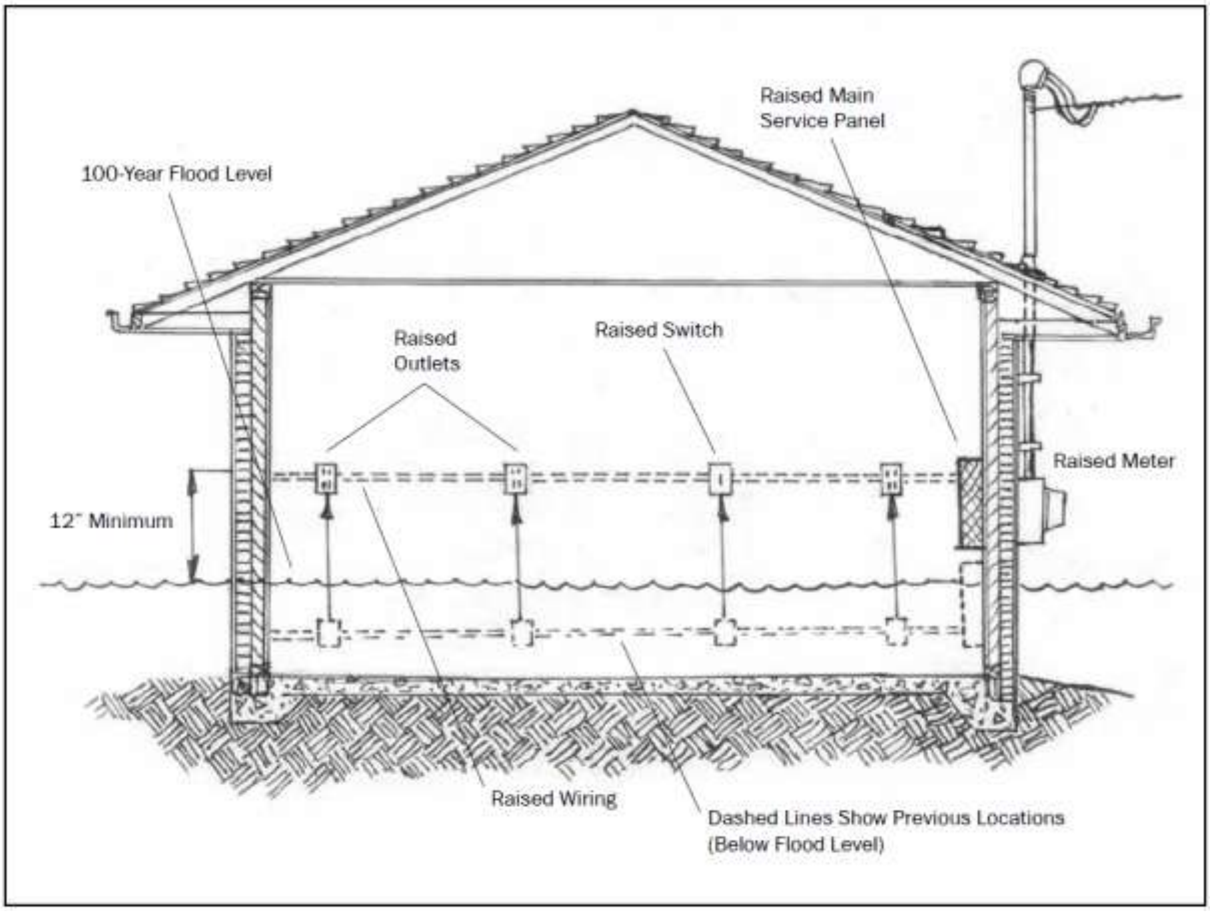
| | exercises to determine properties at risk.<br><br>Implementation of flood proofing measures may require a proactive planning approach.<br><br>Individual households may be able to finance some basic flood proofing measures themselves. However, due to the reluctance of individual home owners to undertake flood-proofing it may be necessary to inspect properties in the hazard zone to ensure that flood-proofing measures have been employed and to an acceptable standard. |

**Figure 28 Raised Electrical Wiring**




Source: FEMA 2010


SGS Economics & Planning

### 3.2.10 Floating houses and other structures

| | |
|---|---|
| Description | The latest designs of floating homes incorporate foundations which are made up of multiple layers of light plastic foam supporting concrete, allowing it to float. The most current building method uses polystyrene (EPS). This modified polystyrene is inserted in multiple layers in between stratums of composite and concrete and divided into beam-like modules that can easily be assembled into a bigger supporting structure like building blocks. The modules are arranged in a floating grid into which the concrete is cast. There are many other variations developing, with Holland showing leadership. |
| Suitability | Homes that can float do not necessarily float under 'normal' conditions. Rather they can be designed so that under flood conditions, they float and are not damaged. They will need to be held in position so they do not float off site and damage other structures. |
| General Impacts and Outcomes | The FLOATEC project sees the primary market for the houses as the Netherlands, whose low-lying land makes it particularly susceptible to the effects of rising sea levels. |
| Modes of Failure | Sinking, capsizing, being torn from 'moorings' in fast flowing floods. |
| Complimentary Options | Floating gardens, driveways, shops, roads and walkways, other forms of raised access. |
| Costs | Relatively novel as full floatable dwellings (as opposed to house boats and living on 'conventional' water transport). Costs are not well established. |
| Implications | Dwellings that float or can be raised have greater flexibility for unknown future flood levels<br><br>Floating houses could lead to a radical change to format and style of community. Alternatively, they could be designed to mimic conventional suburban development that simply floats when required. Another format may mimic many of the elements of canal estates, albeit the canals are not formed and walled, the structures are.<br><br>Larger communities primarily made from floating structures |

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| | may require complementary floating services (schools?) for unless close to higher land areas with reliable access. |

# 4 Works to address infrastructure and public assets

## 4.1 Sealed sewer systems

| | |
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| Description | Sewer systems designed and maintained to operate while submersed or below the ground water table. |
| Suitability | Suitable for newer systems because of recent improvements in jointing and sealing systems and materials technology. |
| General Impacts and Outcomes | Will increase capital costs slightly for systems designed for occasional or intermittent inundation. May require pressure system or vacuum system if construction conditions are affected by high water tables – this may increase capital and recurrent costs considerably if systems are designed for permanent or long term inundation. |
| Modes of Failure | Poorly jointed pipes, non-water-tight manholes and pump station wells, cracked pipes and shafts. |
| Complimentary Options | Raising other services, roads, etc. |
| Costs | From Southern Water (particularly the premium above conventional) per km of main, per property served. |
| Implications | Don't need to raise in future? Easier to flood proof dwellings (no backing up of wastewater into house?). |

## 4.2 Raised roads/services

| | |
|---|---|
| Description | Roads are raised above flood levels, or at least to depths that allow continued access during flood events. |
| 0Suitability | Raising roads may be necessary to provide access to properties that are not directly affected by coastal hazards but depend upon roads in the flood hazard area for access.<br><br>In low lying areas, raising roads implies continued commitment to maintaining a community in an area that is expected to be exposed to current or future flood hazards. |

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| General Impacts and Outcomes | Roads would not necessarily need to be raised above the height of the expected flood level, as long as the depth of flooding over the road was low enough to permit safe access. This will depend on the duration of the flood and the expected flow rate of the water. |
| Modes of Failure | The road is not high enough for an extreme flood, resulting in flooding but to a lower depth than if the road was not raised.<br><br>Failure may also occur from settlement and subsidence if the road bed is poorly prepared, consistently waterlogged or subject to erosion on the edges. |
| Complimentary Options | Roads would be raised to provide access to locations where land or structures are elevated above flood levels<br><br>Elevation of other structures in the hazard area or other suitable forms of protection.<br><br>Edge protection against erosion may occur with dykes.<br><br>Elevated roads may run on the top of dykes or levees. |
| Costs | Indicative cost to raise roads;<br>Suburban roads, $400/m to raise 0.5 m; $600 /m to raise roads 1.0 m.<br><br>Major highways, $1500/m or more including hardening of seaward face (depending on exposure).<br><br>It is most appropriate and cost effective to raise roads when roads are being resurfaced or otherwise undergoing major repairs. |
| Implications | If land is being raised by filling, raising roads would fit in to maintain a ‘normal’ landscape. If roads are being raised to maintain access to areas of higher land, they may become ‘causeways’ during floods. Raising roads in this case may have significant effects on drainage patterns and could potentially affect some low lying properties adversely. |

## 4.3 Liftable bridges

| | |
|---|---|
| Description | Design a bridge section that spans between two piers where the piers can be extended upward later and the span lifted to sit on the new, higher end pieces. |
| Suitability | Where a key road section between low points in unavoidable and there is a need to allow water flow (river outlet or tidal flushing of a wetland), provision for allowing the bridge section to be elevated if the service life of the span is longer than the time between needing to raise the bridge. This could occur with a relatively fast sea level rise or where a river may experience strongly increasing peak flows from more intense rainfall but this is uncertain or hard to quantify. |
| General Impacts and Outcomes | Not defined. |
| Modes of Failure | Not defined. |
| Complimentary Options | Not defined. |
| Costs | Not defined. |
| Implications | Not defined. |

## 4.4 Alternate routes via higher land

| | |
|---|---|
| Description | Low lying coastal roads or roads on eroding shorelines may become extremely expensive to maintain and be closed either briefly while flooded in a storm or for longer periods if washed away by erosion. In some cases such roads are the only means of access for people living on a peninsula or otherwise isolated higher land.<br>Purchasing an option to use land in the future, either adjacent inland areas or entirely alternative routes may be desirable to avoid large sunk costs becoming a barrier to these alternatives[53]. |
| Suitability | This option applies only where there is a need and a realistic alternative. |
| General Impacts and Outcomes | These will often change the 'connectedness' of an area, making new people neighbours while where old routes are |

[53] http://www.innovation.gov.au/Science/PMSEIC/Documents/ClimateChangeinAustralia.pdf

| | |
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| | abandoned, cutting what were once neighbours apart. Often a longer or less attractive route (or it would have been favoured originally). |
| Modes of Failure | An alternative route may be subject to its own risks. If it becomes the new single route after a coastal route is abandoned, those using it may be subject to other risks if it is cut off (emergency access for bush fires, medical or road accident access) |
| Complimentary Options | Retreat for hard to access areas.<br><br>Water transport to access isolated areas. |
| Costs | Highly location specific. |
| Implications | The ability to identify cost effective alternative access routes can greatly affect the future of areas currently vulnerable to isolation by loss of a road access. In most cases, the alternative route will lead to different influences on the pattern of development, some time substantially so. It may also affect travel time if much less direct and have other impacts (environmental, economic, social) that need to be considered. |

## 4.5 Floating roads

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| Description | Floating roads have been used for 'pontoon bridges' (eg across the Derwent River until the Tasman Bridge was built) for a long time. Typically they are tied to vertical piles that allow them to rise vertically while being retained in position.<br><br> |

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| Suitability | Floating roads are not widespread and at this time should be regarded as a novel technology with limited experience. The Dutch Directorate-General for Public Works and Water Management has launched a pilot project for the development of such roads as part of the "Roads to the Future" innovation programme. Floating roads are also commonly associated with marinas. |
| General Impacts and Outcomes | The Netherlands has a 100 m long experimental floating road over a tributary of the River Maas. It consists of linked up aluminium pontoons with a sealed road surface on top, filled with polystyrene foam to make them unsinkable. Passenger vehicles are able to travel over the road at up to 80 km per hour.<br><br>Floating roads can provide an alternative to traditional roads built on a sand foundation, particularly in low-lying clay and peat areas, which form a large part of the Netherlands. A single-carriageway road floating on groundwater takes up just 20 metres in width, whereas a traditional road at 1 metre above ground level takes up 45 metres in width[54].<br>The roads would normally sit on the ground level, but float during floods to maintain safe access. They would also need to be restrained against being displaced by water flow. |
| Modes of Failure | If flotation fails or traffic exceeds load capacity.<br><br>If tethering insufficient to resist water flows, waves or very high water levels.<br><br>If in sections, a break at a point of connection. |
| Complimentary Options | Raised roads to end points.<br><br>Floating dwellings or other structures alongside the floating road. |
| Costs | Limited information. Likely to be high until the technology becomes commercially established. |
| Implications | Very different environment with different ambience, risks, costs etc. Likely to create a different social, economic and environmental context than conventional land based roads and adjacent areas. There are precedents in some locations either |

[54] http://www.projectsmonitor.com/detailnews.asp?newsid=4510

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| | on poles/stilts or limited floating areas. Some similarities with canal estates except likely to be better flushed due to freer water flow. |

**Figure 29 Example of a Floating Road**

Source: http://www.nauticexpo.com/prod/clement-yacht-harbour-systems/floating-roads-22437-252731.html

## 4.6 Independence from connection to services

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| Description | Services may be disrupted by flooding or erosion in a coastal storm. In some cases restoring service may require significant repair works to pipes and wires serving the area.<br><br>A planned focus on services that are less dependent on connections may reduce the importance of these service risks. This is increasingly practical for wireless communications, and will become so as the cost of independent solar electricity with battery backup falls. On-site water treatment options may also become more acceptable as new membrane and other technologies mature. |
| Suitability | Many areas are already independent of direct connections to |

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| | services by virtue of relative remoteness and the cost (or lack of availability) of connections. Technology is likely to make this an option for more households in the future, including those at risk of service interruptions from coastal flooding and erosion. |
| General Impacts and Outcomes | Independence from connection to services provides greater flexibility to locate housing and potentially fewer or shorter impacts from service interruptions. However, further advances in technology are likely required before this option is considered realistic. |
| Modes of Failure | Failure of the on-site service infrastructure – damage to solar panels, loss of wireless base station, water treatment failure with potential health consequences. |
| Complimentary Options | May be particularly suitable to floating structures that would otherwise require flexible connections |
| Costs | Generally higher than conventional services where connections are available but used by many remote dwellings based on necessity. |
| Implications | Fixed service networks are cost effective in part because of a high proportion of properties in an area are connected. Allowing a significant proportion of users to opt out can make fixed services economically unviable without cross subsidy. In general it would be desirable for a community to all be on fixed services or all be off. The transition from one to the other would be potentially quite disruptive. |

## 4.7 Management measures for parks and public open spaces

Parks and public open spaces can include a mixture of built assets (shelters, benches, public toilets, sheds, etc), planted landscaped areas with paths, other features, sports grounds and natural areas. In general these represent less intensive development than residential, business or other developed land use.

These spaces will be affected by climate change impacts including erosion and flooding, but the cost of responding to changes may be less, both because there are fewer vulnerable built assets, and because strategies such as raising land levels may be far easier on an open sports field, landscaped area or even a caravan park than for an area developed with housing. This makes these uses potentially good candidates for coastal areas where land may be subject to the hazards of rising sea levels.

Where coastal areas are used for public use, the question becomes whether that use should be defended and preserved against coast hazards, even where it may have been chosen as a lower value, potentially 'sacrificial' use rather than permitting more intensive development. Arguments for defending even lower intensity public uses include:

- The use is highly valued by the community and cannot be easily replaced in the same locale
- Protecting or defending this land in a low state of development is cheaper and entails lower risks than seeking to defend developed property further inland, and as long as it remains in place, it serves as a defence and buffer to that higher value development
- It may be easier to raise and repurpose coastal public lands as sea levels rise and slow the rate of impacts on more landward properties, retaining valuable occupancy for many more years or readying the developed land for retreat over a longer time scale.

The actual options to protect the public land would be much the same as those described in the earlier sections dealing with erosion and inundation risks of built assets and land. In general the implications would also be similar. The major difference is consideration of the beneficiary of the response, which would often be a wider group than the protection of individual private property.

# 5 Climate change and natural assets

As climate changes and sea levels rise, natural areas will be subject to a variety of factors that will lead them to change and respond. Under climate change, natural areas will change, to a greater or lesser degree. Changes include:

- Loss of some of the existing flora and fauna and emergence of different dominant vegetation and associated fauna communities as temperature and rainfall conditions change
- Influence of saline coastal waters and ground waters leading to loss of salt intolerant vegetation and landward movement of saltwater tolerant vegetation.
- New areas of offshore habitat developing in previously dry land or coastal vegetation that is now 'drowned' by higher water levels being converted to marine environments.

At a local level, the changed ecosystems will appear as one type replacing another. At a broader scale, many of the changes may be seen as movements across a landscape – from low altitudes to higher, from low latitudes to higher, and from the existing shoreline inland to the new shoreline.

The effectiveness of these movements will be in part determined by the continuity or connectedness of the initial location and the future location. Where there are continuous connections, species are expected to be better able to move from their current location to the future location. Where there are barriers and gaps, some species may be unable to move and may become locally extinct.

The other major issue is that conditions may not exist, after climate change, that are suitable for existing ecosystems. Examples include:

- Where hills or mountains are not high enough to provide the cooler conditions required
- Where the new conditions represent a different combination of temperature and rainfall – moving to a cooler location may also become a dryer location
- For coastal areas, an area may become saline and wet, but be poorly flushed or exposed to different nutrient conditions and not support the same species and previously
- Marine ecosystems will not only have to deal with higher temperatures but also higher levels of dissolved $CO_2$ making the sea water more acidic.

In general we expect that ecosystems will be exposed to different combinations of conditions and so will change in character compared to recently. Such changes have been constant over the evolution of life on earth. The difference arising from climate change in locations heavily occupied by people is that these changes will be so much faster and in these locations, the modifications of the environment (roads, drainage patterns, introduced species, nutrient and pollution flows) affect the capacity of ecosystems to respond.

This section looks briefly at these impacts on coastal ecosystems, their expected responses to climate change effects and how these ecosystems can be assisted to adapt, even if they will be different in the future.

## 5.1 Wetlands & salt marshes

Wetlands and salt marshes in coastal areas provide a number of benefits including:

- Filtration of water runoff from the land
- Fish breeding and nursery sites
- Feeding and breeding grounds for a variety of birds
- A buffer area from coastal storms for land lying further inland

These benefits of wetlands don't provide value only to the immediately adjacent residents but also to the wider community.

**Figure 30 Wetland Restoration**

Source: http://climatetechwiki.org/content/wetland-restoration

Many coastal wetlands have been filled in the past to enable development, sometimes as dumping grounds for waste and sometimes to eliminate breeding grounds for mosquitoes or other pests.

Consequently the area of available wetlands is much reduced in most locations compared to conditions per human settlement (a statement that could be made of many other forms of ecosystem as well).

As sea levels rise the coast advances inland. In some cases, the existing coastal wetlands may be bounded by steeper land that will produce a steeper, rocky shore dissimilar to what currently exists. Elsewhere, previously low lying but dry areas are potentially future sites for new wetlands and marshes. However, a number of conditions may prevent this from occurring:

- Roads or other barriers prevent access by tides and the flushing conditions that enable some functions (eg fish breeding) to occur

- The land may already be partly occupied and occupants don't wish to leave or have property damaged
- The land may have been heavily modified (paved) or contaminated (land fills with toxic wastes or other pollutants) making it unsuitable to develop into a healthy wetland.

The result is that the number of locations in which shoreward migration of wetlands is possible may be quite limited. This suggests that opportunities that do exist should have a relatively high priority for protection or assistance.

Coastal wetlands naturally trap sediment both from runoff and brought in by tides and storms[55]. This process is slow but may allow wetland to rise with sea levels where changes are slow. However, where sea levels rise quickly, they would be unable to keep up, eventually 'drowning' by being permanently underwater.

The following describes some of the potential and implications for assisting the shoreward movement of coastal wetlands.

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| Description | Provisions that allow or encourage natural process of wetland formation and functioning to migrate shoreward with sea level rise. This could include:<br>• Moving coastal roadways inland where they block shoreward movement of wetlands<br>• Raising coastal roads on bridges or well flushed causeways to connect the open water to the wetland<br>• Reserving flat, low lying coastal areas as corridors for wetland, particularly where the corridor can connect to further areas over the long term<br>• Removal of contaminants and unsuitable development that otherwise cannot adapt to sea level rise and is expected to be abandoned<br>• Assisting existing areas to trap sediment and event augmenting the sediment supply to they can rise with sea level while rates of rise permit. |
| Suitability | This is only suitable where there is a shoreward migration path available to an area likely to offer a viable wetland of reasonable size. For example, it would not be worthwhile raising a road to allow flushing to a small pocket of suitable land backed by steeper rocky terrain.<br><br>The approach may also be attractive in areas where there is not currently a coastal wetland but the flat land behind the |

[55] They may also build outward from the shore at the mouth of sediment rich rivers, but there are relatively few of these in Tasmania.

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| | shore would allow one to develop in the future. |
| General Impacts and Outcomes | The approach would help maintain some level of this ecosystem in the region where otherwise it may be lost entirely. In general, it would be better to assess the locations to be 'assisted' or reserved based on a regional scale assessment as the potential opportunities and the benefits are both likely to be most meaningful at this scale. As the benefits are regional, it is appropriate that any funding or other impacts are also addressed at this scale. |
| Modes of Failure | Coastal wetland are relatively resilient ecosystems. Provided conditions are available, they are likely to be successfully colonised by suitable species. However, the extent to which they provide the services valued by the community (as opposed to providing biodiversity with its own inherent value independent of people) may depend on the effectiveness of the linkage between the wetlands and the open water and other site specific factors. Thus while absolute failure is unlikely, there may be more or less effective outcomes. For example, spending heavily to protect or assist a wetland with a limited capability may represent failure through a poor use of resources.<br>Another potential source of failure might be if a wetland subsequently becomes a source of disease vector due to rising temperatures and is seen to be more a source of harm than benefits. This may lead to calls to have it filled, defeating any value in investments to preserve it. |
| Complimentary Options | Treatment of coastal roads and other developments that allow relatively free shoreward movement of tidal activity. |
| Costs | This is highly site specific. The main costs are associated with the costs of reconfiguring roads, and of land foregone that may have had continued use enabled by filling or occupancy on elevated or floating structures. |
| Implications | A local community is likely to seek compensation from the wider community if it is to give up currently or potentially occupied land for future wetlands.<br>As sites for shoreward migration of wetlands may be limited, and the value to the wider community quite large, opportunities that do exist to assist shoreward migration should be given serious consideration. |

## 5.2 Beaches

A large proportion of coastal settlements occur along or very near beaches. Beaches and associated coastal dune systems and vegetation are the natural response of the land to interaction between vigorous surf action and low lying land where suitable sediment (sand) is captured. They are mobile land forms that can shift quite suddenly, and then shift back. The form at any beach is the sometimes quite short term equilibrium between waves, wind and coastal vegetation.

Development or disturbance within this active area will inevitably challenge the equilibrium. Changes such as sea level rise will also mean that the system will try to adjust to changed conditions. While this response is normal, it will have potentially large effects on any development within the active area.

While the areas are attractive to communities in their natural state, if efforts to defend property prevent the beach system from responding to changes, the beach may become heavily modified or even lost, making the area less attractive to the people drawn to it in the first place. Thus there may be a tension between wanting to be near beaches and the long term response of those beaches to the forces that form them, if they are to retain their attractive natural character[56].

Many of the adaptation options described in earlier sections involved interventions that were aimed at protecting property assets near beaches from erosion and waves. This section reviews some of these from the point of view of protecting the beach, and introduces other considerations from the perspective of supporting natural processes.

**Figure 31 An Example of Beach Nourishment Works**

Source: http://climatetechwiki.org/content/beach-nourishment

[56] Some former beaches, now heavily modified or even lost as 'beaches', may still be very attractive to many people, but not for their natural values.

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| Description | 1. Providing additional sand (beach nourishment) can allow beaches to adjust to rising sea level without (or with less) shoreward recession than would otherwise be necessary. The additional sand would need to be captured from outside the local sediment cell.<br>2. Preserving and assisting dune formation and stabilising processes will minimise mobility of dunes while still maintaining natural landforms and vegetation. Over time, the dunes need to be allowed to rise with the beach level, not constrained by hardening or significant modification of the dune vegetation to non-sand trapping conditions. |
| Suitability | The first response is most appropriate where there is an available supply of sufficient suitable sediment that can be introduced to the system. This may be used to keep non-eroding beaches filled above sea level where they are backed by rocky shores or a sea wall and so cannot access an additional local sand supply.<br><br>Providing additional sand may be realistic for modest sea level rises. However, it may not be capable to keeping up with rapid rates of change or very much higher levels than today without excessive cost or running out of sediment supply.<br><br>The second approach suits locations where coastal dune forming processes are largely still operating and the continued health of dune vegetation is compatible with adjacent use. Such an approach would not suit a beach where the dunes have been entirely hardened or constrained (parking lots or other development that prevent dune vegetation and dune formation from occurring). |
| General Impacts and Outcomes | Beach character can be largely retained by supplying additional sand to the area. This may not be entirely the case where the imported sand has a different colour, grain size or parent rock from the original beach. The character of the surf and other aspects of the coastal dynamics may also be altered by the combination of the additional sand and the higher sea level.<br><br>Any realistic attempt to maintain a natural beach setting would need to keep development back from fore dunes as well as provide sufficient additional sand to prevent significant erosion of those dunes. This will limit development potential in these areas which may or may not be acceptable to the local |

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| | community.<br><br>The process will lead to the continuing elevation of both the beach and the dunes behind it. To avoid inundation from land based flooding and rising water tables, property behind the beach would also have to be lifted eventually. |
| Modes of Failure | If the objective is to maintain the natural values of a beach environment, any excessively intrusive development or any development that greatly constrains the natural response to change could be regarded as a failure. However, if the development is valued more than the beach that may simply reflect community values rather than be regarded as a failure. A greater failure may be where development intrudes on natural processes but ultimately fails due to inadequate design or the greater power of natural forces. In the long run, nature will prevail but in the intermediate term the result can be ugly and messy, neither natural nor an intended development. |
| Complimentary Options | Another means of allowing beaches to respond naturally to sea level rise is to avoid and remove existing development on or adjacent to these mobile land forms. This is discussed further in sections 6.2 Avoidance and 6.3 Planned Retreat. |
| Costs | This will be highly dependent on location and the rate of sea level rise. |
| Implications | Action to maintain natural beach conditions can retain the attractiveness of these areas, at least for a time, even with sea level rise, provided the basic processes are intact, that there is a source of suitable sand to nourish the beach and development is not allowed to encroach on the most active fore dunes of the beach. In the long term, either the cost of availability of sediment may be insufficient to keep up with continued sea level rise. |

## 5.3 Changes to other natural assets

With rising sea levels, ground water in low lying areas near the coast is likely to become increasingly salty. This is likely to lead to the loss of some less salt tolerant trees and other deeply rooted vegetation. Coastal vegetation communities may thus change in character, potentially dramatically, to be replaced with more salt tolerant species and associated fauna. This change in vegetation and the changed character may affect the value placed on the area by residents.

To some extent this may be addressed by raising the level of the land, keeping roots above the salty water table. However, this would effectively bury the existing vegetation and require reestablishment of the vegetation at the higher elevation. Further, this would have to be repeated as sea levels keep rising. It is not obvious that such a process would retain the 'natural values' of the original ecosystems of the area, particularly long lived large trees.

Coastal and marine ecosystems are likely to be affected by the increased acidity of the sea. Apart from reducing greenhouse gas emissions, there are few possibilities to reduce impacts on life in the sea. It may result in a change, possibly dramatic, in available species for fishers and the coastal marine life (kelp, sea grasses etc.) distribution and abundance. It may lead to changed prescriptions for dealing with invasive species that are favoured or hampered by these changes. Both the changes and possible responses to them are not well characterised at this time.

Adaptation to these changes will largely consist of identifying and encouraging species with desirable attributes to colonise the changed conditions. The underlying conditions cannot realistically be influenced over areas of significant scale.

# 6 Other risk management measures

## 6.1 Early warning systems, emergency response

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| Description | Where hazards cannot be avoided, at least in the short term, early warning systems and emergency response plans can at least reduce the danger to life and safety and can in some cases significantly reduce damage to items that can be moved to safety or be protected by temporary measures (eg flood skirts).<br><br>An effective system would require a forecasting method that can detect a risk situation with enough notice to be useful, a notification system to those affected, and a plan to respond to minimise harm from the event which may also include response by emergency crews if warranted. |
| Suitability | Where risks have not been managed to acceptable levels by other means, and even where they have, where the event exceeds the capacity of the risk management approach used. This applies in virtually all situations as more extreme events than planned for can occur. |
| General Impacts and Outcomes | This approach is reactive, seeking to minimise harm to people when some damage may be unavoidable. While the level of damage may be reduced, it may not be reduced by much and significant property may be lost. |
| Modes of Failure | Inability to recognise an impending event or to recognise it in time to act.<br><br>Failure of the warning to reach those who need to respond. Poorly planned or ineffective response resulting in life still at risk including those of emergency service workers. Refusal of some to comply with a plan.<br><br>Complacency and unfamiliarity with the plan if a long time between events and there is not attempt to reinforce or 'practice' the response. |
| Complimentary Options | Elements of a response plan may include flood skirts and other temporary measures to reduce water entry into buildings, moving items that may be damaged out of the hazard area and moving or tying down items that may become hazardous |

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| | to neighbours or the environment. |
| Costs | The early warning system would likely be built on the back of the existing Bureau of Meteorology forecasting systems and weather alerts. There may be a need to improve notification and response planning. No cost has been developed for this. |
| Implications | This approach accepts that there are some risks that cannot be avoided and prepares to minimise their impact. |

## 6.2 Avoidance

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| Description | Avoidance involves not allowing occupation or significant use of an area subject to hazards so that assets in the area are not subject to potential damage, either from present day hazards or from expected future hazards due to climate change, coastal erosion or other natural hazards.<br><br>Avoidance is quite commonly a feature of public policy to address climate change in Australian states. In particular, it is attractive where otherwise there is no effective mechanism for managing developing risk as sea levels rise or shorelines erode. In this case Government, typically at the state or national level, are left to provide assistance and cover much of the cost after extreme events cause property damage and danger to life and safety. |
| Suitability | Avoidance applies primarily to development of new built assets. It has some role in protecting natural assets from change, insofar as leaving an area undeveloped may allow coastal vegetation and landforms to move inland unimpeded as sea levels rise.<br><br>Avoidance is certainly effective in reducing future damage where there is currently limited or no development by avoiding putting that development in harm's way.<br><br>Avoidance has much more limited application to existing development, but may have an effect over time by limiting or prohibiting redevelopment or reinvestment in an area. In this way it is a form of planned retreat. |
| General Impacts and Outcomes | Avoidance prevents the use of a hazard area (present day or anticipated) in order to reduce futures risks and costs. Where there are alternative locations that are equally attractive but not subject to such hazards, or where substantial investment would be required to access, service and support development and the lifetime of use is limited, such an approach is both effective and has little opportunity cost.<br><br>In areas that have a very high appeal and which provides a high level of benefit from use, avoidance loses that potential benefit. It is notable for example that the majority of coastal settlements are located as close as practical to beaches and |

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| | river mouths. People find these highly attractive locations and are prepared to pay a premium to locate in these settings. However, with climate change they are almost all eventually going to be exposed to increasing coastal hazards. Here avoidance may have a high opportunity cost.<br><br>Some of these areas may be occupied for a significant period of time before hazards become significant, much longer than the life of many developments. However, if avoidance is employed, some of that useable lifetime will not be available. |
| Modes of Failure | Areas that have been avoided don't fail in the form of loss of property due to natural hazards. However, constraints on development of attractive areas may result in economic loses to a community: reduced income, population, economic activity as development of attractive locations is prevented. In this case a certain short term loss is borne to make a potential long term saving. |
| Complimentary Options | Planned retreat is often needed to deal with existing development in an area being avoided.<br><br>If an area is avoided for permanent development, it may be attractive for other public uses (foreshore reserves), retention (or reversion) to a natural area to provide ecosystem services, or use for intentionally short lived or removable forms of development (camping or caravan park, park or landscaped open space with limited infrastructure development appropriate to the expected lifetime of the site). |
| Costs | The main cost of avoidance is the opportunity cost of lost use and development. Where use value is low, particularly compared to the cost of servicing new land and eventual loss of investment should retreat become necessary, compared to the value of alternative community benefits, the cost of avoidance is low or even negative and the option is very attractive.<br><br>If the forgone use value is high, particularly if there are significant local economic benefits to occupancy (eg port or other coastal access, key tourism activities or attraction of residents to spectacular settings not available out of the hazard zone) and the risks to the assets can be well managed by other means at least to the end or beyond their normal service life, the potential cost of avoidance may be very high. |

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| Implications | Avoidance is an effective and cost effective strategy for undeveloped areas with limited use value or high value as undeveloped land. Avoidance may be an expensive strategy if if prevents enjoyment and use of areas with high development value where risks can be effectively managed by other means. |

## 6.3 Planned Retreat

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| Description | Planned retreat may involve the dismantling or abandonment of assets prior to being destroyed by hazards and extreme events or on the basis of prior commitment not to rebuild after such events or a combination of both.<br><br>Progressive retreat is sometimes propose on the grounds that the most sustainable coastal form will reflect the form that will emerge under natural conditions, conditions that are inhibited by the presence of development. For sandy shores, dunes will move inland to add sand to the coastal system, rebuilding to continue to protect the area behind.<br><br>In other cases planned retreat is simply a response to conditions where risk becomes excessive and the cost of recovery or the cost of risk minimisation are very high compared to the value of occupancy. |
| Suitability | This option applies to areas already occupied or in use or where an asset already exists in a present day or expected hazard area.<br><br>It is particularly suitable where costs of risk management exceed the value of remaining in an area and the probable costs of damage are both high and likely.<br><br>It will also be suitable where retreat permits the re-establishment of natural coastal areas that have a high community value or a high ecosystem services value. |
| General Impacts and Outcomes | Retreat inevitably means the loss of established assets, locations, community and memories associated with the areas being given up. In some cases it means giving up only a small area or a few properties that are vulnerable with little impact on the wider community. In other cases, it may result in entire |

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| | communities ceasing to be viable, at least in their present form or location. |
| Modes of Failure | Planned retreat may fail if residents refuse to leave their dwellings, even after storm damage.<br><br>It is most likely to fail if current governments provide assistance to re-establish after storm events even when past policy had been not to do so. This may arise from a change in policy or effective lobbying by residents unwilling to leave.<br><br>If some residents leave, the remaining community may not be viable and other may leave for social or economic reasons, not due to the hazard. This is most likely if no provision has been made to ensure a sustainable community can be maintained in adjacent areas not subject to hazards.<br><br>Arguably such a policy is ineffective if a large proportion of property that is lost or abandoned still had a significant lifetime when lost to storms resulting in large economic losses. While retreat may be appropriate and even desirable in this situation, it could not be regarded as a desirable outcome. |
| Complimentary Options | Avoidance of development in adjacent undeveloped hazard areas would be desirable unless these areas are inherently more 'defendable' from coastal hazards than the areas being abandoned. It would be a poor approach to be abandoning one area while occupying another that is equally vulnerable (or nearly so). |
| Costs | Progressive retreat generally means the loss of prime coastal property. The fact that it had been developed strongly suggests that at least at the time of development this was an attractive place for settlement to be established and to grow. In spite of this, it may prove to be the lowest cost long term alternative available, especially if the cumulative cost of maintaining a shoreline against increasingly severe erosive forces into the future is considered.<br><br>This is particularly the case where there is a single row of houses and they are vulnerable to erosion or inundation from both the front and back sides.<br><br>The cost of planned retreat is generally high but may be less than the cost of alternatives. It can be diminished to the cost of land if a process of planned disinvestment occurs. For |

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| | properties at risk where the cost of protection is very high, it would not be prudent to add improvements or even to renew features such as kitchens and bathrooms when they become substantially aged.<br><br>The properties may eventually be reduced to the status of 'shacks' rather than full time occupied residences if it is not renewed or maintained to a high standard because of an expected limited remaining lifetime. In this way, when the property is finally abandoned or lost to an extreme event, the main loss is in the land value.<br><br>If the land has a public benefit as open space or public beach, this may be recognised in a re-purchase by the public[57]. |
| Implications | Planned retreat generally occurs where the cost of protecting property exceeds the value, or the condition as undeveloped land has unusually high environmental or other values. It always results in loss but this may be less that for alternatives. In general we can expect it to be quite disruptive to communities economically and socially. It may provide some offsetting environmental benefits. |

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Brisbane
Level 9
269 Wickham Street
Fortitude Valley QLD 4006
PO Box 1177
Fortitude Valley QLD 4006
P: +61 7 3124 9026
F: +61 7 3124 9031
E: sgsqld@sgsep.com.au

Canberra
Level 1
55 Woolley Street
Dickson ACT 2602
PO Box 788
Dickson ACT 2602
P: +61 2 6262 7603
F: +61 2 6262 7564
E: sgsact@sgsep.com.au

Hobart
P: 0439 941 934
F: +61 3 6244 4154
E: sgstas@sgsep.com.au

Melbourne
Level 5
171 La Trobe Street
Melbourne VIC 3000
P: +61 3 8616 0331
F: +61 3 8616 0332
E: sgsvic@sgsep.com.au

Sydney
Suite 12
50 Reservoir Street
Surry Hills NSW 2010
P: +61 2 8307 0121
F: +61 2 8307 0126
E: sgsnsw@sgsep.com.au