Nearshore Nourishment Theory and Application

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Abstract
For almost 40 years nearshore nourishment has been a well proven technique for cost effective upper beach protection and improvement. In suitable areas with large offshore sand reserves, it is also a good tool for mitigating long term climate change impacts. The paper's aim is to provide the theory behind nearshore nourishment, identify suitable site conditions and show examples with costs of nearshore nourishment projects.

Nearshore Nourishment is a nature-based solution that was first trialled on the Gold Coast in 1985 after extensive investigations of equilibrium profile and natural storm bar onshore transport involving bathymetry survey and dyed sand tracking. There were 3 reasons for the development of nearshore nourishment – lower cost, utilisation of offshore reserves (often finer) and the perceived community and political failure of the large-scale onshore nourishment in 1975 halting further large-scale nourishment funding. The trials were technically and politically positive and made restoration of the southern Gold Coast beaches economically viable. Since that time nearshore nourishment has been used extensively along the Gold Coast and other areas. Sources of sand include offshore and navigation channel maintenance. Recently placement has been designed to improve surfing conditions in the short term while the sand migrates shoreward. This has had huge public support.

Design considerations that influence dredge size, placement methodology and cost include wave climate, depth of closure and location, depth and characteristics of offshore sand reserves. Suitable dredgers to work in exposed coastal conditions are typically trailing suction hopper dredges. These are often used for port dredging and are readily available. Deposition methods include direct placement as artificial storm bars or mounds by dumping in the active zone by smaller dredgers or, for larger deeper draft dredgers, rainbowing into shallower water or, most expensively, pumping shoreward. Typical costs for nearshore nourishment with bottom dumping is about 50% and by rainbowing about 75% of pump ashore costs.

Keywords: nourishment, nearshore, climate change, cost

1. Introduction

Ongoing sea level rises will increase the demand for nourishment and in many places the most likely sources will be from offshore. Areas along the east coast of Australia including Sydney, Byron Bay and Gold Coast have already identified large offshore reserves of suitable sand. This is not unexpected as the present offshore seabed up to 130m below present sea level has left relic beaches as sea level increased over the last 20,000 years and the coastline retreated landward to its present location (Gordon 2009).

Offshore dredging is generally carried out by a trailing suction hopper dredge (TSHD) as this type of dredge is relatively common being suitable for port access maintenance dredging and as this type of dredger can operate safely and efficiently in swell conditions. The nourishment material, generally sand, can be placed as nourishment in different zones (Figure 1) which dictates the dredge placement method, capabilities and characteristics of the dredge vessel.

The typical locations and placement methods are:

1. Nearshore in the sub-aerial profile between low water and the seaward extent of the active profile by
   a. Bottom dumping
   b. Rainbowing
2. Onshore on the beach and / or dunes above low water by
   a. Pumping through temporary pipe

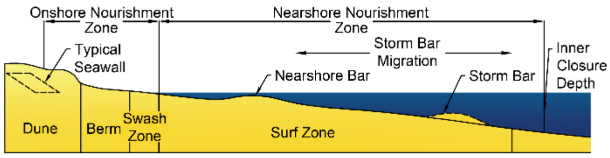

Figure 1 Typical nourishment zones on barred profile like Gold Coast

Nearshore nourishment is a nature-based solution that relies on natural onshore transport mechanisms and has proven effective to protect and improve the upper beach for over 40 years. It is desirable for a range of reasons, including significantly lower costs compared with pumping through a pipeline onshore.

Nearshore nourishment at the outer limit of the active profile also fits well as a longer-term method to offset sea level rise. Figure 4 shows the Bruun Rule (Bruun 1983) for erosion due to sea level rise (SLR). By placing sand, ideally at least at a comparable rate to SLR, the volume of the profile is gradually increased, and the beaches widened, reducing the erosion experienced as a result of sea level rise.

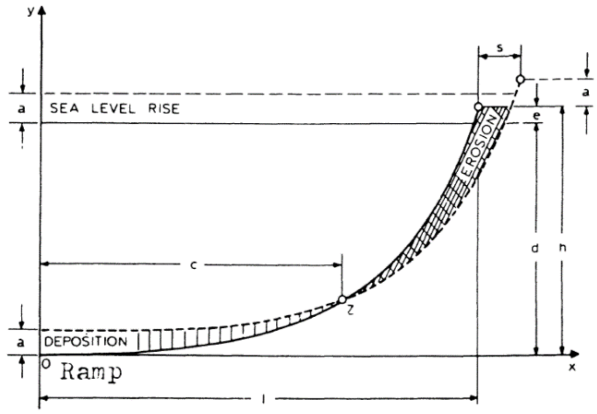

Figure 2 The Bruun Rule – translation of the beach and bottom profile with SLR resulting in shoreline recession and deposition of sediments (Bruun 1983)

Stive et al. (1991) investigated the use of nourishment to counteract the effect of sea level rise and determined it was an effective solution when combined with monitoring to account for long-term SLR forecast uncertainties.

2. History

The development of Nearshore Nourishment was driven by the need to provide large scale nourishment of the Gold Coast beaches at an achievable cost.

After the Gold Coast beaches suffered extensive erosion during the 1950's and 60's, regular surveys of beach profiles and investigations of beach processes were implemented (Delft 1965) and after the very severe erosion events in 1967 large scale beach nourishment was recommended (Delft 1970) to restore the valuable tourism industry and local economy. The recommended capital maintenance volume was 20M yd^3 over the first 20 years to provide adequate dunal buffer volume, against future cyclone erosion with ongoing maintenance nourishment of 300,000yd^3 pa thereafter. The cost of these works was estimated at $12M in 1970.

The city relied on tourism and after further erosion events in 1972, the city proceeded with only 25% State subsidy with the first major beach nourishment campaigns on the Gold Coast (and in Australia) at Kirra and Surfers Paradise using large cutter suction dredgers (CSDs) pumping sand from local estuaries through pipelines onto the upper beach (Jackson & Tomlinson 2017).

The 1.0Mm^3 of nourishment at Kirra proved to be inadequate to maintain a beach with large scale ongoing erosion (about 7Mm^3) from the Tweed River entrance training walls prior to the bypassing system (Jackson & Tomlinson 1990). The 1.4Mm^3 placed on Surfers Paradise beach was technically effective in widening the beach but caused disruption of the public access and safe use of the beach and erosion of the seaward section of the wider beach resulted in high erosion scarps that were perceived by the broader public as a loss of expensive sand (Jackson & Tomlinson 2017). The Gold Coast was then a small city of only 104,000 residents with pressure to fund water, sewerage, and transport infrastructure. These first campaigns were a political failure and funding for further expensive large-scale nourishment was lost. However, minor works, regular surveys of beach profiles and investigations into beach processes monitoring did continue.

A decade later, in the early 1980's, the data collected showed that the widespread erosion along the southern Gold Coast beaches would be considerably larger than predicted in the 1970 Delft Report and would continue northward as the Tweed River training walls to the south (updrift) of the Gold Coast, had trapped some 7Mm^3 of sand and this loss to the littoral supply would continue. Also, the need to counteract sea level rise was also becoming evident and requiring additional nourishment if the iconic Gold Coast beaches were to be preserved (Jackson 1987).

The first major project funded was to restore a 300m section of beach at the North Kirra SLSC where there was no beach at high tide. The plan was to construct a temporary low crested sand filled geotextile groyne and import 300,000m^3 of sand to restore a visible and usable beach until investigations into bypassing the Tweed River entrance were completed and a long-term solution implemented. A terrestrial source of suitable sand was located in a potential borrow area about 3km from the site but, with a depressed dredging industry and confidence in the nearshore nourishment concept, even though untried elsewhere, an option for offshore dredging with onshore and nearshore nourishment was included in the tender to obtain prices and feasibility of tapping into the large offshore sand reserves identified by geotechnical investigations. The dredging from the offshore sand reserves proved to be a viable option with 100,000m^3 placed nearshore (about -8m depth at msl) as a trial and to reduce project costs (Smith & Jackson 1990).

The works were carried out by Dredeco for $1.5M using the Belgium seagoing TSHD Vlaanderen XX mobilised from Malaysia after import restrictions on the foreign vessel were lifted. This total operation was carried out in 10 days in September 1985. In the light of the success of the initial works and to amortise the establishment / disestablishment costs, the contract was extended to include nourishment of other beaches, with 325,000m^3 of the 525,000m^3 being dredged from offshore and deposited in the nearshore zone (Smith & Jackson 1993).

The projects were monitored and model studies further increased confidence in the method (Jackson & Tomlinson 1990, REF) providing confidence that the restoration of severely eroded Southern Gold Coast Beaches was a viable undertaking. Public education of the concept has proved important and the next project in 1989 that was 1.5Mm^3 of nearshore nourishment bottom dumped only included a public information centre on the beachfront (Coomber and Nott 1989).

Storm wave conditions post nourishment were observed to accelerate erosion down drift of the nourishment, while the area of nourishment experienced significant accretion (Jackson & Tomlinson 1990, Smith & Jackson 1993).

The lessons learnt on the Gold Coast provided a sound knowledge base for nearshore nourishment that was applied elsewhere. Nearshore nourishment was included in the Dutch Manual on Artificial Nourishment in 1987 after reviewing the success of the Gold Coast nearshore nourishments (CUR 1987, Meisner 1991).

More recently, nearshore nourishment of over 3Mm^3 has been placed by bottom dumping and rainbowing by TSHD Balder R as part of the 2017 Gold Coast Beach Nourishment Project costing approx. $13.9M (Figure 4). The project formed part of the Gold Coast's Three Point Plan for Coastal Protection. Offshore reserves were utilised after an extensive sand source review (Jackson et al. 2014). The nearshore nourishment design focussed on placement on central and southern sections of the compartment to enhance longevity while retaining flexibility to respond to conditions at the time of the works (Strauss et al. 2014b). The project also involved pattern placement as distinct 'slugs' or sandy shoals to temporarily provide additional surfing opportunities and avoided placement in areas of existing high surf amenity (Strauss et al. 2014a).

With rainbowing activities occurring on high profile beaches, extensive community engagement and operational management was undertaken to ensure successful project delivery (Elliot-Perkins et al 2021). Detailed monitoring of short-term evolution of the morphology was undertaken and onshore movement, beach widening and northerly migration of sand slugs was evident as expected (Colleter et al. 2019). The nourished areas experienced no major erosion as a result of multiple subsequent storm events (Elliot-Perkins et al 2021).

Figure 3: Rhode Nielsen *Balder R* rainbowing during the 2017 Gold Coast Beach Nourishment Project.

To date there has been over 6.8Mm^3 of nearshore nourishment on Gold Coast beaches (Table 1). This has been a combination of large-scale nourishment campaigns from offshore and as well as placement of sand dredged from navigation channels by smaller TSHD. Upper beach and dune nourishment is still carried out using sand from building sites and estuary dredging using CSD equipment.

Table 1 Gold Coast Nearshore Nourishment Campaigns (not including TRESBP bypassing or onshore placement). Sources: Strauss et al. 2014, Jackson et al. 2013, Colleter et al 2019, TfNSW 2023.

Year	**Location**	**Source**	**Qty (m^3)**
1985	Nth Kirra Beach Palm Beach Burleigh Beach Surfers Paradise	Offshore Offshore Offshore Offshore	100,000 100,000 183,000 142,000
1988	Kirra – Bilinga	Offshore	1,500,000
1989/90	Kirra – Tugun	Offshore	395,000
2004	Palm Beach	Offshore	145,000
2005	Palm Beach	Offshore	124,000
2006	Palm Beach	Offshore	101,000
2012	Surfers Paradise	Nerang River	127,000
2013	Surfers Paradise	Seaway Delta	330,000
2016	South Stradbroke	Tipplers Passage	5,000
2016	Surfers Paradise	Coomera River	34,000
2017	Palm Beach Miami to Surfers paradise	Offshore	3,026,000
2019	Surfers Paradise	Coomera River	38,000
2020	South Stradbroke	West Crab Is.	31,000
2021	Surfers Paradise	Coomera River & Seaway	421,000
2022	Surfers Paradise	West Crab Is.	31,000
TOTAL			**6,833,000**

The ongoing coastal management methods on the Gold Coast have proven successful in mitigating approximately 100mm of sea level rise since the 1960s (Bird 1985, Jackson 1987, Jackson and Tomlinson 2017, Ware et al. 2020).

Over the years, nearshore nourishment has also been adopted more widely, including Noosa Main Beach, Mooloolaba Beach, Bribie Island (Moreton Bay), Iluka Beach (Clarence River), Airforce Beach (Evans River), Park Beach (Coffs Harbour) and Cronulla Beach (Port Hacking). A trial was recently implemented at Maroochydore Beach in late 2022.

3. Theory

3.1.1 Natural Storm Bar Migration

The intent of nearshore nourishment is to mimic the natural behaviour of storm bars and their protection of the beaches (Boczar-Karakiewicz and Jackson 1990). Storm bars are a feature of moderate to high energy dissipative beach systems. The longshore and cross shore sediment transport processes are 3D and complex forming rips, gutters and bars that are constantly changing in response to changes in tide and wave conditions. However, the behaviour has been well studied and can be shown as below (Figure 5) for Gold Coast conditions.

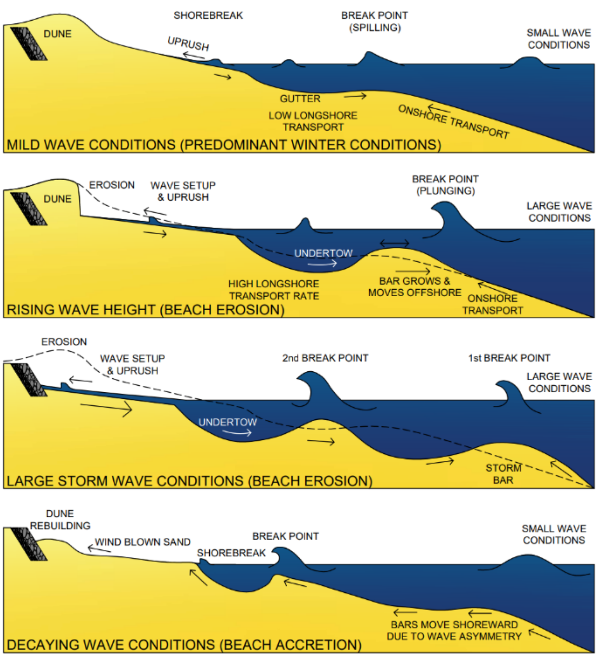

Figure 4 Bar formation diagram (updated from Jackson 1991)

In simple terms, the bars dissipate the wave energy from offshore to the swash zone. This energy dissipation is primarily by wave breaking on the bar(s) and shore break. If, for a given nearshore profile there is excess energy reaching the swash zone there will be erosion to form a wider and flatter swash zone and a corresponding increase in the bar volume until a dynamic equilibrium profile is reached.

During high energy wave conditions, the wave setup creates strong offshore rips that result in a large net transport of sand offshore. In very large erosion events, a large 2nd "storm" bar is formed (Figure 5). The storm bar is linear and seaward of the 3D bars, troughs and rips. The bar causes additional wave breaking and energy dissipation (Figure 6), thus reducing the energy that reaches the beach and further erosion. When the wave energy reduces after an erosion event the low wave energy reaching the swash zone results in reduced longshore transport and deposition. The bar(s) migrate onshore under bed shear.

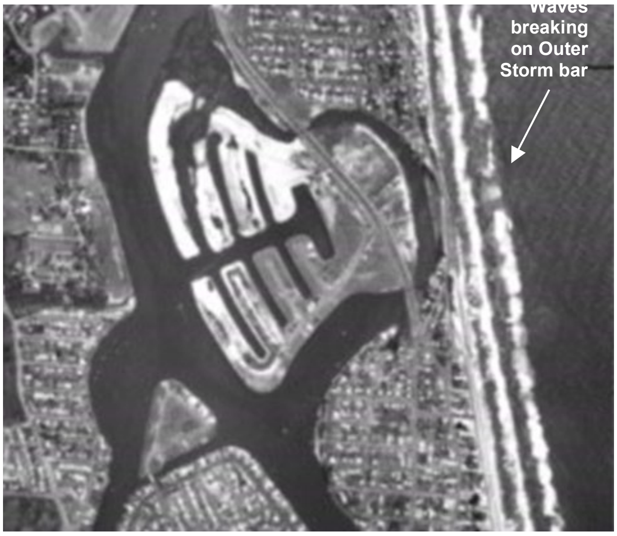

Figure 5 Aerial photography shortly after cyclone Wendy. Waves breaking on the linear storm bar (labelled) are clearly visible. Source of aerial image: RAAF 2/3/1972.

The survey profile monitoring along the Gold Coast beaches commenced in the mid-1960's and captured the very large storm bar that formed in 1967 and subsequent natural recovery (Figure 3). A rule of thumb for the Gold Coast from the regular surveys is that recovery after a severe erosion event takes about 18 months. The envelope of beach profiles (Jackson and Goetsch 1988, Goetsch and Jackson 1989) for Surfers Paradise (Figure 7) shows the seaward limit of significant changes is out to about 20m for these extreme storm conditions. It is interesting that subsequent surveys show that none of the sand eroded from the beach in the severe storms in the 1960's and 70's was lost from the active beach system.

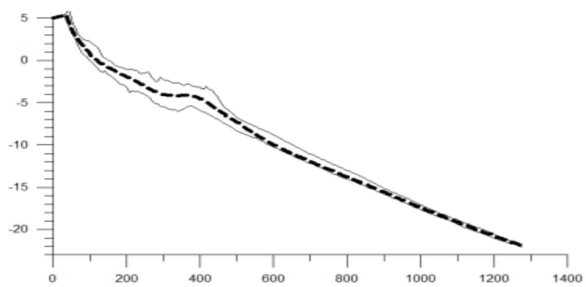

Figure 6. Envelope of cross-shore profiles 1976 – 1997 at Surfers Paradise, Gold Coast (ETA 63). Shows storm bar extending to approximately 20m water depth. Source: Carley and Cox (2017)

During the investigations for the 1985 nearshore nourishment, a series of daily high precision transects using a survey staff out to 9m were undertaken. Dive observations in 6.5m water depth (the expected depth of deposition) with a 1.5m swell using dyed sand showed that there was generally a slow shoreward transport by ripples with bursts of suspended sand as larger waves passed overhead. The ripples quickly reformed under the wave orbits. There was a distinct sorting of the shell grit from the sand matrix. It was also noted that the grain size distribution varied across the profile with finer sand grains distributed into the dunes by wind and offshore by rip currents. The finer sediments deposited most seawards at the limit of sand movements after erosion are able to be moved shoreward by the decreasing swell waves. The shoreward progression of the bar was evident between daily surveys (Boczar-Karakiewicz and Jackson 1990).

3.1.2 Artificial Storm Bar Migration

By placing an artificial storm bar the profile is out of balance and the nearshore nourishment widens and protects the beach via the following:

1. Bed shear moves the nourished bars and seabed shoreward.
2. The overfull profile reduces the wave energy reaching the swash zone and with the reduced littoral drift to landward of the nourishment deposition occurs increasing visible beach width (Smith and Jackson, 1990).

If an artificial storm bar is in position before a storm arrives the wave energy is reduced as the waves pass over, and larger waves break so that the wave energy that reaches the swash zone is considerably reduced, decreasing erosion of the upper beach.

The widening of the visible beach was very evident during the 1988 nearshore nourishment project and local residents, many of whom visited the information centre for daily dredged quantity and survey updates, provided strong support.

4. Design Considerations

The following needs to be determined for each nearshore nourishment project:

- Volume required
- Closure depth
- Deposition depth
- Sand source(s)
- Suitable plant
- Weather windows
- Estimated costs and benefits

4.1 Volume

Volumes are dependent on the site characteristics as well as project objectives and constraints. Target beach widening should consider volume required to widen the entire beach profile. Migration of sediments onshore and alongshore over time, natural variability and response to storm events should also be considered. Longshore transport often results in a preference for non-uniform spread of nourishment within the compartment.

Because the nourishment will spread alongshore as well as onshore, larger campaigns or nourishment of a compartment are preferable. However, opportunistic use of suitable plant that is available without large mobilisation costs or is idle may make smaller volumes placed more regularly an economic proposition. For example:

- a suitable dredge mobilised from overseas for another project
- a port based/owned dredge that is idle or can utilise dredge spoil from channel dredging for nourishment with a short extra haul distance. The latter has occurred at a number of locations including Port Hacking-Cronulla, Newcastle Harbour-Stockton Beach and Port of Brisbane-Bribie Beach.

4.2 Closure depth

The closure depth is determined by a number of factors including wave climate and sediment characteristics. As described by Carley and Cox (2017), closure depth is broadly defined as the depth at which profile change is small on an annual basis or over the duration of a planning horizon.

For nearshore nourishment it is prudent to consider the 2 closure depths as defined by Hallermeier (1981, 1983):

- The inner closure depth corresponds to the seaward limit of the upper shore face (i.e. the littoral zone). This is best used for seaward extent of deposition.
- The outer closure depth corresponds to the depth at which waves do not interact with the seabed. This is best used as the inner limits of dredging except in the case of bypassing.

These closure depths can be calculated from surveys, empirically or from sediment sampling. Calculation methods and formulae are readily available (Lindenberg 2023). Survey accuracy by sonar will be about 200-300mm.

A sheltered site with a relatively small maximum wave height and variability will have shallower depths of closure than a more exposed site.

4.3 Deposition depth

To be effective, the nearshore nourishment needs to be deposited in the active zone landward of the inner closure depth.

The deposition depth will also depend on availability of plant. The choice is usually between a small-medium sized TSHD that can bottom dump in the outer area of the active zone or a medium to large TSHD that needs to rainbow shoreward from its safe under keel depth.

Pattern placing for large volumes has been proven to allow higher volumes to be placed as this allows time for initially placed nourishment to move landward. Pattern placing can also provide benefits such as improved surfing breaks, in the short term.

The onshore transport rate will be determined by both the depth and the wave conditions after the nourishment.

4.4 Sand Sources

A range of sand sources can be considered, including:

- Navigation dredging of adjacent waterways
- Offshore reserves (i.e. relict deposits beyond the active littoral system)
- Inside active system where circumstances result in acceptable impacts, such as the Tweed River entrance (Carley and Cox 2017).

Ideally, sand for nourishment should be similar in grain size, composition, angularity, colour, and grading (Carley and Cox 2017). Smith and Jackson (1990) note that nearshore nourishment is particularly tolerant of sediment quality compared to other nourishment methods for two main reasons:

- In nature, offshore sandbars are generally made of finer sand than that on the visible beach and in the swash zone.
- As the storm bar migrates ashore, material is naturally winnowed, and the coarser material ends up in its natural position on the visible beach.

Also, the colour of the sands dredged from offshore is less important as the sand is mixed, and the majority remains in the sub aerial profile. For onshore nourishment the initial colour is usually darker than the native beach and this is a source of complaint until bleaching and washing / blowing out of the silt content occurs.

Sediments also needs to be compliant with the contaminant requirements of the National Assessment Guidelines for Dredging (2009).

4.5 Plant

TSHD are a common type of dredge for port channel maintenance and their ability to operate in swell conditions and seagoing steaming ability lends itself to the exposed conditions faced along the open coastline. Suitable plant needs to be able to dredge seaward of the outer depth of closure to avoid loss of sand from the beach system back into the dredged area.

The dredge also needs to be able to have suitable draft and capabilities to bottom dump or rainbow within the target deposition depths.

4.6 Weather Windows

The optimum conditions for nearshore nourishment are mild wave conditions with an accreted upper beach profile where the bars have migrated landward. This provides good conditions for bottom dumping to seaward of the bar and/or rainbowing onto the bar. Timing the works for periods of typically milder weather also minimises standby of plant during larger swell conditions.

4.7 Costs

From costs in the public domain, a good estimation is that bottom dumping is about ½ the cost of pumping ashore and the cost of rainbowing is about midway between these.

5. Benefits

Potential benefits compared to onshore nourishment include:

- Significantly lower project costs.
- No disruption to or risks to beach users.
- Less sensitive to sand characteristics.
- Can access offshore sand reserves as well as navigation channels.
- Opportunity to improve surfing amenity. (Jackson 1995, Jackson et al. 2001, Strauss et al. 2014).

The most serious potential disadvantage of nearshore nourishment is lack of understanding by the public and politicians, but this can overcome by public education and awareness. It should also be planned such that there is time for the sediment to migrate onshore rather than being undertaken ad-hoc in response to erosion events.

6. Summary

Nearshore Nourishment is a well proven nature-based solution that mimics the natural processes of storm bar migration. It was first trialled on the Gold Coast in 1985. Since that time, nearshore nourishment has been used extensively along the Gold Coast and other locations within Australia and worldwide.

Nearshore nourishment provides the following benefits:

- Significantly lower project costs.
- No disruption to or risks to beach users.
- Less sensitive to sand characteristics.

- Can access offshore sand reserves as well as navigation channels.
- Opportunity to improve surfing amenity.

Suitable dredgers to work in exposed coastal conditions are typically trailing suction hopper dredges. These are readily available as they are often used for port dredging.

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