3 Generic Shoreline Management Options

3.1 Generic Option Considerations

A range of generic management options are available for consideration, which may be classified in terms of their consistency with natural coastal and environmental processes and the natural character and values of the coastline as follows:

"Soft" Options: Options which restore and/or preserve the natural character, behaviour and values of the coastal system. These will ensure the sustainable existence and natural character of the shoreline and foreshore such that future erosion, both during short term storms and over the longer term, can be accommodated in a coastal buffer zone without threat to development requiring protective works.

Soft options may include works such as beach nourishment with sand, re-vegetation of foreshore areas and/or planning solutions that require development to be outside the zone of potential erosion (buffer zone), including:

- Regulatory controls on building in undeveloped areas;
- Removal controls on building in undeveloped areas; and
- Works aimed at restoration of the shoreline/foreshore system seaward of the development to provide an adequate buffer width to accommodate erosion.

"Hard" Options: Options that involve construction of works either to form a barrier to natural coastal erosion to protect development (seawalls) or to alter the natural processes to change the way in which the shoreline behaves (groynes and breakwaters).

Combinations of options or "hybrid" management approaches are often the most suitable where existing development lies within the erosion prone area. For example, works options such as terminal protection (seawalls) are sometimes combined with partial set-back of development, or may be augmented with ongoing beach nourishment to offset associated undesirable environmental and recreational amenity impacts. In addition, most options need to be supplemented with relevant amendments to local planning controls.

Thus, engineering works options for the shoreline may include "soft" or "hard" solutions, or a combination of both. The most common feasible works options for overcoming beach erosion problems include the following and are discussed in more detail below:

- Beach nourishment with sand to restore the beach and dune system;
- Seawalls to protect assets;
- Groynes to control the longshore movements of sand; and
- Offshore breakwaters or submerged reefs to modify wave processes which erode the beach.

Such works options are generally expensive, typically in the range $3,000 to $8,000 per metre length of beach to construct for adequate protection, and the hard structural options typically have adverse side effects on the beach system. Ongoing maintenance requirements must be considered in both the design and financing. Experience indicates that careful design in full cognisance of the prevailing coastal and ocean processes and the short and longer term effects is essential for success and cost-effectiveness of such works.

For example, it is known that seawalls constructed on retreating shorelines may give protection to land based assets, but will eventually cause loss of the adjacent beach. There is a need to ensure that the foundations of the seawall are sufficiently deep for stability to cater for the loss of the beach, typically requiring deeper foundations the more seaward the seawall is located. Similarly, beach nourishment must be designed and implemented to provide for the cross-shore and longshore movements of sand affecting the area for long term effectiveness in providing property protection while maintaining the recreational amenity of sandy beach systems.

3.2 Decision Matrix

It is convenient to consider beach protection options in the broad terms of the simple matrix illustrated in Table 3-1. This matrix, in effect, represents a decision tool based on criteria relating to:

- ‘Natural’ versus ‘Altered’ character; and
- ‘Non-works’ (planning) versus ‘Works’ options.

Table 3-1 Matrix of Beach System Management Options

	Preserve Natural Beach System Character	Accept Change to Natural Beach System Character
Non-Works Options **(planning, management and regulation)**	Development free buffer zones via planning or land use regulation; Resumptions of erosion prone development; Set-back of buildings; and Building guidelines and controls; Land use guidelines and controls; Management including dune care activities.	Accept development on vulnerable erosion prone land, but prevent any protection works (allow loss of buildings and facilities as erosion occurs).
Works Options	Beach nourishment with sand to restore the beach and dune system; Multi-purpose submerged reefs for shoreline protection and recreation (e.g. fishing, snorkelling, and surfing).	Seawalls to protect assets; Groynes to control the longshore movements of sand; and Offshore breakwaters to modify patterns of sand transport and shoreline shape.

To be consistent with coastal management policy guidelines and the priorities generally adopted by the community in areas where beach amenity and ecological integrity[7] is important, the options in the column headed ‘Preserve Natural Beach System Character’ would normally have highest ranking in any assessment criteria. Consideration may also be given to other low cost temporary works options and hybrid options that combine the beneficial characteristics and offset undesirable characteristics of specific individual options.

[7] The ecological impacts of erosion control and beach nourishment from a fisheries resources point of view are discussed in (Batton, 2007) and will be considered in this SEMP.

The likelihood of success (or the risk of failure) is a key consideration in the selection of possible solution options. The options adopted involving expenditure of public funds should preferably be tried and proven techniques for dealing with beach erosion problems. There are a number of other (generally lower cost) options that are commonly put forward, covering a wide range of operational modes and with various claims of success. Most of these options typically have limited theoretical backing, have limited potential for providing significant long term benefits and/or have generally not been proven as an effective means of beach stabilisation. Such options would be ranked as low feasibility of success and would not be recommended.

3.3 Generic Shoreline Erosion Management Options

The options to deal with an erosion problem at a specific location depend on the nature and level of threat and consequences if it is left unchecked. The most appropriate shoreline management options may vary throughout the study area.

It must be recognised that some options aimed primarily at protection of assets located within the erosion prone area (e.g. seawall construction) may be detrimental to the shoreline amenity and recreational value. Considerations are set out below in the context of the nature of the erosion threat and the priority objective to be achieved.

3.3.1 Undeveloped Areas

In presently undeveloped areas, the key objective is to prevent an erosion problem from occurring in the future. That is, allowing the natural shoreline processes of erosion and accretion, including any progressive long term trend of shoreline retreat to occur without threat to assets.

Often the most successful coastal management strategy is to prevent development within the erosion prone area. The natural processes, including shoreline fluctuations, will thus be allowed to continue unimpeded and the natural amenity and character of the shoreline will be retained.

This may require a set-back control on any future development. To achieve this, the following coastline management strategies would need to be adopted:

- Ensure appropriate planning controls are in place to prevent infrastructure and residential development occurring in erosion prone areas which are presently undeveloped (preferably over a 100 year planning timeframe);
- Allow natural processes to occur with ongoing monitoring of coastline behaviour; and
- Continue dune/foreshore management and protection works and controlled access to the shoreline as required.

3.3.2 Areas with Existing Development

Where present development is not under immediate erosion threat, but may potentially come under threat over time, forward planning is needed to prevent future problems. The degree of natural variability in the coastal processes and the level of uncertainty in predicting future shoreline behaviour over long timeframes are such that the need for and nature of any future action will be dependent on uncertain factors such:

- Realisation of the erosion threat and the likelihood of ongoing recession;
- Effects of potential climate change impacts (e.g. sea level rise); and
- Future opportunities and attitudes towards coastline management and options for dealing with erosion threat.

The potential future threat from erosion should be recognised in present planning and appropriate strategies put in place that will not compromise future management decisions.

There are two basic strategic approaches for dealing with the problems of erosion threat to the development and loss of the shoreline, namely:

- Undertake works to hold or improve the present shoreline alignment, thereby preventing future recession; or
- Allow the shoreline to recede in such a way that the natural processes would maintain the beach characteristics and amenity, but at the expense of existing land and infrastructure.

There are alternative approaches within these two categories, as discussed below.

3.3.3 Retreat Options

The intent of retreat options is to remove the development under threat and allow the beach and dune to behave in the natural manner, thus restoring and retaining the natural character and amenity of the beach as the shoreline recedes. The planned retreat option acknowledges that erosion is an ongoing phenomenon and seeks to address the issue by removal of threatened facilities rather than trying to protect them. This would release a quantity of sand into the active beach from the receding dune system and provide some additional space for the natural beach movements to occur.

At some beaches there may be scope for setting back (retreating) some assets. Generally there are two different approaches to planned retreat which essentially relate to the ownership of the land and the responsibility for removal of structures. There are substantial differences between these options in terms of cost, who pays, likelihood of success and ultimate ownership of the beach as discussed below.

3.3.3.1 Retreat under Public Ownership

This option involves the upfront transfer of ownership of all land with an erosion risk to the Crown so that it is under public ownership as recession occurs. Key factors for consideration of planned retreat under public ownership are as follows:

- Transfer of ownership to the Crown should be controlled and implemented via a voluntary acquisition process by government;
- 100% of the affected properties must be obtained in any one beach location for this option to be effective;
- Coastal land values have increased over recent times and could increase further, which may result in high acquisition cost;

- Once implemented, a need would subsequently arise to address the erosion threat of the "new erosion prone area" (as the shoreline progressively moves landward) and this may entail further significant expenditure to purchase. Unless this land was also purchased, all previous money spent on acquisition could be wasted; and
- At some locations, this retreat option could provide opportunities to establish or enhance public access to and along the beach as land ownership is transferred to the Crown.

3.3.3.2 Retreat under Private Ownership

This option involves the land remaining in private ownership as recession occurs. Key factors for consideration of planned retreat under private ownership are as follows:

- The affected land (currently privately owned) would remain in private ownership when it is lost to erosion and private individuals would be responsible for their own planning in terms of loss of buildings, infrastructure and relocation.
- This option would require regulations to prevent implementation of erosion protection structures by private property owners that comprise principles set out in the QCP.
- Ad-hoc loss of private property to erosion typically causes significant adverse visual impacts.
- As a public shoreline progressively erodes, the beach could become private property, which could privatise access to and along the beach.
- In terms of equity, it is relevant that the beachfront allotments were historically created by the community (i.e. their representative being the government of the time) for residential use, prior to recognition of the erosion hazard.
- It is noted that experience at other coastal townships where the retreat option has been implemented (e.g. Byron Shire) has learnt that residents are reluctant to leave their beachfront locations and will utilise legal and practical means to protect their properties.

3.3.4 Protection Options

Options to hold the present coastal alignment generally fall into the following sub categories:

- Beach re-profiling through the redistribution of the existing sand on the beach and active dune/foreshore restoration;
- Beach nourishment to rebuild the beach with sand imported from outside the active beach system to make up the deficit, either alone or with other control structures to improve the longevity and give added protection; and
- Structural measures such as seawalls, groynes or offshore breakwaters/reefs to either directly protect assets or trap sand to rebuild the beach in front.

These protection options are discussed in more detail below.

3.3.4.1 Shoreline Re-profiling Options

Beach re-profiling, or "beach scraping", generally involves relocating sand from the lower part of the beach to the upper beach and dune system using mechanical equipment (refer Figure 3-1). The action is assumed to mimic natural beach recovery processes, albeit at an increased rate.

Figure 3-1 Beach Re-profiling using Mechanical Equipment (Carley et al., 2010)

Beach scraping can be successfully used to restore beach amenity, widen the upper beach and rebuild dunes. MBRC often undertakes beach re-profiling at Redcliffe Beaches as part of beach nourishment and dune reconstruction works. These actions will temporarily improve the protection of adjacent assets by increasing the beach width. Such works are relatively inexpensive, can be implemented quickly and are often undertaken in response to a significant beach erosion event. The main short coming of beach scraping as an erosion control measure is it needs to be repeated frequently and may only offer limited shoreline protection.

3.3.4.2 Sand Recycling

Sand recycling or relocation refers to moving sand within the beach system. Sand recycling differs from beach nourishment as no additional sand is added to system, rather the sand is simply redistributed to help maintain beach amenity or protect a section of shoreline susceptible to storm erosion. Sand relocation works are most successful on beaches where the direction of longshore sediment transport is evident and sand accumulates at a location where it can be readily accessed. Groynes often trap suitable quantities of sand that can be relocated to updrift shoreline locations.

3.3.4.3 Shoreline Nourishment Options

The primary intent of beach nourishment is to ensure existence of the recreational beach and provide protection to the development by rebuilding the beach with sand imported from outside the active beach system. This effectively replaces the loss of sand from the system and/or the deficit in the supply of sand that is causing the erosion. In this way a natural beach and its associated values will be returned and maintained while providing a buffer of sand to accommodate natural beach fluctuations and protect the assets and facilities behind.

The quantity of sand required will depend on the level of initial and ongoing protection, the grain size of the material and the use of structures to enhance the longevity of the works. Sufficient sand should ideally be provided to be able to accommodate short term storm erosion and a period of long term recession associated longshore sediment transport differentials and sea level rise.

Provision should be made for the placed sand to extend across the full beach profile to nourish depleted nearshore areas as well as the upper beach, the total quantity of sand being determined accordingly. If the sand is placed only on the upper visible portion of the beach, redistribution will quickly occur to establish an equilibrium profile giving the impression that the sand is 'lost' and the project is a failure. In such a case, the sand is, in fact, not 'lost' but remains in the active system providing an overall net gain commensurate with the quantity placed after cross-shore distribution.

Dune construction and stabilisation works to prevent sand loss due to wind erosion usually needs to form part of any substantial beach nourishment scheme aimed at restoring the beach and dune system. In that case, it would incorporate design provisions to prevent dune overtopping and oceanic inundation as well as to accommodate the effects of climate change including sea level rise. Where the aim of the nourishment is to re-establish a beach in front of an existing seawall without provision of a dune, the need for stabilisation works such as establishment of native dune vegetation would depend on the potential for wind erosion resulting from the works.

While beach nourishment may affect the ecological values of the beach and nearshore areas, it needs to be recognised that the nourishment sand would be placed in the active zone where the natural environment is one of substantial fluctuations and disturbances to which the ecological communities adapt naturally. Furthermore, the nourishment would effectively rebuild the beach and nearshore profile to where they once were. As such, while there may be some short term ecological impacts, in the longer term the environment will adapt and recolonise to behave as a natural beach system.

One of the inherent advantages of beach nourishment is that it maintains the natural character and recreational amenity of the beach while also providing protection of coastal assets. As such, where the beach is severely depleted, it provides many intangible benefits to the general community, as well as a direct economic benefit to those businesses that rely on tourism and the presence of a usable beach.

However, identification and access to sources of suitable nourishment sand is usually a key issue, as is the ongoing cost to maintain this protection and amenity. When suitable marine sand sources are in close proximity project areas, the transport of sand to the beach is most cost-effectively achieved by dredging procedures. This method of sand delivery is not always operationally feasible and requires consideration of the vessel characteristics (e.g. draft, pumping distance) and environmental conditions (e.g. nearshore depth, wave climate).

3.3.5 Structural Protection Options

Structural options provide protection of assets against ongoing erosion either directly through the construction of a seawall or by rebuilding of the beach through the construction of groynes. They are options that could be considered in the event that sufficient beach nourishment sand is not available and/or retreat options are not viable. However, there are always some adverse impacts of such an approach where no additional sand is provided, as outlined below.

Such structures would typically be of flexible rubble mound design with rock being sourced and trucked to the site from quarries in the region. While they may be effective in protecting assets or providing a localised wider beach, they are generally accompanied by associated costs related to adverse impacts on the adjacent beaches. This cost is typically made up of direct costs associated with lost income from the tourist industry and other intangible costs associated with the natural coastal amenity, beach access, loss of recreational beach area and degradation of ecological values.

3.3.5.1 Seawalls and Revetments

Seawalls or rock revetments are commonly built with the intent of providing terminal protection against shoreline retreat. Seawalls are robust structures constructed along the shoreline which provide a physical barrier separating the erodible material immediately behind the structure from wave and current forces acting on the beach itself. They are typically constructed of loosely placed rock to allow for some flexible movement and need to be designed to withstand severe wave attack. Figure 3-2 provides an example cross-section of a rock revetment on a sandy shoreline with the toe of the structure down to the bedrock (impermeable layer).

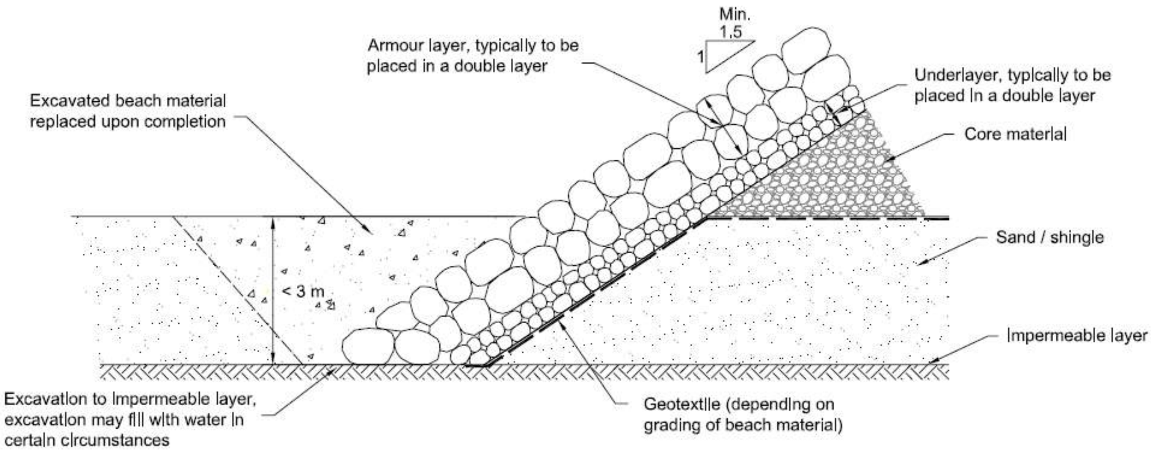

Figure 3-2 Cross-section of a Typical Rock Revetment Seawall (CIRIA, 2007)

Where possible, seawalls should be continuous to prevent end effects and/or discontinuities that could threaten the overall integrity of the wall. They also have to be suitably founded for stability against scour at the toe of the structure, particularly on a receding shoreline. Haphazardly placed rock and/or the use of inappropriate materials intended to provide shoreline erosion protection can have the opposite affect by accelerating the erosion problem.

While a properly designed and constructed seawall can protect the landward assets from erosion, it effectively isolates the sand located behind the wall from the active beach system and may lead to other adverse consequences.

On a receding shoreline, the seawall becomes progressively further seaward on the beach profile over time. This leads to a gradual increase in the quantity of sand effectively lost from the beach system, with:

- Lowering and eventual loss of the beach in front of the wall; and

- Exacerbation of the erosion on the downdrift end of the wall where the losses are transferred and concentrated.

Scour and lowering of the beach in front of the wall ultimately exposes it to higher wave attack and can lead to slumping and the need for ongoing maintenance. Such maintenance is typically in the form of topping up of the wall with additional rock. However, where the seawall is not adequately designed or constructed, complete reconstruction may be needed.

Existing revetment seawalls are common throughout the NMBSEMP study area and vary in design and material type. Some sections are of an uncertain design standard and may have been constructed without approval. Some typical examples show in Figure 3-3.

Figure 3-3 Exampled of Revetment Seawalls throughout the Northern Bay SEMP Study Area: a) Stepped Concrete, Deception Bay; b) Stone Pitched, Deception Bay; c) Slopped Concrete, Godwin Beach; d) Rock and Concrete, Toorbul.

3.3.5.2 Groynes

Groynes and artificial headlands are impermeable structures typically constructed perpendicular to the shoreline and extend across the beach and the nearshore surf zone. Their function is to trap sand moving along the shoreline under longshore transport processes to build up and stabilise the alignment of the beach on the updrift side. By necessity they starve the beach of sand supply on the downdrift side causing erosion. Groynes have been effectively implemented throughout

Redcliffe and Scarborough areas (refer Figure 3-4) however are not common within the Northern Moreton Bay SEMP study area.

Figure 3-4 Groynes between Redcliffe and Scarborough

The sand trapped on the updrift side provides a buffer of sand to accommodate short term storm erosion. The shoreline alignment will also change providing greater stability and reduced long term erosion immediately updrift of the structure. The extent of accretion and length of shoreline affected is dependent on the length of the structure as well as the characteristics of the longshore transport processes. Generally, the longer the groyne, the more sand it will trap over a longer distance with decreasing influence away from the structure.

There is a physical limit to the length of shoreline affected and therefore a number of structures may be needed if substantial benefit or protection is required over a long stretch of shoreline. In such a case, there is a balance between the length and spacing of groynes that needs to be optimised as part of a detailed design process.

An artificial headland is a substantial groyne type structure that has a physical width at its head in comparison to a conventional narrow groyne. It is believed that this width alters the mechanisms of sand transport past the end of the structure and may allow a wider/longer beach to be retained on the updrift side for the same protrusion offshore. This could have the benefit of minimising the need for, or maximising the spacing of, additional structures to provide protection for a long stretch of coastline. However, such headland type structures would be larger and more expensive to construct.

Groynes or artificial headlands can thus be used to rebuild a beach and stabilise the shoreline against ongoing recession on the updrift side. However, in the absence of other works such as beach nourishment, this comes at the cost of exacerbated erosion on the downdrift side to where the erosion trend is transferred.

Another significant consideration associated with groynes is their potential visual intrusion to the vista of a long sweeping beach and interruption to direct access along the beach. There are various design options with respect to the style and crest height of the structures that could be considered to minimise such adverse effects.

3.3.5.3 Offshore Breakwaters

Emergent offshore breakwaters (with crest level above the water surface at some or all stages of the tide) are commonly used to reduce wave induced beach erosion in the US, Europe and Japan. Offshore breakwaters are typically constructed parallel to the shoreline and slightly seaward of the surf zone. The structure is intended to dissipate part of the incident wave energy and reduce the direct impact of storm waves. Under prevailing conditions, the presence of a breakwater will modify wave, flow and sediment transport patterns in the lee of the structure may promote the growth of a shoreline salient or tombolo. This effectively widens the target area of the beach and provides an additional erosion buffer. Offshore breakwaters are often constructed in a series to protect long sections of coastline, similar to a groyne field however with the advantage of not completing blocking longshore sediment transport (unless tombolos form).

Figure 3-5 Offshore Breakwater Series and Salient Formation (U.S. Army Corps of Engineers, 2002)

A major problem associated with the construction and maintenance of offshore breakwaters is their large cost. By design, offshore breakwaters must be placed in the most energetic part of the nearshore zone which leads to operational difficulties during construction and renders them prone to damage during severe wave conditions.

3.3.5.4 Submerged Artificial Reefs

Submerged artificial reefs are designed to dissipate wave energy and/or rotate the average wave direction. The reduction in wave energy and/or induced wave refraction modifies the nearshore sediment transport patterns and can lead to the formation of a salient in the lee of the reef and therefore widens the beach. In this regard, a submerged artificial reef is intended to function in a similar way to an offshore breakwater (noting that the crest of a traditional breakwater is above the water surface). Some submerged reefs, such as 'The Twins' at Narrowneck on the Gold Coast (see Figure 3-6), attempt to combine shoreline protection with recreational surfing and/or snorkelling/SCUBA diving benefits and are referred to as 'multi-purpose submerged reefs'. Submerged reefs don't intrude on the beach and have the advantage of low visual impact. Consequently, the scenic amenity of an area is not altered.

Figure 3-6 Geotextile Sand Container Artificial Reef at Narrowneck, Gold Coast (Source: NearMap, 2011)

It is important to consider that a submerged artificial reef aims to take sand from the total sediment budget in order to form a salient and rebuild a targeted section of the beach. This typically moves the erosion problem to downdrift areas as observed with other shoreline structures that interrupt the natural sediment transport such as groynes or artificial headlands. To avoid undesired downdrift erosion beach nourishment should be undertaken to balance the material stored in the salient. Like offshore breakwaters, submerged artificial reefs may be considered a feasible option when there is a sufficient source of beach nourishment sand to balance any losses from the sediment budget.

It should be noted that the key environmental and/or structural parameters governing shoreline response to submerged structures remain uncertain. A fundamental research challenge is to establish and understand the mechanisms that cause erosion or accretion in the lee of such structures (Ranasinghe and Turner, 2006). The performance of offshore artificial reefs, from a shoreline protection perspective, is difficult to quantify due to the necessary complementary beach nourishment (e.g. Prenzler 2013, pers. comm.). For this reason, offshore artificial reef design requires detailed assessment and demonstration of an available source of nourishment material (to balance any potential adverse shoreline responses) to be considered as part of a viable shoreline erosion management strategy.

3.4 Material Sources and Costing Considerations

The implementation of coastal protection works is dependent on suitable material being able to be obtained and placed in a practical, economical and environmentally acceptable manner. General considerations associated with sourcing, cost and applicability of different material types are discussed below, including preliminary estimates in terms of unit costs for capital and ongoing maintenance works provided on the basis of available information.

Cost estimates for the various options are based on these unit rates for comparison purposes. Specific recommended works would be subject to detailed design, impact assessment and tendering processes that may influence the final cost. There will also be on-costs associated with the design, impact assessment and approval processes for the recommended options.

3.4.1 Shoreline Nourishment

The feasibility of shoreline nourishment is dependent on the practical and cost-effective availability of a suitable source of sand. Sand should be of suitable quality (grain size and colour) and would ideally match the existing beach sand. When nourishment sand is imported from outside the beach system, sufficient quantities of sand should be available for both initial and ongoing nourishment.

Sand for beach nourishments should be able to be obtained and placed without adverse environmental impacts. In environment sensitive areas, this may be challenging. Potential nourishment sand sources have been considered in terms of their location as discussed below.

3.4.1.1 Marine-based Sources

Possible offshore sources of sand for nourishment for the study area have not been investigated in detail. General considerations with respect to use of offshore sand sourcing sites include:

- Identification of sand source(s);
- Suitability of the sand;
- Quantity required for initial campaign and ongoing maintenance;
- Transport of the sand to the site;
- Rezoning and approval for sand extraction; and
- Potential environmental impacts.

Costs of such sources, if viable, are typically around $10-$20/m3, depending on the distance and method of transport. This cost estimate does not consider the associated project costs such as environmental studies, beach profiling, pre and post construction surveys and ongoing monitoring.

Port of Brisbane Pty Ltd maintenance dredge material is currently used by Council to nourish the beach at Woorim (refer Figure 3-7).

Figure 3-7 Nourishment Sand being Delivered 'over-the-bow' to Woorim Beach

3.4.1.2 Land-based Sources

Land sources may include river sources or alluvial fan deposits. Sand from such sources would be transported to site by conventional equipment and trucks. If viable, the costs of such sources are typically around \$20-\$50/m^3 depending on the distance and method of transport.

Possible onshore sources of material for shoreline nourishment purposes have not been investigated in detail however potential locations for consideration are within the lower estuaries of the study area. Considerations with respect to use of such sites include:

- Identification of sand source(s);
- Suitability of the sand;
- Quantity required for initial campaign and ongoing maintenance;
- Transport of the sand to the site;
- Possible need to purchase the property involved;
- Rezoning and approval for sand extraction;
- Potential environmental impacts including acid sulfate soil considerations; and
- Site rehabilitation.

Transportation of the nourishment material may be an issue, particularly if large quantities are involved. Trucks would cause disruption and damage along access roads. Small suction dredges are only used if the transport distance is less than about 1.0-1.5 km. Costs of such sources, if viable, are typically around $10-15/m^3 but the transportation costs become prohibitive.

3.4.2 Shoreline Structures

Shoreline protection structures are typically of a flexible mound construction type to allow for some movement and to absorb some of the wave energy. Rock is the dominant material used in such structures and is dependent on suitable local sources being available. Alternative construction materials such as concrete armour units and sand filled geotextile bags could also be considered for such structures but have limitations such as high cost and poor visual amenity of concrete units and short practical life due to decay, failure and vandalism of geotextile units. This latter type of shoreline protection method has been successfully implemented at a number of locations throughout southeast Queensland.

Rock armour units would need to be obtained from local hard rock quarries. While the specific extent and limitations of the available resource is not known, it is evident that sufficient rock would be available but would need to be sourced by truck from quarries at substantial distance and cost. A significant constraint associated with rock armour is the need to truck the material to the site over local roads. For large projects, this can mean frequent truck movements over an extended time frame.

Indicative cost estimates for the supply and transport to site of rock based on typical experience are as follows:

- Armour rock (typically large individual units) supply to site: $40 - $50/tonne; and
- Quarry run rock (typically smaller individual units used for core material) supply to site: $25 - $35/tonne.

On this basis, typical coastal structure costs including design costs and on-site placement are estimated as follows:

- Seawall (toe level -1m AHD, crest +4m AHD) ~ $5,000/m; and
- Groyne (toe 2m below seabed, crest +3.0m AHD) ~ $6,000/m.

Rock structures by their nature are subject to movement and settlement over time. They are also subject to damage during storm events although they are designed to withstand major wave attack. A typical design criterion is for less than 5% damage during a 50 year storm. As such, ongoing maintenance will be required to ensure the structural stability is not compromised.

This will necessitate maintaining access to the top of any seawall to allow ‘top up’ works to be carried out. Minor slumping of land based or offshore structures after initial construction may not be an issue provided that the function and structural stability are retained. An ongoing maintenance cost of 1% per year is typically adopted for rock structures subject to storm wave attack.

3.4.3 Comparison Summary

A brief comparison of the various alternative means of combating erosion problems is shown in Table 3-2.

In many practical cases, a combination of methods may be more applicable than relying on any single approach. For example, a commonly used combination is beach nourishment and groyne construction. From the viewpoint of beach protection only, those approaches which do not involve direct interference with the beach system, namely “do nothing" and “planned retreat", are the most desirable. For most developed areas these options are not viable because of low public acceptance for lack of long-term property protection and/or prohibitive long-term costs.

Structural solutions such as rock revetments, groynes and offshore breakwaters are effective in some cases but all cause adverse impacts unless used in conjunction with beach nourishment. Beach nourishment does not cause adverse impacts with regard to long-term or short-term erosion at the beach nourishment site, or adjacent beaches and has been carried out with success on many beaches worldwide. The only real limitation of beach nourishment is its reliance on the local availability of a sand source from which material can be economically extracted and transported to the beach site and the funding commitment needed by Council. For many locations throughout the NMBSEMP study area beach nourishment in isolation is unlikely to provide the necessary level of shoreline and asset protection during severe wave attack.

Table 3-2 Comparison of Erosion Control Measures

Erosion Control Measures	Advantages	Disadvantages	Comments
1. Do nothing/Maintain Status Quo	a) Beach continues to behave naturally b) No direct expenditure required on protective measures – removal of debris may be required	a) Assets and improvements are lost by continued erosion b) Limited application in developed areas	This approach is only practical where threatened assets are of limited value and the loss can be accepted
2. Planned Retreat	a) Effectively solves the beach erosion problem b) Beach continues to behave naturally	a) Public reaction against relocation is usually strong b) Compensation payments may be prohibitive	In spite of the apparent drawbacks may be more cost effective over long term
3. Seawalls	a) Well suited to emergency erosion control b) Provides direct asset protection	a) Only effective if properly designed and constructed b) Potential to adversely affect (lower) the beach during extreme erosion event	Should only be used in emergency situations or when an immediate threat to property and/or public safety exists; protects

Erosion Control Measures	Advantages	Disadvantages	Comments
		c) Decreased scenic amenity	asset but not the beach
4. Groynes	a) Generally effective in building beach on updrift side b) Construction and maintenance is shore based and comparatively more cost effective that offshore operations	a) Does not prevent erosion – merely transfers it b) High level of maintenance c) Intrusion on beach and high visual impact	Only useful in conjunction with beach nourishment or if erosion on downdrift side is acceptable
5. Offshore Breakwater	a) May promote the growth of a shoreline salient or tombolo and therefore widen beach b) Shelters beach from storm-induced wave attack	a) Construction and maintenance are offshore operations and typically difficult and expensive in areas exposed to wave activity b) Results in downdrift erosion, nourishment usually required in lee of structure to balance sand lost to salient	Commonly used in low wave energy environments in US, Europe and Japan however not typically found on the east coast of Australia
6. Submerged Artificial Reef	a) No intrusion on beach or impact to scenic amenity b) Potential recreational benefits (e.g. enhanced surfing and/or snorkelling/SCUBA diving conditions)	a) Uncertainty regarding the mechanisms that lead to accretion or erosion of target shoreline b) Construction and maintenance are offshore operations and typically difficult and expensive in areas exposed to wave activity c) Nourishment usually required in lee of structure to balance sand lost to salient	The key environmental and/or structural parameters governing shoreline response to submerged structures remain uncertain

Erosion Control Measures	Advantages	Disadvantages	Comments
7. Beach Nourishment	a) Widens beach and therefore improves protection against coastal erosion events b) Visually consistent with natural sandy shoreline	a) Sources of nourishment sand not always close to nourishment site b) Requires viable sand reserves and necessary commitment to quickly renourish beach following erosion event	Generally effective at alleviating local erosion problems
8. Lower River Channel Relocation	a) May relieve immediate erosion threat and will pass a design flood if developed and maintained appropriately. b) High-flow relief channel moves erosion pressure away from vulnerable areas	a) Ongoing maintenance of modified channel required.	Significant modification to natural processes and may create undesirable impacts at other locations

3.5 Environmental Considerations

As well as the cost and effectiveness of each management option, environmental impact issues also need to be considered. Applicable legislation (refer Section 2) may require detailed environmental assessments (e.g. Environmental Impact Assessments), and approvals processes and government authorities may require additional studies. Note that a comprehensive list of environmental issues for each site and recommended shoreline erosion management measures cannot be determined until the final details of proposed works are known. However, an indication of likely environmental issues is provided below as a guide.

3.5.1 Shoreline Nourishment

Beach nourishment is dependent on being able to source and place suitable sand in an environmentally acceptable, practical and economic manner. Sand can either be obtained from land or marine-based sources with specific considerations as outlined below.

3.5.1.1 Marine-based Sand Extraction

The following is a summary of the potential environmental impacts of marine sand extraction in the study area. This assessment does not include noise, traffic and transport associated impacts, and social and cultural aspects.

Water Quality

The disturbance of the substrata by sand extraction activities generally results in the remobilisation of sediments. The creation of turbid plumes can have indirect effects on aquatic biota and their habitats (e.g. smothering of benthic communities, reduced light in the water column and altered sediment-water dynamics). The extent and magnitude of such increases in turbidity depends on the type of equipment used, the volume and nature of any overflow from the dredge, the material being excavated and the currents present at the excavation site.

The material that would be excavated in marine-based sand supply is typically clean sand from highly active shoal areas with negligible fines content. Hence, turbidity plumes are expected to be of limited spatial and temporal extent.

In areas where there are other materials underlying the clean sands, extraction may result in elevated turbidity, and may potentially release contaminants or elevated oxygen demand into the water column. Wherever possible, disturbance of fine material should be avoided. This requires knowledge of the depths, quantities and characteristics of sand to be dredged.

Ecological Factors

The ecological impacts of sand extraction will vary according to the spatial/temporal scale being considered and the intensity of the disturbance, as well as the resilience of the populations and assemblages to disturbance. Generally, ecological impacts of sand extraction may include:

- Changes to biotope (habitat) structure associated with changes to the morphology of the dredged area. In this regard, shallow banks may be replaced by deep holes/channels.
- Direct effects on seagrass and mangroves due to removal and/or smothering, or indirect effects due to increases in turbidity.
- Disturbance of megafauna. Various cetaceans (dolphins and whales) may occur offshore. The slow speed of vessels used in sand extraction activities is not anticipated to cause mortality of megafauna from boat strike.
- Six species of marine turtles are known to occur in the region. These include the Green (*Chelonia mydas*), Loggerhead (*Caretta caretta*), Hawksbill (*Eretmochelys imbricata*), Leatherback (*Dermochelys coriacea*), Olive Ridley (*Lepidochelys olivacea*) and Flatback (*Natator depressus*). Environment management actions are required to ensure turtles are not harmed by proposed dredging activities, and a strategy to manage nests and hatchlings would be required to be developed in conjunction with DHEP.
- Changes to the diversity, abundance, and structure of macrobenthic assemblages in and adjacent to the dredged area. Some species of benthic macroinvertebrates are of commercial importance (e.g. mud worms *Marphysa sanguinea* cf.) and are collected by recreational harvesters for use as bait (e.g. yabbies *Trypea australiensis*).

- Changes to the fish assemblages in and adjacent to the dredged area, with potential impacts to commercial and recreational fisheries.
- Changes to the population structure of species (e.g. sand crabs *Portunus pelagicus*, that utilise different habitat according to sex).
- Changes to the migration patterns of animals (e.g. crustaceans such as prawns and crabs), with potential impacts to commercial and recreational fisheries.
- Changes to the recruitment dynamics of fish and macrobenthic species. Impacts to recruitment dynamics potentially may have flow-on effects to recreational and commercial fisheries.
- Mobilisation of contaminants and nutrients following disturbance of sediments.

3.5.1.2 Land-based Sand Extraction

There are a wide range of potential environmental issues associated with land-based extraction, from the natural, social and economic perspectives. Potential impacts to natural environment are considered below.

Groundwater and Surface Water

Sand extraction operations on land have the potential to influence both groundwater and surface water through the release of toxicants and turbidity. The potential for disturbance of acid sulfate soils and the mobilisation of heavy metals is of concern. These contaminants may impact on either the underlying groundwater or surface water adjacent to the operations. *Often land based sand extraction results in the creation of an artificial lake at the completion of the works with associated water quality considerations.* The Coastal Act (Non-tidal artificial waterways)[8] aims to manage construction, location and management of artificial waterways. Note that in some situations, the creation of artificial lakes is not supported. Where the creation of artificial lakes is permitted, no direct or indirect adverse impacts on other aspects under the SPP may result from the development. However, land-based extraction may also occur in conjunction with development of building sites pursuant to the *Building Act 1975.*

Ecological Impacts

Land-based extraction has the potential to have effects on fauna and flora communities and supporting ecological processes through a variety of means including:

- Loss of species as a direct consequence of habitat removal, reduction in habitat area (e.g. decreased habitat suitability for species requiring large home ranges) and habitat isolation (e.g. reduced opportunity to escape the effect of environmental perturbations and recolonise after such events). This may include impacts to species, habitats or ecological communities listed under the EPBC Act, NC Act, VM Act and *Land Act 1994*.
- Alterations to ecosystem processes due to the development of edge environments, especially areas adjacent to small remnants. This usually involves changes in abiotic and biotic conditions such as microclimate changes (wind, radiation, soil moisture regimes) and increased presence of introduced flora and predatory fauna and disturbance-tolerant aggressive native species).

[8] Policy 2.1.15.

- Disturbance of acid sulfate soils, which when exposed to air produce sulfuric acid and may release toxic quantities of associated metals into the surrounding environment. Disturbance of other contaminated sediments may also be an issue.
- Negative pressures accompanying development and operations, including disturbance through increased human activity, traffic, noise and light pollution, etc.
- Potentially, large scale disturbances such as:

  a) Reduction of population viability and genetic diversity resulting from disruption of ecological connectivity and population isolation. This results from decreases in, and/or cessation of regular successful dispersal between populations; and

  b) Alterations to ground water levels (e.g. rising water table and increased salinity) and surface water hydrology (e.g. changes to runoff patterns and increased erosion). These effects may result in waterway degradation through increased salinity, turbidity and nutrient pollution.

3.5.1.3 Placement of Sand for Shoreline Nourishment

Change in Benthic Communities and Habitat Loss

The placement of sand on the shoreline has the potential for immediate impacts associated with burial of existing surface sediments and biota (macroinvertebrates and seagrasses). Sandy material that is placed onshore is unlikely to cause significant changes in the composition of surface sediments and habitat type, but would result in the burial of organisms that have colonised the area. Some buried organisms may be able to migrate through appreciable depths of placed material, but other organisms are likely to be lost. Assuming the surface sediments are similar to those prior to nourishment, recolonistation of the placement area would occur within a short time. Opportunistic and/or mobile species would recolonise the nourishment area within a relatively short period of time.

Further Ecological Considerations

Any loss of benthic macroinvertebrates and/or seagrass associated with burial from nourishment would represent a short-term reduction in available food/habitat resources for fish. Most fish species that inhabit the area would be capable to move from the placement area to forage in other parts of the study area.

Further, placement of sand for beach nourishment may temporarily disturb roosting, breeding or feeding activities of wading birds. Throughout southeast Queensland, the highest number of waders has been recorded in October, during the southern migration when population densities of migratory birds reach an annual peak. The lowest counts are typically recorded during August, a time when mainly resident and juvenile migratory birds (<one year old) stay in the region rather than migrate to breeding grounds in the Northern Hemisphere. In tidally influenced areas, waders forage across the exposed sand and mudflats at low tide (both day and night). At high tide, they move to higher ground to roost on beaches, salt marshes, claypans and artificial ponds.

Where nourishment is recommended, studies would need to be conducted to determine species using the impacted areas, and periods when roosting and breeding periods for these species can be avoided.

3.5.2 Shoreline and Offshore Structures Considerations

Historically, constructed features have been added throughout the study area and consequently the extent of artificial habitats increased. No known studies have been carried out on the flora and fauna assemblages of artificial shoreline habitats within the region. This is probably due to the fact that constructed features are not regarded as high priority conservation areas. However, in general, artificial structures in the coastal zone contribute to the maintenance of coastal ecosystems and the local richness of habitats and species in the region.

The erosion management options involving constructed features are:

- Replacement of existing rock seawalls;
- New rock seawall construction;
- Groyne construction;
- Offshore breakwater construction; and
- Submerged artificial reef construction.

Environmental considerations associated with these works are outlined below.

3.5.2.1 Terrestrial Vegetation

Replacement or construction of rock walls and groynes would require access to the foreshore. In many cases, there is vegetation in foreshore areas that would have to be removed.

Removal of vegetation for construction will cause a temporary loss of habitat and long term habitat change if there are limited opportunities for re-vegetation. Rebuilding of rock walls is likely to require a corridor of about 10 metres and construction of new rock walls could require a 10-20 metre corridor along the foreshore. In developed areas, removal of unprotected vegetation is likely to have a low impact on regional environmental values. However, these areas are important given the encroachment of urban areas on remaining patches of vegetated habitat.

3.5.2.2 Disturbance of Marine Habitat

Replacement of rock walls and construction of new rock walls, groynes, offshore breakwaters and offshore artificial reefs would impact on inter-tidal and/or marine communities. For example, where unvegetated soft sediments would be replaced by artificial substratum, different assemblages of biota would colonise the surface and may cause a change in biodiversity of the area.

The initial removal of rock required for the replacement of a wall would cause disturbance to benthic communities at the base of the wall and in nearby areas from physical removal and elevated levels of turbidity when works are conducted at high tide. Any adjacent beds of seagrass may also be affected. The effects would depend on the characteristics of the community and the nature of the disturbance. It is likely however, that natural coastal processes such as waves and currents disturb these areas on a regular basis, and as such, are likely to support opportunistic (early successional) communities comprised of species that are capable of rapid recolonisation. Likewise, disturbance to communities by the construction of new rock walls, groynes or offshore structures would have a similar effect, with nearby areas recolonising in a short period of time. Changes in current velocities and wave influences due to the construction of rock walls, groynes or offshore structures may potentially change the habitat type/substrata and, thus, result in a change in benthic community structure. Further, changes to water and sediment quality and depth of water may have significant effects on the nature of the system.

Flow on effects may occur in areas used for roosting/feeding by wading birds. The sensitivity of wading birds to disturbance and habitat loss, and the potential for future effects on the viability of local populations should be considered.

Although benthic communities used as food resources by fish and crustaceans may be removed (temporarily/permanently), it is expected that the high mobility exhibited by most common species in the area may result in fish temporarily moving elsewhere if food is in short supply to forage in other parts of the study region.

3.5.2.3 Creation of New Habitat

The artificial structures in the inter-tidal and sub-tidal zone would result in the creation of a new, albeit artificial, substratum that would eventually be colonised by a range of rocky shore associated species. Studies elsewhere have shown that assemblages that colonise artificial structures differ from those that may occur on natural reefs and substrata and that epibiota occurring on vertical surfaces can differ from that occurring on horizontal surfaces. Options promoted in the NMBSEMP that involve the creation of new habitat may require additional studies to determine the potential beneficial and adverse impacts.

3.5.3 Managed Retreat Considerations

Planned retreat or the "do nothing" approach would affect terrestrial communities through the physical loss of vegetation due to erosion. Where vegetation of conservation value occurs in close proximity to the shoreline, there is a possibility that retreat may cause loss of this vegetation. However, it should be recognised that retreat is a natural process. Fauna species using the vegetation as habitat would be likely to move elsewhere as this gradual natural process occurs.[9]

Retreat would also be likely to result in the disturbance of marine fauna species associated with intertidal areas and dune areas. It is probable that these areas would be recolonised by similar fauna as presently occurs. Such a process would occur in association with natural movement of the shoreline. In this regard, impacts resulting from retreat would be short-term and localised.

3.6 Climate Change Considerations

Planning and management agencies are likely to be faced with undesired impacts of climate change and sea level rise, particularly on developed coastlines. It is convenient to consider appropriate climate change adaptation measures using the simple tool developed by BMT WBM (described in Fisk and Kay, 2010). The tool works by establishing a time continuum for each

[9] Note: there may be limited areas of available habitat with an increase in climate change and associated impacts.

climate change parameter or impact being assessed and identifies three key stages for the parameter or impact:

- The baseline (current condition) of the climate change parameter being examined at the time of plan preparation;
- The identification of one or more trigger points along the time continuum that flags to planners and/or responsible management agencies that more aggressive or decisive adaptation actions need to occur prior to the undesirable impact occurring; and
- The undesirable impact or end-state of the climate change parameter being examined (e.g. what are the impacts from climate change that are trying to be avoided?).

The tool can help decision-makers align perceived risk to infrastructure with the selection of the most appropriate adaptation measures and actions. In this regard, the tool is not limited to only climate change studies but can also be used to guide more immediate shoreline planning and management decisions. The tool is illustrated in Figure 3-8.

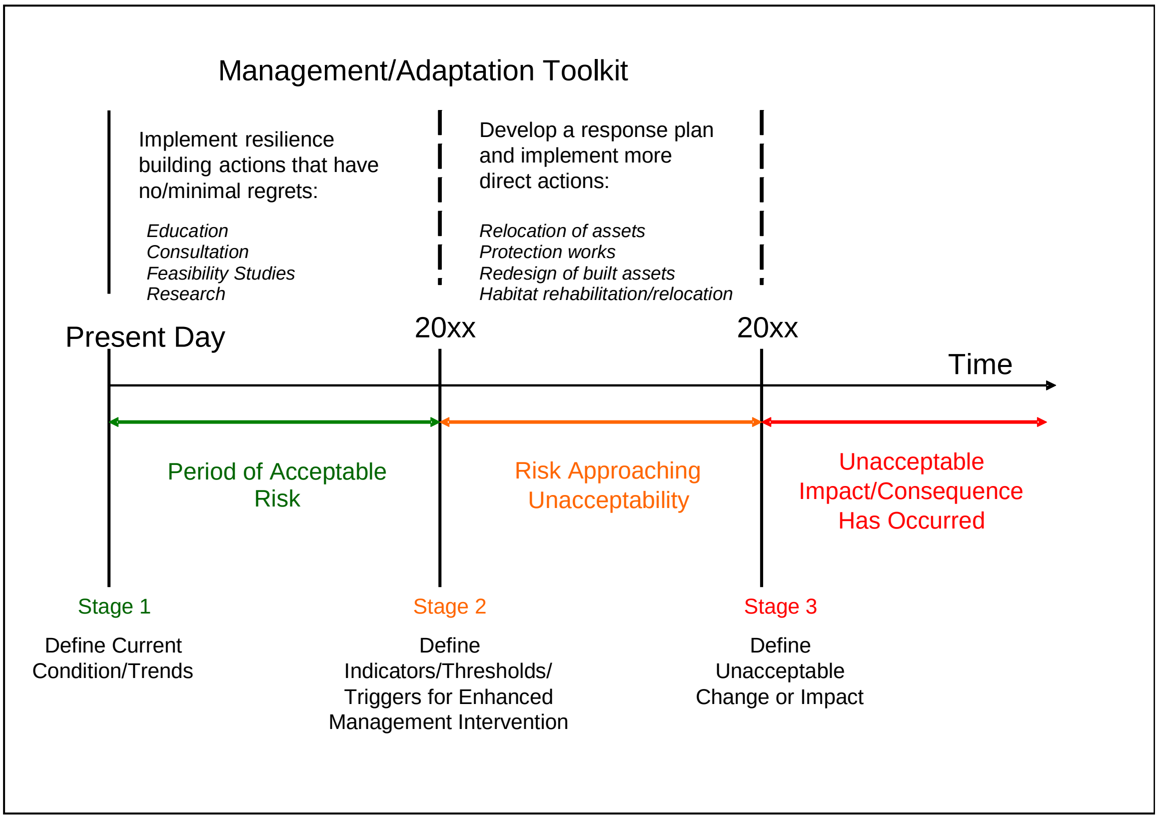

Figure 3-8 Application of Adaptation Actions along the Climate Change Risk Continuum

As discussed by Fisk and Kay (2010), using the tool to characterise climate change risks (and associated impacts) has a number of advantages, including:

- It provides a starting point in terms of establishing the context or the current condition of the risk parameter at the present day (on the left hand side of the continuum – Stage 1).
- It can be used to define and obtain agreement about the undesirable future impact that is trying to be avoided (on the right hand side of the continuum – Stage 3). An undesirable impact may

be defined any number of ways but could include, for example, defining what is unacceptable in terms of regular inundation of critical infrastructure by tidal incursion and flooding or the loss of a particular coastal habitat type.

- It starts to try and define the risk over time and introduces the idea of one or more trigger points (between the two end points) that serve as flags for enhanced management action or consideration.