Guidelines for Sand Nourishment

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Guidelines for Sand Nourishment

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by

J T Carley and R J Cox

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Abstract

This report presents guidelines for sand nourishment, with a focus on application within New South Wales, Australia. Sand nourishment is usually undertaken to provide a buffer against storm erosion and/or to enhance public beach amenity through increased beach width.

Reduced sand nourishment volumes may be viable when nourishment is used for public beach amenity compared with the provision of erosion protection for backshore assets during extreme ocean storm events. The report details potential sand sources and desirable sand characteristics for physical compatibility between borrow sand and native sand. A range of methods are presented for sand extraction, transport and placement, which can range from simple dozer and truck operations to large international dredgers.

The report also considers the precedent, costs, economics and environmental impacts of beach nourishment from both Australian and international projects. A range of international literature and precedent projects have been considered in developing these generic guidelines. The guidelines can be used to assist with site specific studies for the consideration of sand nourishment as a potential option for coastal adaptation.

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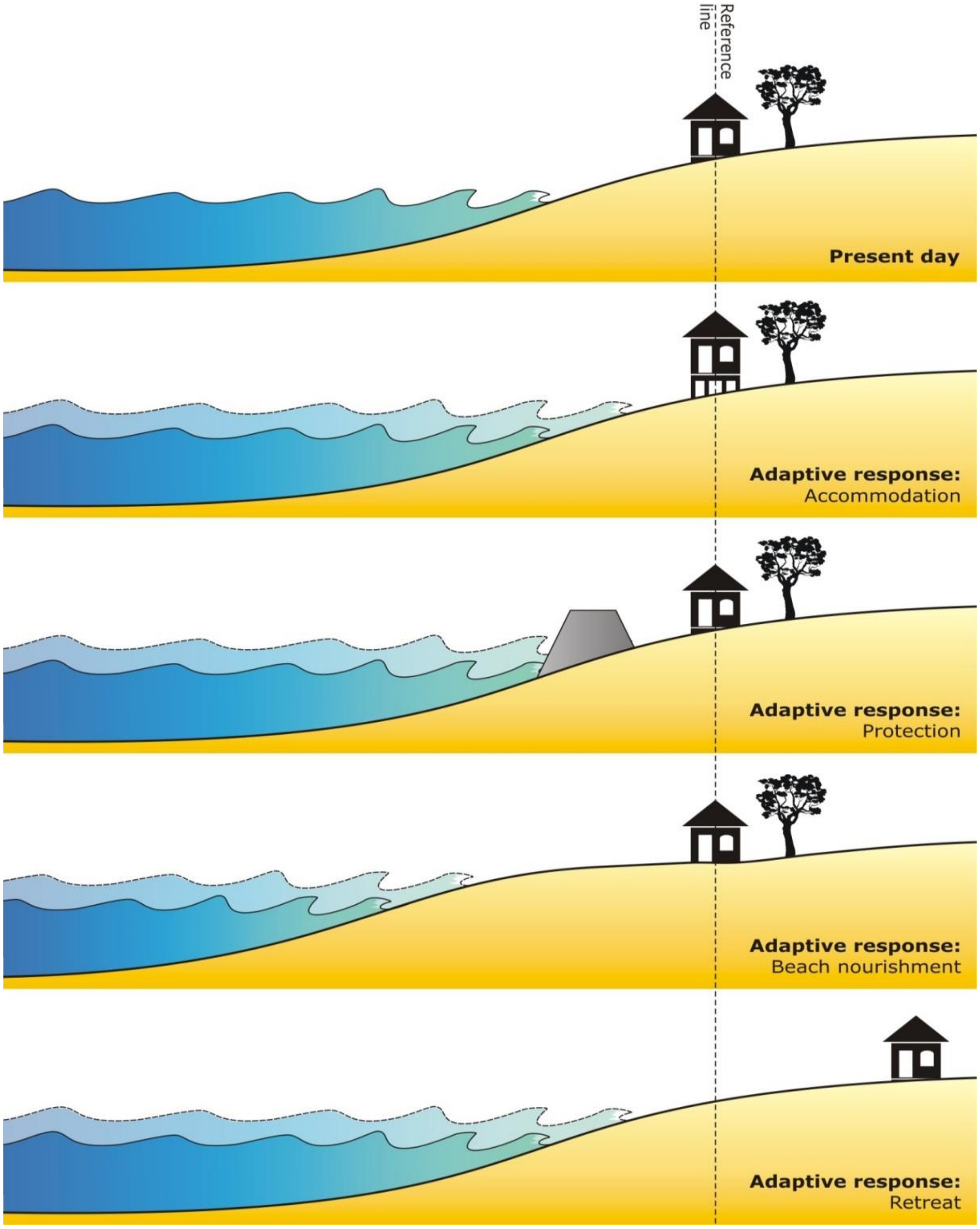
1. Introduction

Coastal hazards, predominantly erosion, recession and inundation may arise from present day storms, ongoing processes or future climate change. Adaptation to coastal hazards can take the form of (Figure 1.1)

- Protect (which can take many forms, such as a seawall or beach nourishment);
- Accommodate;
- Retreat.



(Based on: CEM, 2006, Figure V-3-2)

Figure 1.1: Alternative Coastal Adaptation Strategies

Beach nourishment is defined as:

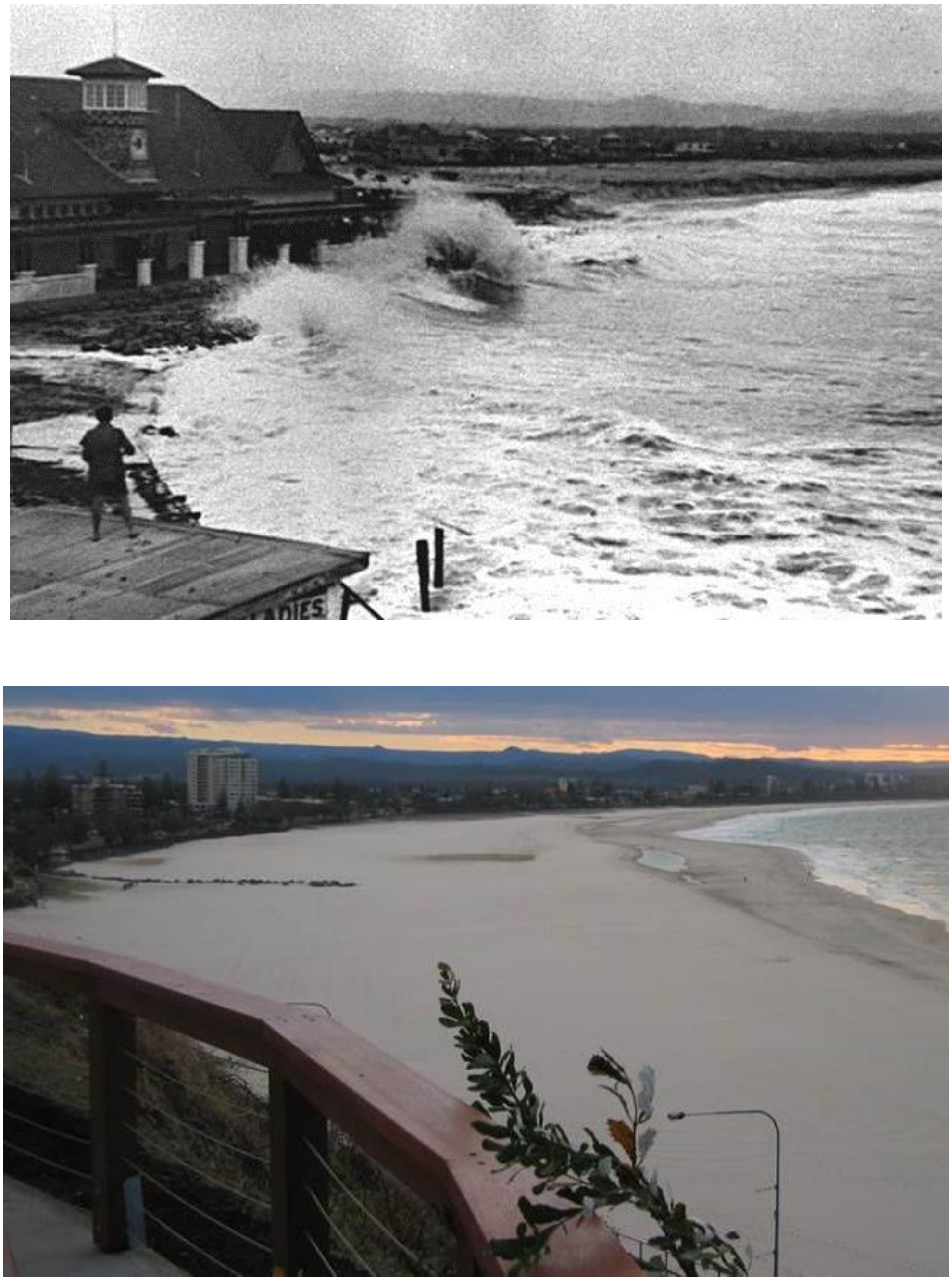
***Artificial emplacement of sand (or coarser material) to improve beach amenity and/or increase protection for backshore assets*.**

Beach nourishment is one possible protection adaptation pathway to coastal hazards. It may be a standalone measure for protection, or be used to improve the beach amenity when used in combination with other adaptation measures such as a seawall.

Beach nourishment is considered to be a "soft" management/engineering option and usually mimics natural beach and dune systems. When compatible sand is available for beach nourishment projects, if they are well designed, constructed and maintained, the artificial nature of the project may be undetectable to most of the community. An example of beach nourishment at Kirra, Queensland is shown in Figure 1.2.

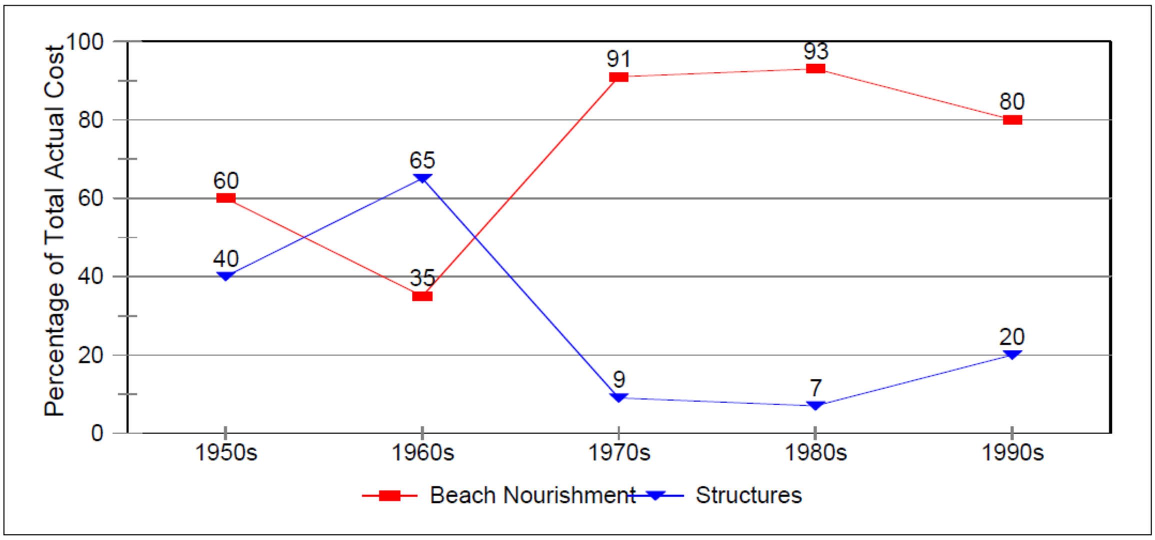
This report provides a concise overview of the main considerations if beach nourishment projects are to be implemented in NSW in the future. Substantial additional details are provided in the reference materials cited. The report is intended for local government staff and the broader community, and as a reference document to complement future state government guidelines or toolkits.

In the USA, expenditure on coastal protection works by the US Army Corps of Engineers (CEM, 2006, Figure I-3-13) was 35% nourishment, 65% structures in the 1960s. This shifted to proportions of 80% to 93% nourishment in the 1970s, 1980s and 1990s (Figure 1.3).



(top: Gold Coast City Council Library; bottom; James. Carley WRL UNSW)

Figure 1.2: Kirra Beach in 1936 and 2004



(Source CEM, 2006, Figure I-3-13)

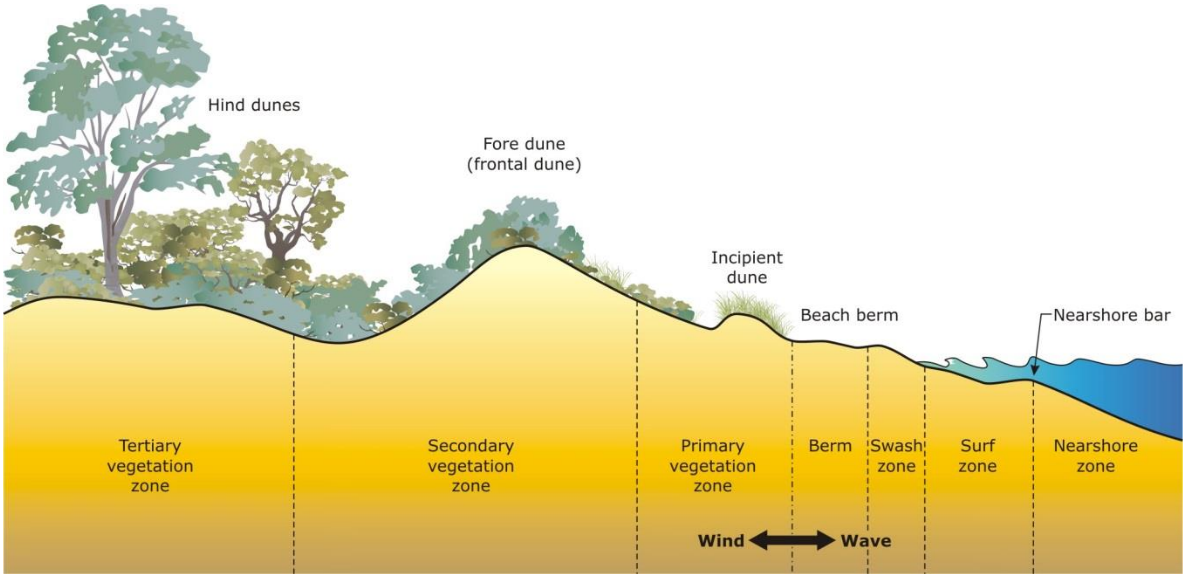
Figure 1.3: US Army Corps of Engineers Expenditure on Fixed Structures and Nourishment

2. Beach Width and Sediment Compartments

2.1 Zones on Beach

The various zones on a beach are shown in Figure 2.1. On most Australian beaches in inhabited areas, the landward limit of useable beach is demarcated by a seawall or vegetated dune. Vegetated dunes are often demarcated with a fence.

As stated above, beach nourishment may be undertaken to improve beach amenity and/or increase protection for backshore assets.



(Based on NSW Government, 2001)

Figure 2.1: Beach Profile Zones

2.2 Closure Depth

2.2.1 Concept of Closure Depth

The envelope of regular profile surveys over 30 years at Surfers Paradise is shown in Figure 2.2. This shows that the active littoral zone extends seaward to a "closure depth".

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 (Kraus et al, 1998; Cowell et al, 2001; Hanson et al, 2003). Sand may still be mobile seaward of the closure depth in response to wave orbital velocities and ocean currents, but this movement may not noticeably affect the beach profile in the surf zone or the dry beach (Figure 2.3). Komar et al. (1972) found changes in ripples at depths of more than 100 m, however, Kraus et al. (1998) cautioned that "… the engineer must not confuse nearshore processes that control sediment movement at the beach with processes occurring far offshore, which are usually not related to time scales of beach fill projects."

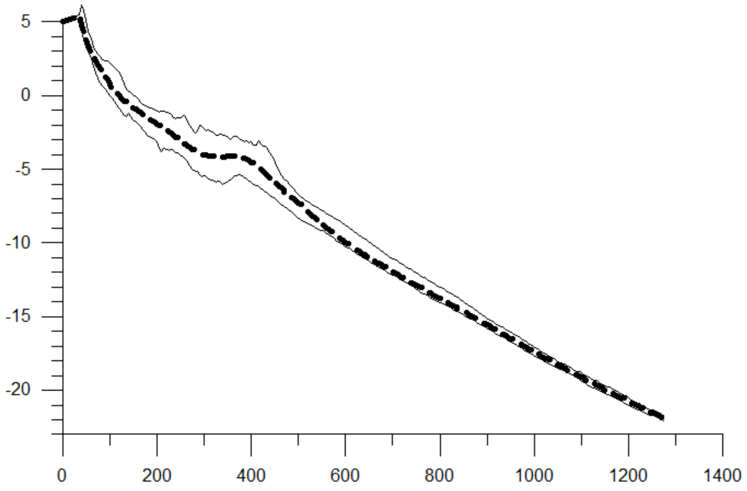
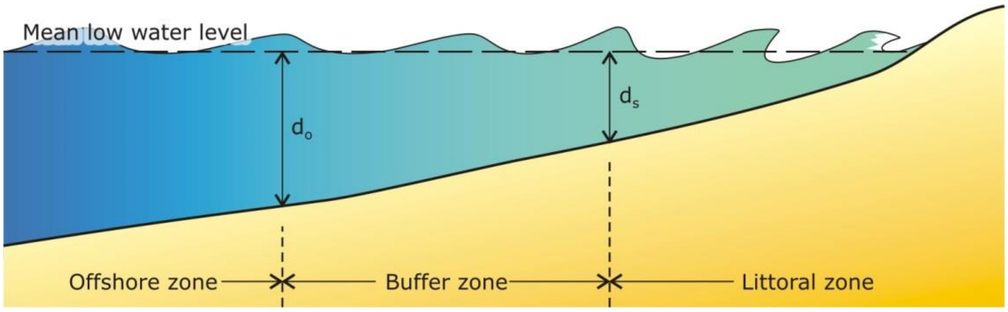


Figure 2.2: Envelope of surveyed cross-shore (ETA63) profiles of Surfers Paradise (1976 to 1997)



(Based on Hallermeier, 1983)

Figure 2.3: Concept of Closure Depth

2.2.2 Uncertainty in Estimating Closure Depth

The quantification of closure depth, as with other quantifications of sediment transport involves considerable uncertainty.

Hans Albert Einstein was one of the world’s leading researchers in the field of sediment transport and was the son of the famous Albert Einstein. Albert was reported to have discouraged his son from studying sediment transport: “*… the older Einstein is said to have warned his son strongly of the difficulties in dealing with sediment transport processes*” (Vollmers, 1989 in Hughes, 1993). Hughes (1993) also gave his own opinion that: “*Understanding sediment transport in coastal regimes is a perplexing challenge that in all likelihood will continue to frustrate coastal researchers and engineers for generations to come*”.

2.2.3 Available Methods for Estimating Closure Depth

The most widely used method for calculating closure depth is that of Hallermeier (1978, 1981, 1983), which is based on laboratory and field measurements. He defined two boundaries, namely an *inner boundary*, which is the limit of intense bed activity and an *outer boundary*, seaward of which there is little sand transport by waves.

Cowell et al. (2001) and Patterson (2013) provided evidence of an onshore supply of shelf sand at some locations in NSW and Queensland. The magnitude of this (of the order of 1 m^3/m/year) explains the evolution of observed coastal features over millennia. This onshore supply is also of importance in assessing beach response to sea level rise (over centuries), but is relatively minor on the NSW coast over the expected life of beach nourishment projects (years to decades).

CEM (2006, p III-3-20) noted: "The shallower of the [Hallermeier] two appears to be of the greatest engineering relevance". The inner Hallermeier limit is generally accepted as a suitable closure depth for sand nourishment and engineering design.

It is based on the "effective" significant wave height H_e and the associated wave period T_e – that is exceeded for 12 hours per year. This 12 hours per year criterion is sometimes interpreted to simply be any 12 hours (0.137% of the time), while Kraus et al. (1998) suggest that it should be 12 *consecutive* hours. When applied in NSW, T_e is usually considered to be the associated spectral peak wave period T_p. Strictly speaking this closure depth is relative to mean low tide, which is about –0.5 m AHD on the NSW coast. While this inner closure depth is based on the wave height exceeded for 12 hours per year, this does not necessarily make it an "annual" closure depth. Kraus et al. (1998) suggested that the 12 consecutive hours criterion be set to the average recurrence interval (ARI) of the planning period for the nourishment (e.g. 5 year ARI). Work by Nichols et al. (1999) showed that the measured closure depth for monitoring periods of up to four (4) years did not exceed the theoretical values for 1 year. Project specific design is needed to resolve many of these issues, however, alternative formulations of closure depth may change calculated nourishment volumes by 10 or 20%, but not by orders of magnitude.

For the open NSW coast, typical values (Shand et al., 2011; Nielsen, 1994) for fully exposed beaches are:

- H_e = 5 to 6 m and median H_s = 1.6 m
- T_e = 10 to 11 s and median T_p = 10 s
- Inner closure depth, inner d_c or d_s ≈-10 to -12 m AHD
- Outer closure depth d_o ≈-30 to -38 m AHD.

Birkemeier (1985) provided a further simplification on Hallermeier based on additional field measurements, namely:

$$\text{inner } d_c = 1.57\ H_e$$

That is, with d_c relative to mean low water, the Birkemeier method gives typical values for the open NSW coast of -8 to -10 m AHD. The closure depth is shallower for more sheltered beaches.

Nielsen (1994) noted sedimentary boundaries which were broadly consistent with the Hallermeier limits. Based on a synthesis of field, laboratory and theoretical studies, he suggested the following boundaries for the open coast of south-east Australia:

Offshore limit of significant wave breaking and beach fluctuations:	-12 m AHD ±4 m
Offshore limit of extreme storm events:	-22 m AHD ±4 m
Limit of reworking and onshore transport of beach sand by waves	-30 m AHD ±5 m

AECOM (2010) adopted -22 m AHD as a closure depth for hypothetical nourishment design for Sydney based on typical sedimentological boundaries.

Evans et al. (2001) reported on current meters installed at 12 and 24 m water depths off Macmasters Beach NSW. They observed that the visual plume from "mega rips" during large storms extended "… probably to depths in excess of 30 m." The inner current meter (in 12 m of water) was buried in sand. Mariani et al. (2013) also considered similar mega rips at nearby Avoca and concluded that while locally important, they comprised a modest proportion of the overall long term sediment budget for the embayment.

2.3 Beach Width for Protection of Backshore Assets

Ideally, beach width requirements for coastal protection should be determined in a risk-based manner, noting that risk equals likelihood times consequence. This is a similar approach to that which would be used for design of other more "engineered" coastal protection forms.

An example of nourishment as protection is shown in Figure 2.4, for protection criteria of:

> *"The 100 year ARI Zone of Reduced Foundation Capacity should not enter private property".*

A lesser volume of nourishment sand could be used if this criterion was relaxed to:

> *"The 100 year ARI Zone of Reduced Foundation Capacity should not reach un-piled structures"*

For the example case of a 100 year ARI storm erosion volume of 250 m^3/m above AHD, this is often mistakenly taken to be the nourishment requirement to provide the required protection, however, this ignores the requirement for nourishment of the subaqueous profile (Section 3). Notwithstanding other factors above, for an active nourished beach profile extending from +6 m AHD to -12 m AHD, the addition of an effective volume of 250 m^3/m above AHD would require a typical nourishment volume of the order of 750 m^3/m.

The required dune crest level to prevent wave overtopping by wave runup also needs to be considered in the design dune profile, with typical design levels on the open coast of 6 to 8 m AHD.

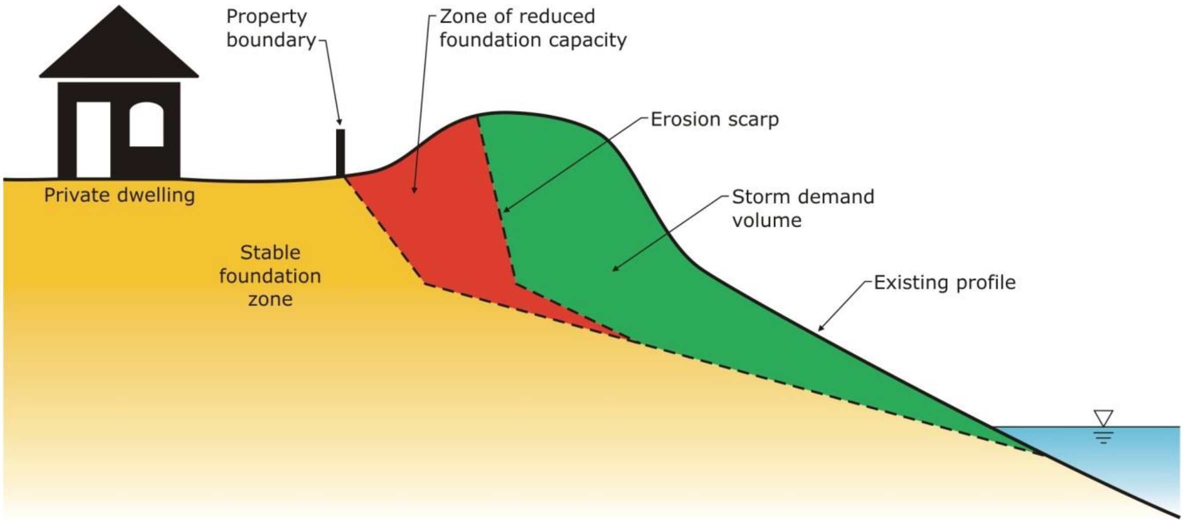


Figure 2.4: Definition of 'Protection' Applied for Analysis

2.4 Beach Width for Amenity

An example of a nourishment project providing beach width for amenity at Noosa, Queensland is shown in Figure 2.5.

Figure 2.5: Noosa, Queensland, before (left) and after (right) nourishment program

2.4.1 Beach Width Literature

Beach width is an important criterion in the community's enjoyment of a beach, and up to a limit, people prefer wider beaches (King, 2006). Anning (2012), investigating the economic value of selected Sydney beaches, highlighted that while beach width has been used extensively in valuation literature as a proxy for beach quality, determining what is acceptable to a community for recreational use is complex. Anning noted that the majority of beach width studies have been based on housing market impacts, rather than recreational use.

Parsons et al. (2000), considering beaches in the mid-Atlantic region of the USA (primarily Delaware and New Jersey), suggested that beaches can be both too narrow and too wide, and proposed that the ideal beach width was between 75 and 200 ft between the dune toe and the berm (approximately 23 to 61 m). Morgan (1999) investigated beach width in Wales, finding the optimal beach width to fall between 50 and 200 yards at low tide (46 - 183 m) and 20 to 50 yards at high tide (18 – 46 m), similar values to those of Parsons et al. (2000). King (2006) suggested that the ideal beach width is approximately 100 - 250 ft (30 – 76 m), without reference to the tidal stage of the beach. King (2006) also highlighted that it is possible that a beach could be so wide that access to the water is too onerous.

The US Army Corps of Engineers, responsible for many beach nourishment programs in the USA, often follow a policy that 100 ft^2 (approximately 9 m^2) of beach area is desirable per person (King, 2006), which means that estimates of beach user numbers are also needed to establish estimates of beach width/area required for beach amenity.

Large scale nourishment of the southern Gold Coast beaches has been occurring as part of the Tweed River Entrance Sand Bypassing Project (TRESBP). A number of dredging campaigns of the Tweed River entrance have taken place and a permanent sand bypass system was introduced in 2001. This has resulted in significant changes in the Coolangatta Bay morphology, with the southern beaches of the Gold Coast thought to be the only Gold Coast beaches able to manage a high succession of large wave events (Castelle et al., 2006). However, some of these beaches are now very wide. A seaward migration of the shoreline by more than 200 m has occurred at Kirra Beach, compared to the shoreline prior to the TRESBP. Some local stakeholders and tourists consider that the beaches are too wide, especially at Kirra, and that surfing, swimming, fishing, diving and beach use amenity has been compromised as a result of over nourishment (Castelle et al., 2006).

Carley et al. (2003) analysed Manly Ocean Beach and assessed the average mid-tide beach width seaward of the seawall to 0 m AHD between 1930 and 2001. The average mid-tide width of the entire beach over this period was 48 m, ranging between 32 m at the southern end, to 75 m at the northern end. Their qualitative observations are that the northern end is almost always acceptably wide for the community, but the southern end is too narrow at times (high tides, large waves and/or eroded beach).

To simply allow alongshore pedestrian access seaward of a backshore feature such as a dune fence, seawall or cliff, a dry beach width of only 1 to 2 m may be all that is required.

2.4.2 Beach Width for Amenity Criteria

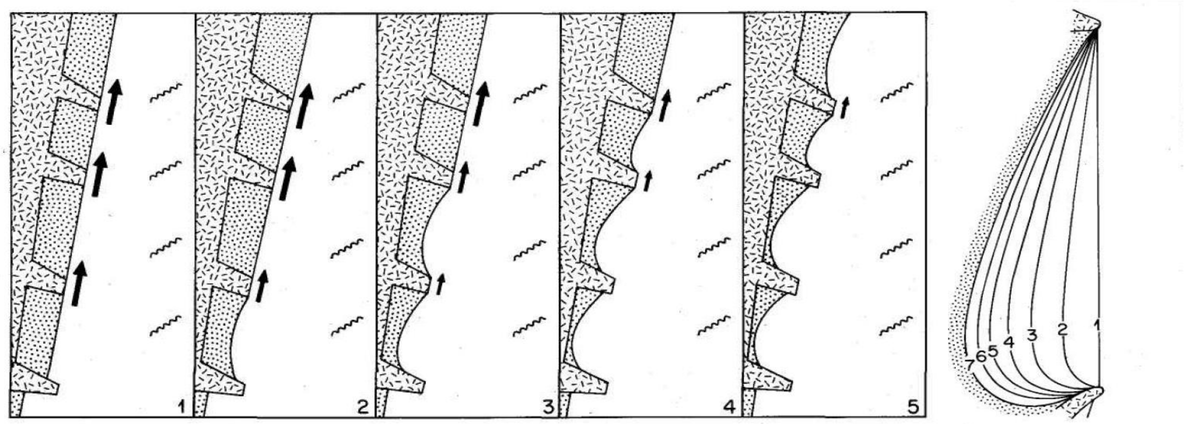
It is unrealistic to expect an acceptable beach width to be present during or following an extreme storm event. Ideally, realistic criteria should be set regarding acceptable beach width to assist with project design and/or to establish triggers for more action. Examples of acceptable beach width criteria could include:

- “After a 1 year ARI erosion event, there is a 20 m wide dry beach on a mean high water spring tide under average wave conditions (above say 2 m AHD)”.
- “There is a 30 m wide dry beach 95% of the time”.
- “A beach allows alongshore pedestrian access (1 to 2 m) seaward of a seawall, dune fence or cliff 99% of the time” (noting that precise design of such a small width in a dynamic system may be difficult).

Todd et al. (2015) presented a “Beach Volume Index” (BVI) for quantifying beach width on the Gold Coast. Calculation of index has evolved since its initial development in the 1970s, noting that the “A-line” boulder wall provides structural property protection. BVI is an indicator of the beach amenity which would be available (seaward of the seawall) following major storm erosion. The current BVI number comprises components of sand volume seaward of the seawall above 0 m AHD and between 0 m and -14 m AHD. This is somewhat specific to the Gold Coast, but various BVI scores are associated with descriptors of *Excellent, Good, Adequate, Poor* and *Critical*. Low BVI scores are a trigger for more targeted management intervention on that section of coast. The earlier 1970s work of the Queensland Beach Protection Authority cited in Todd et al. (2015) developed a “design beach profile” for the Gold Coast which had a beach width of 120 m between the crest of the A-line seawall and mean sea level.

2.5 Sediment Compartments

The Coastal Management Act 2016 defines a "coastal sediment compartment" as “an area of the coast defined by its sediment flows and landforms”. Neighbouring beaches within sediment compartments may have sediment linkages through littoral drift sand transport and an absence of underwater features such as submarine cliffs which limit sediment transport. Conversely, in some locations, coastal alignment and headlands extending below the water results in beaches that are relatively closed compartments without significant sediment linkages to their neighbours. This is well illustrated in Stephens et al. (1981), as shown in Figure 2.6.



Source: Stephens et al., (1981)

Figure 2.6: Coastal evolution and headland bypassing on a littoral drift coast

In NSW, net northward littoral drift generally prevails north of about Newcastle (Chapman et al, 1982; Gordon, 1987; Cowell et al. 2001), which will generally transport nourishment sand northward over the longer term. South of about Newcastle, most coastal embayments are reasonably closed littoral compartments between headlands.

2.6 Sand Quantities Required

The required sand volume on a beach needs consideration of the following factors:

- Storm erosion;
- The sediment budget, including ongoing underlying recession, littoral drift and headland bypassing;
- Future recession due to sea level rise;
- Wave runup;
- Actual composition of borrowed sand and its loss rate when emplaced;
- Borrow area volumes available;
- Availability of suitable plant for renourishment.

The concept of "overfill" ratio is discussed in Section 3.2.5.

The so-called "Dutch" method of design (Verhagen, 1992) involves the following steps:

1. Perform coastal measurements for at least 10 years to determine ongoing recession rates.
2. Utilise these measurements to estimate the sand volume lost (m^3) in the coastal section.
3. Add to this loss an additional 40% loss.
4. Multiply this amount by a convenient renourishment time (say 5 years).
5. Carry out the nourishment by placing the required volume between the dune foot and the low water minus 1 metre line.

3. Sand Sources and Properties

3.1 Location of Borrow Sand

The following locations of borrow sand may be viable for nourishment:

- Areas requiring dredging or excavation, such as navigation channels, lake or lagoon mouths, port expansions or basements of large buildings;
- Terrestrial, river and estuarine sand deposits, including commercial quarries;
- The intertidal area (for beach scraping);
- The active littoral zone for bypassing of stable or accreting littoral features, such as natural headlands, breakwaters, training walls or groynes;
- Non-relict (active) offshore sand sources where the impacts are deemed to be acceptable;
- Relict offshore sand deposits beyond the active littoral system, which may be the only viable option for large scale nourishment.

Impacts specific to different borrow locations are discussed in Sections 4 and 5.

3.2 Sand Compatibility

The compatibility of borrow sand with the native sand of a beach should be considered in terms of:

- Grain size;
- Colour.

More detailed assessments can also consider:

- Shape;
- Fall velocity;
- Grading curve and proportion of fine material;
- Mineralogy and biogenic fraction.

The potential for contamination in the borrow sand also requires consideration.

3.2.1 Chemical/Mineral Composition

CEM (2006, p V-4-21) noted:

> "In most places [including NSW], sand-sized sediment is predominantly composed of quartz particles with lesser amounts of other minerals such as feldspar. Quartz has good mechanical strength, resistance to abrasion, and chemical stability. In some deposits, particularly those of marine origin, there is a large and sometimes dominant amount of calcium carbonate that is in most cases of organic origin (biogenic). Calcium carbonate is more susceptible than quartz to breakage, abrasion, and chemical dissolution; but, if it is not highly porous or hollow, it will make serviceable beach fill."

3.2.2 Grain Size Compatibility

Except for beach scraping and sand bypass plants, usually borrow material will not exactly match the native beach grain size. Ideally, it should be similar in grain size (or slightly coarser), composition, angularity and colour.

An assessment is required of compatibility of the borrow material with the native beach, as the grain size of the borrow material has a significant effect on the cross-shore shape of the nourished beach profile, sand loss rates and how the beach will respond to storms. Consideration of borrow sand compatibility is important in predicting the performance of nourishment and the volume of nourishment sand required.

3.2.3 Grading Curve

While the median grain size (D_{50}) is usually the primary consideration, the **grading curve** and **proportion of fine material** are also important to more accurately estimate project performance.

Sand grading curves should be undertaken in accordance with Australian Standard AS 1289.3.6.1-2009 Methods of Testing Soils for Engineering Purposes. The outcome of sand sieving is shown in Figure 3.1. An illustrative grading curve is shown in Figure 3.2.

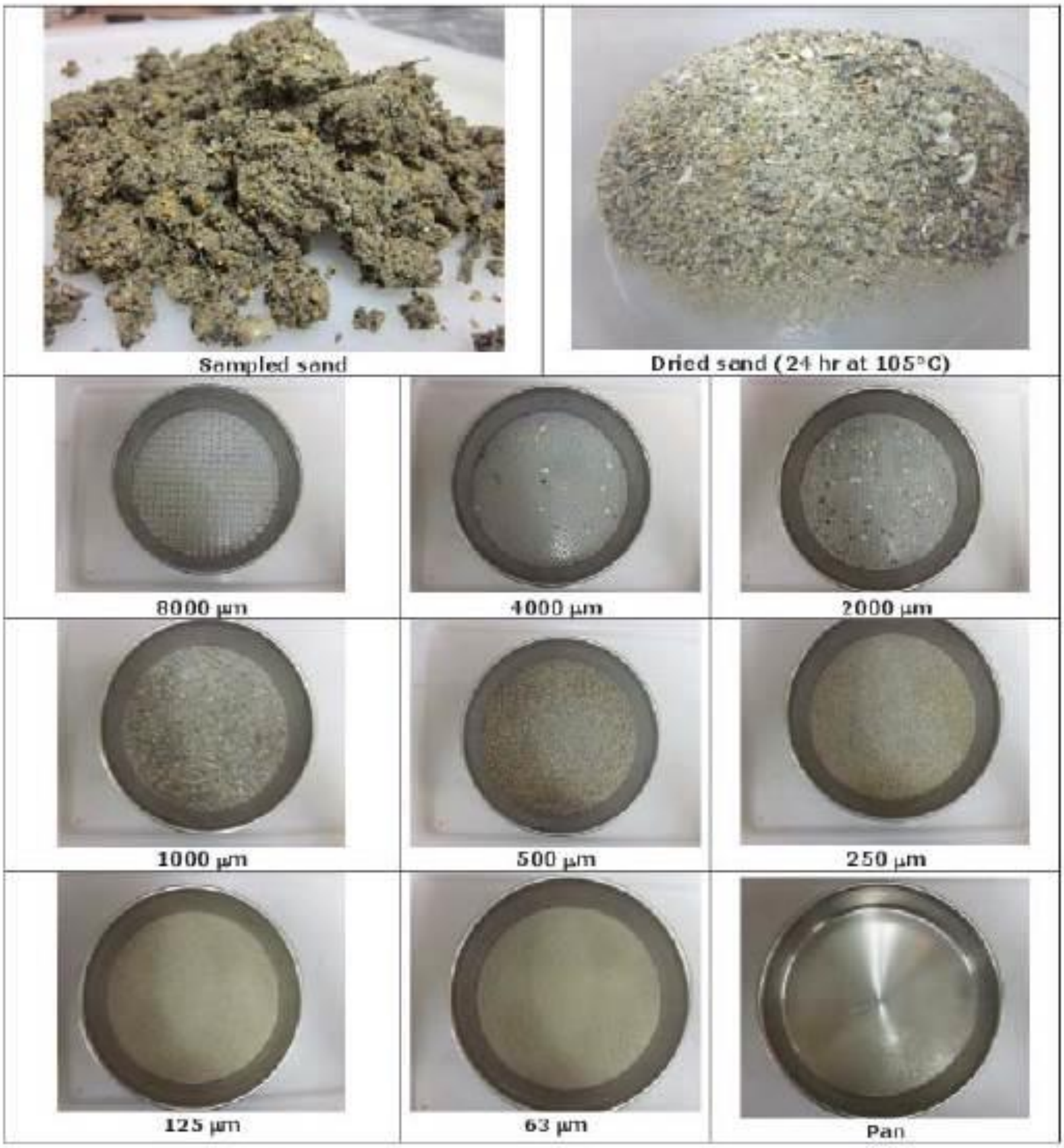


Figure 3.1: Fractions of sand obtained during a sieve analysis

Standard soil mechanics texts (e.g. Terzaghi et al., 1996) defines a uniformity coefficient Cu= D_{60}/D_{10}, with D_{60} being the size for which 60% of particles are smaller, $D_{60} > D_{10}$, and D expressed in millimetres (not phi units). Cu is a measure of the compactibility of a material.

Sand is often described as:

- "well sorted" (= "poorly graded") for $Cu < 4$
- "poorly sorted" (= "well graded") for $Cu > 6$

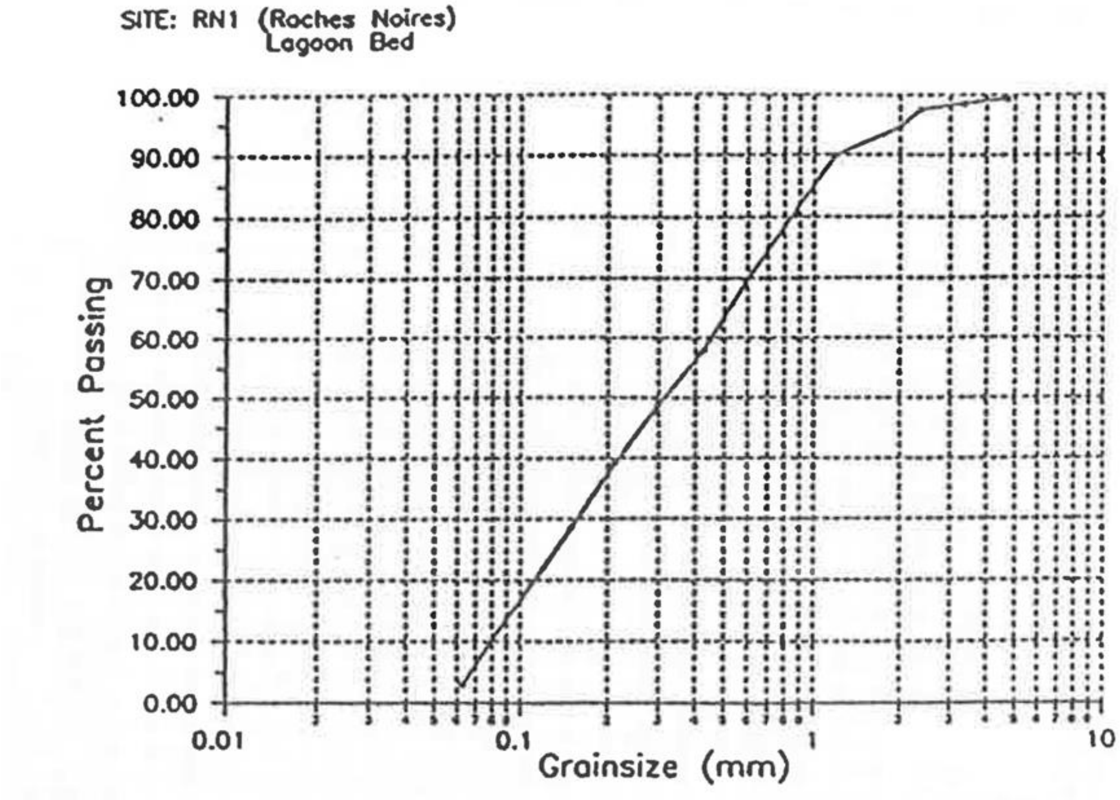


Figure 3.2: Example Sand Grading Curve

Mangor et al., (2012) reported that Cu values less than 2 are desirable to create beaches. Cu values substantially above 2 will compact more and create a beach which is more "concrete" like and will not freely drain when the tide drops, resulting in a "swampy" feel. In practice, Cu values slightly above 2 may need to be accepted if compatible sand is not available, and (unless the project is a reclamation) mixing will occur with the native sand. Higher Cu values are more problematic when waves are consistently below 1 m.

3.2.4 Influence of Grain Size on Profile Shape

Most beaches exhibit an overall concave-up shape below the water, notwithstanding the area around offshore sand bars. This profile shape can be represented by the equation:

$d = Ay^n$ (Equation 1)

where

d = depth below mean sea level

A = a shape parameter which is usually expressed as a function of sand grain size or fall velocity

n is an exponent, usually given a value of 2/3 (Bruun, 1954; Dean, 2002)

Dean (1987) provided a tabulation for A as a function grain size and also expressed A as a function of fall velocity w

$A = 0.067\ w^{0.44}$ (Equation 2)

The GENESIS Technical Reference manual (Hanson and Kraus, 1989, p56) provided the following formulation for A:

$A = 0.41D_{50}^{0.94}$ for $D_{50} < 0.4$ mm (Equation 3)

where

D_{50} is median grain size

Figure 3.3 shows the equilibrium beach profile as a function of commonly encountered grain sizes for the NSW coast using the "Beach Morphology Analysis Package" (BMAP) from the US Army Corps of Engineers, which uses Equations 1 and 2 above.

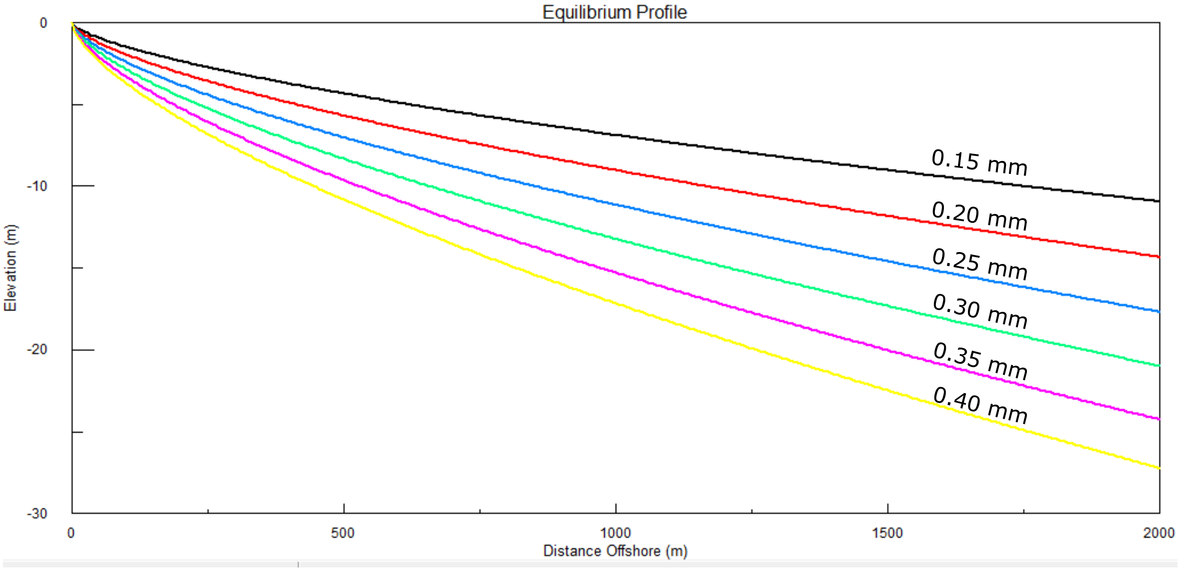
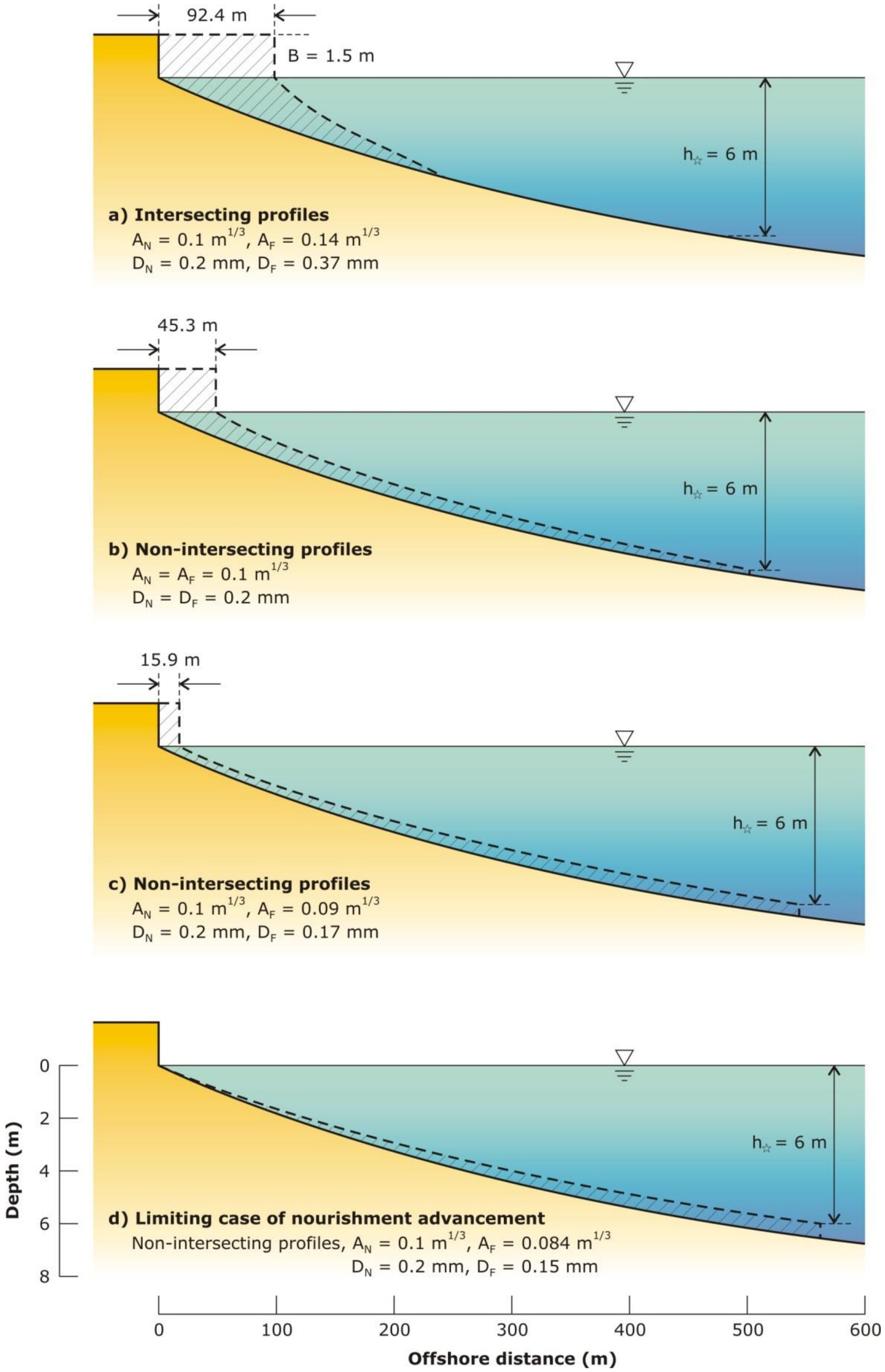


Figure 3.3: Equilibrium Profile for Various Sand Grain Sizes

3.2.5 Concept of Overfill Ratio

Figure 3.4 demonstrates the effect of different fill grain sizes on the equilibrium beach profile. If finer borrow sand is placed on a beach, then the equilibrium profile will be flatter than the natural profile and significantly more borrow sand is required to meet target nourishment volumes (compared with the requirements for nourishment with matching borrow and native sand). While most beach profiles are continually changing, the long term average for a given beach, and any changes to this, may influence the biodiversity, the beach type, surf safety, surfing conditions and wave runup

The overfill ratio R_A is a factor for the required volume of imported sand to make up an equivalent volume of native sand. CEM (2006, p V-4-24) recommends an overfill ratio of 1.0 to 1.05, or a range of D50 of ±0.02 mm. In practice, this may be unobtainable. Potentially feasible projects in Australia have had overfill ratios of 1.1 to 2.0 (AECOM, 2010) and even 2.85 (PBP, 2006).



(Based on CEM, 2002-2011 – Quantities shown are a generic example)

Figure 3.4: Effect of Nourishment Grain Size on Width of Dry Beach and Equilibrium Profile

3.2.6 Colour

All sand exhibits a darker colour when wet than when it is dry. Ideally, borrow sand should be of similar colour to the native beach sand. In practice, this may not be achievable, especially where the borrow sand is sourced from deeper water. Over time, darker borrow sand may lighten in colour due to bleaching and leaching by rain and the sun, wetting/drying and mixing with the native sand.

3.2.7 Other Criteria

Other criteria should be considered in the design of large projects.

Shape will influence fall velocity, with more rounded grains settling faster. Fluvial sand grains are generally more angular than marine sand grains, which are more rounded due to abrasion.

A faster **fall velocity** will result in a steeper equilibrium beach profile. While there are theoretical methods to compute fall velocity, equipment to measure it is not widely available in Australia, but could be commissioned (or samples sent overseas) for a large project.

4. Extraction, Transport and Placement

4.1 Overview

Extracting, transporting and placing sand may involve:

- Scraping with dozers or excavators;
- Bypassing and backpassing plants;
- Conventional excavation;
- Trucking;
- Dredging;
- Reshaping with dozers.

Dean (2002) provided the approximate daily volumes which can be moved by various dredges, as shown in Table 4.1.

Table 4.1: Approximate Average Pipeline Dredger Pumping Rates

Nominal discharge pipe size		**Average approximate daily discharge**
(inches)	(millimetres)	(m^3/day)
12	300	4,000
18	450	9,000
24	600	15,000
30	750	23,000
36	900	34,000

4.2 Beach Scraping

Beach scraping is detailed in Carley et al. (2010) and Gordon (2015). It involves the mechanical movement of small to medium quantities of sand from the intertidal zone to the upper beach and/or dune. It usually involves the use of dozers and/or excavators, with trucks utilised if alongshore distances of more than several hundred metres are required. An example is shown in Figure 4.1.

There is some argument as to whether beach scraping is actually a form of nourishment, since no sand is actually imported into the local system. Nevertheless, this report has included beach scraping as a variation on nourishment. Beach scraping is a simple, low cost method for restoring beach accesses following storms, raising low points in dunes, accelerating beach recovery, and for "buying time" during the development of more comprehensive management options. However, sustainable volumes limit its applicability to fairly small scale works and/or to offset only minor sea level rise. Some locations do not have sufficient sand reserves to undertake scraping.

(James Carley, WRL UNSW)

Figure 4.1: Example of Beach Scraping

4.3 Sand Transfer

A total of nine formal sand transfer systems are currently operating in Australia as shown in Figure 4.2. There are also numerous smaller scale informal truck-based operations. The two largest truck operations carried out on a semi-regular basis (i.e. 2-3 year intervals) take place in Adelaide and at Narrabeen in northern Sydney.

Until 2013, The Adelaide Living Beaches management program relied solely on a truck haulage system for transporting replenishment material, achieving unit rates of \$3 to \$4 per m^3 for haul distances of 2 to 3 km (sometimes directly along the beach) for annual quantities of the order of 40,000 m^3. Due to the large number of truck movements involved in the operation, the management authorities have been progressively reducing the need for truck haulage operations within Adelaide by installing a pipeline network to transport and deliver the sand material to the target beaches.

At Narrabeen, Warringah/Northern Beaches Council undertakes periodic removal of sand from Narrabeen Lagoon, and transports it 2 to 3 km south for placement on the beach. The removal is primarily for flood hazard reduction on the lagoon foreshore. The 2006 beach replenishment campaign involved 45,000 m^3 over 5 months at a cost of \$19 per m^3. The higher unit cost is due to excavating sand in an intertidal estuary entrance zone and trucking along a major arterial road with restricted haulage times and difficult truck manoeuvring.

Sand transfer is specifically limited to sites where an accepted surplus of sand is available (e.g. navigation channels or training walls on a littoral drift coast) to transfer to a location where additional sand is desired. While sand transfer may occur as occasional dredging, bypass plants involve a commitment to long term funding. The available quantities are therefore limited to the available surplus.

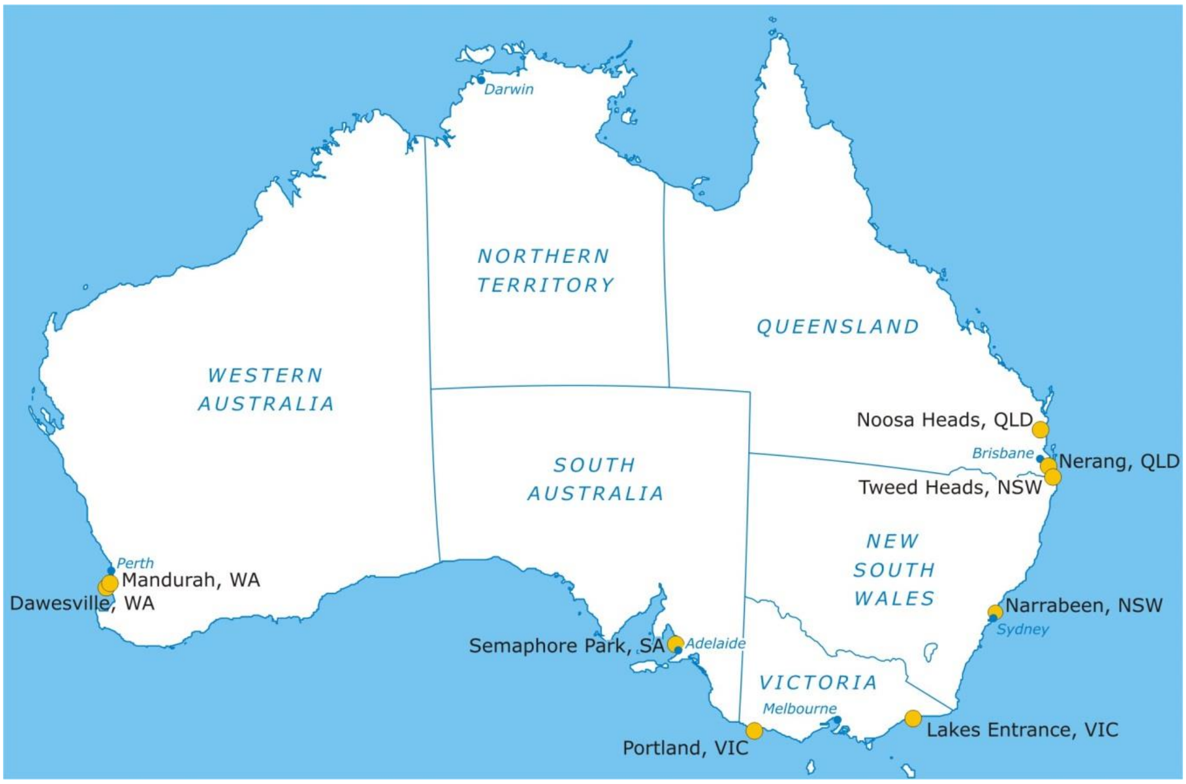


Figure 4.2: Locations of Sand Transfer Projects in use in Australia

4.4 Dredging

Dean (2002) noted that more than 95% of all sand placed in beach nourishment projects uses offshore dredging. Due to the efficiencies that can be achieved through large scale dredging operations, the unit costs are generally lower than by other approaches.

This is the only method which may be viable to offset the impacts of extreme erosion events and sea level rise of up to 0.9 m for large extents of coastline, such as the entire Sydney metropolitan coast (Gordon, 2009).

Large scale nourishment involves a large financial commitment, and usually an additional commitment to future nourishment campaigns. Most projects would require a large international dredger with high mobilisation costs. These costs could be best amortised by undertaking nourishment at more than one location, however, this then introduces additional complexities in the coordination of various jurisdictions, and may alter the economics and viability of nourishment as an option.

Numerous small scale dredging projects are undertaken in NSW using Australian-based dredgers (Section 8).

4.4.1 Types of Dredgers

There are numerous types of dredges/dredgers (Figure 4.3, Figure 4.4), each of which has specific local availability and suitability to project size, dredged material, water depth, transport distance and wave conditions. Only dredging equipment suitable for sand is discussed in this report.

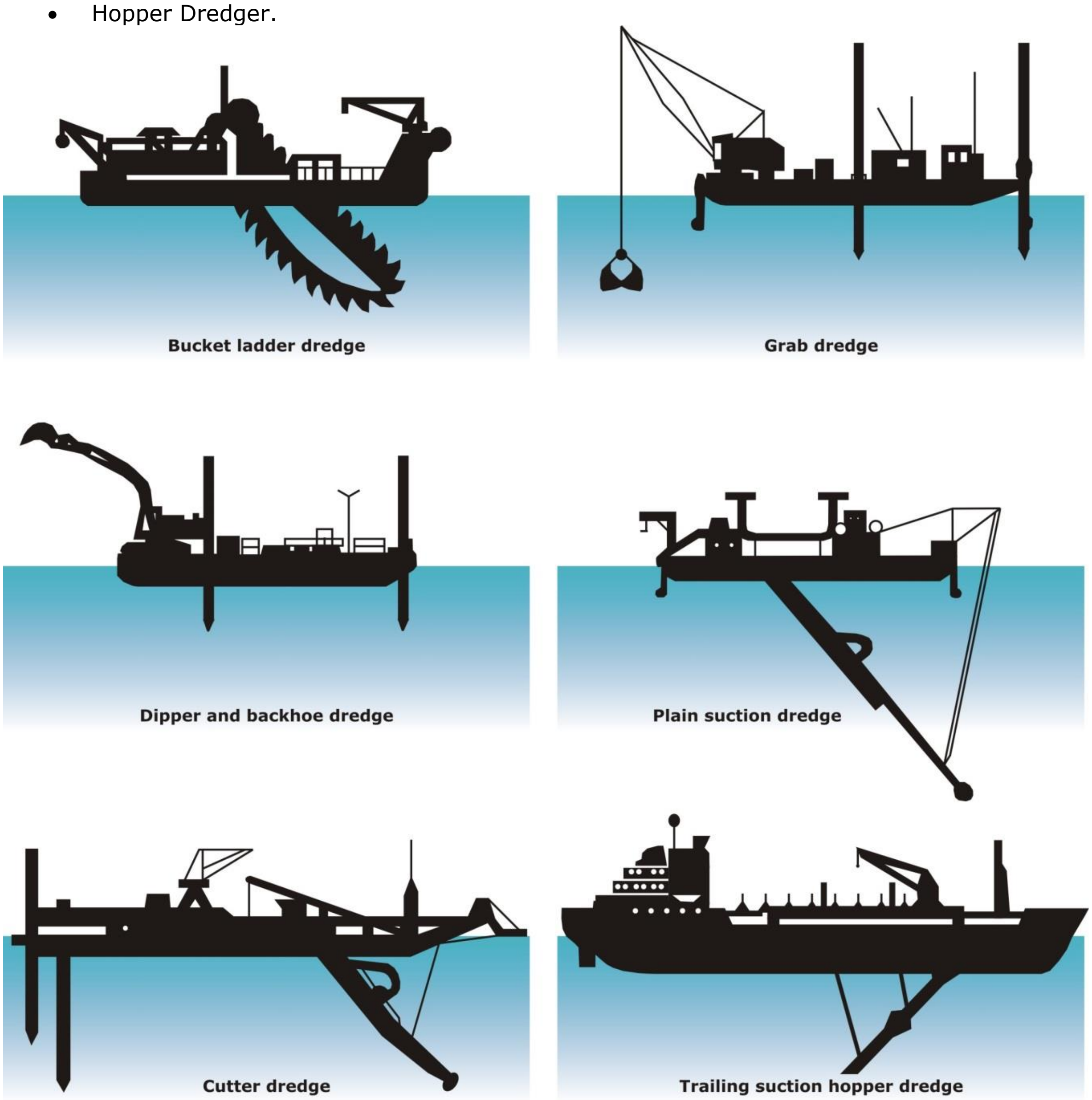
Dredgers may be either mechanical or hydraulic in their extraction of sand (Figure 4.3).

Mechanical dredges include:

- Bucket Dredger;
- Grab Dredger;
- Backhoe Dredger.

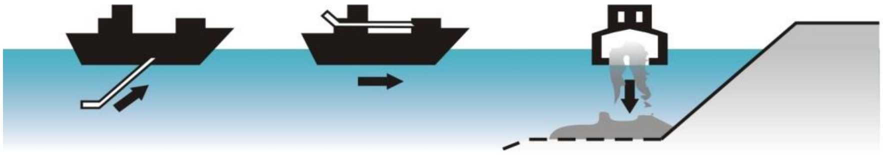
Hydraulic dredges include:

- Suction Dredger;
- Cutter Dredger;
- Trailing Dredger;
- Hopper Dredger.

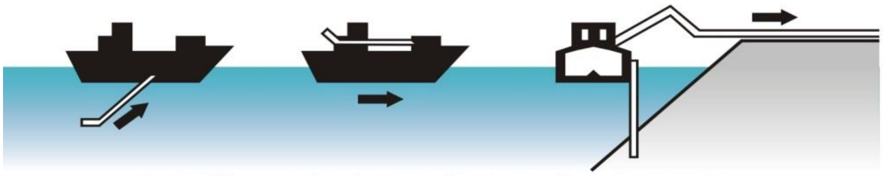


(Based on Vasblom, 2003)

Figure 4.3: Types of Dredgers

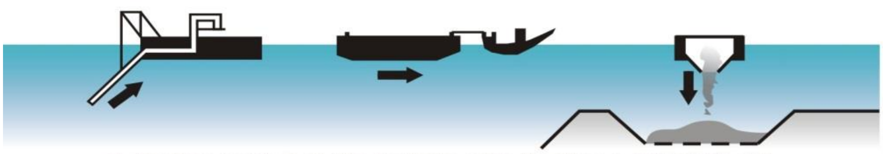


a. Direct dumping in the nearshore zone with hopper dredgers or barges

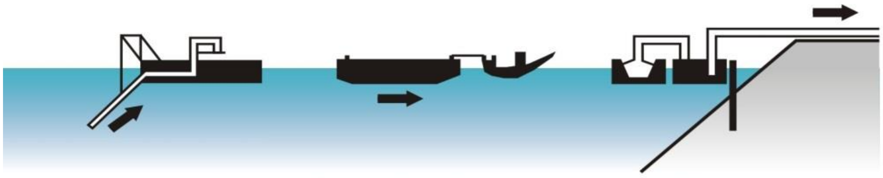


b. Trailing suction hopper dredgers directly pumping through a pipeline to the beach

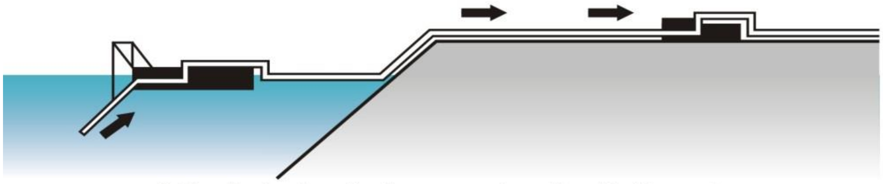
c. Trailing suction hopper dredger feeding a rehandle pit, offshore or in sheltered waters



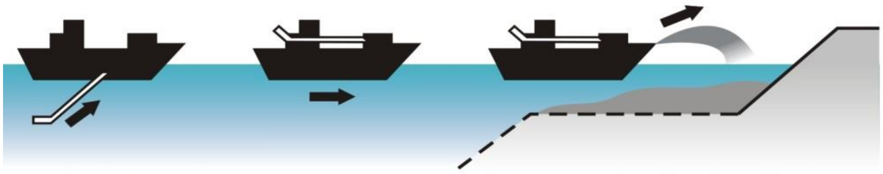
d. Barges loaded at the borrow area feeding a rehandle pit, offshore or in sheltered waters



e. Barges loaded at the borrow area and emptied by a reclamation dredger



f. Sand winning dredger pumping directly through a pipeline to the beach zone



g. Trailing suction hopper dredger pumping via nozzle placed on the bow (Rainbow system)

(Based on: Manual on artificial beach nourishment, 1987)

Figure 4.4: Some Methods of Undertaking Dredger Nourishment

Vasblom (2003) presented dredger type capability for a range of situations, including clay, rock and contaminated sediments. The suitability and capability for situations relevant to sandy beach nourishment are shown in Table 4.2. Further information regarding dredgers most suitable for offshore sand extraction is provided below.

Table 4.2: Suitability and Capability of Different Types of Dredgers

(Extract from Vasblom, 2003; Dean, 2002; AECOM, 2010; Pro Dredging, 2013)

	Bucket Dredger	**Grab Dredger**	**Backhoe Dredger**	**Suction Dredger**	**Cutter Dredger**	**Trailing Dredger**	**Hopper Dredger**
Sizes	0.03-1.2 m^3 bucket	1-200 m^3 bucket	1-20 m^3 bucket				300 to 33,000 m^3 hopper
Dredging sandy materials	yes	yes	yes	yes	yes	yes	yes
Anchoring wires	yes	no	yes	no	yes	no	no
Max dredge depth (m)	30	>100	20	70	25	100	50
Accurate dredging	yes	no	yes	no	yes	no	no
Offshore dredging	no	yes	no	yes	no	yes	yes
Pipeline transport	no	no	no	yes	yes	no	no
Operating wave height				1-1.2 m	1-1.2 m	2 m	2 m

The means of transporting sand from the extraction to placement sites can be classified as:

- Pipeline dredges;
- Hopper dredges (which sometimes connect with nearshore pipeline dredges).

4.4.2 *Trailing Suction Hopper Dredgers*

Offshore sand extraction is most likely to be undertaken by a trailing suction hopper dredger (TSHD; Figure 4.5).

This class can be further separated into:

- Large Vessels (6,000 m^3 to 12,000 m^3 capacity);
- Medium Vessels (3,750 m^3 to 6,000 m^3 capacity);
- Small Vessels (<3,750 m^3 capacity).

Hopper dredgers are basically vessels equipped with dredge pumps and 'drag' arms that extend over one or both sides of the vessel, down to the sea floor. These arms remove material from the sea floor and pump the slurry up through the arms, into the ship hull. This process is carried out while the ship is moving at approximately 2 to 3 knots. Once the ship hopper is filled to capacity the ship moves near the beach nourishment area where it has several options for discharging. It can either drop the material to the sea floor through hopper doors (Figure 4.6), pump the material out through a pipeline up onto the beach or by using the 'rainbow' method (Figure 4.7), discharging the slurry by a jet with the bow of the hopper dredger brought as close to the shore as is practicable.

Rainbowed sand can be placed into the nearshore surf zone for distribution over the active profile by waves or pumped to spill piles on the beach for distribution by bulldozer.

Due to the high cost of the equipment involved, subject to wave conditions, the operation often takes place seven days a week, 24 hours per day. The characteristics of a range of trailing suction hopper dredges, both international and based in Australia, are shown in Table 4.3.

Table 4.3: Capacities of Some Trailing Suction Hopper Dredgers

(Source: PBP, 2006; AECOM, 2010; Pro Dredging, 2013. Owner/vessel names may have changed)

Vessel	Owner	Hopper (m^3)	Draft loaded (m max)	Placement depth (m min)	Pump ashore	Pump dist. (m)	Dredge depth (m max)
International (not exhaustive)							
Geopotes 14	Van Oord	5,020	8.64				
Volvox Delta	Van Oord	5,974	9.12				
Ham316	Van Oord	6,685	9.05				
Geopotes 15	Van Oord	6,680	9.07				
Volvox Asia	Van Oord	8,283	9.45				
Al-Idrisi	Jan De Nul	6,210	8.15				
Vitus Bering	Jan De Nul	6,210	8.15				
Alexander Van Humbolt	Jan De Nul	7,400	8.45				
Cornelius Zanen	Boskalis	8,530	8.85	12	Yes	3,000	51
Cornelia	Boskalis	3,941	7.45				
Cornelia Anen	Boskalis	6,716	8.83				
Barent Zanen	Boskalis	6,728	8.81				
Delta Queen	Boskalis	6,051	9.26				
Willem van Dranje	Boskalis	11,000	10				
Gateway	Boskalis	11,000	10				
Lelystad	ACZ	10,311	8.19	12	Yes	3,000	50
Filippo Brunelleschi	Jan de Nul	11,300	9.1				38.0/57.5/77.0
Francis Beaufort	Jan de Nul	11,300	9.1				38.0/57.5/77.0
James Cook	Jan de Nul	11,300	9.7				38.0/49.0/77.0
Juan Sebastian de Elcano	Jan de Nul	16,500	11.1				40.5/54.5
Seaway	Boskalis	13,200	10.6				57
Lange Wapper	Dredging International	13,700	9.8				28/41/50
Uylenspiegel	Dredeco	13,000	9.45	12.5	Yes	3,000	41/50
Nile River	Dredeco	17,000	10.56	14	Yes	3,000	40
Pearl River	Dredging International	24,100	10.6				30/60/120
Australia/NZ							
Port of Brisbane	PoBC	2,900	6.25	8	Yes	1,500	25
Volvox Anglia	ACZ	1,202	3.62	6	Yes	1,250	18
Pelican	ACZ	965	3.71	6	Yes	900	20
Kawatiri	Westport NZ	635	4.1	6	No	n/a	12
New Era	Otago NZ	635	3.62	6	No	n/a	12
Port Frederick	McQuade	450	3.6	6	No	n/a	10
Faucon	McQuade	320	3.1	5	No	n/a	10

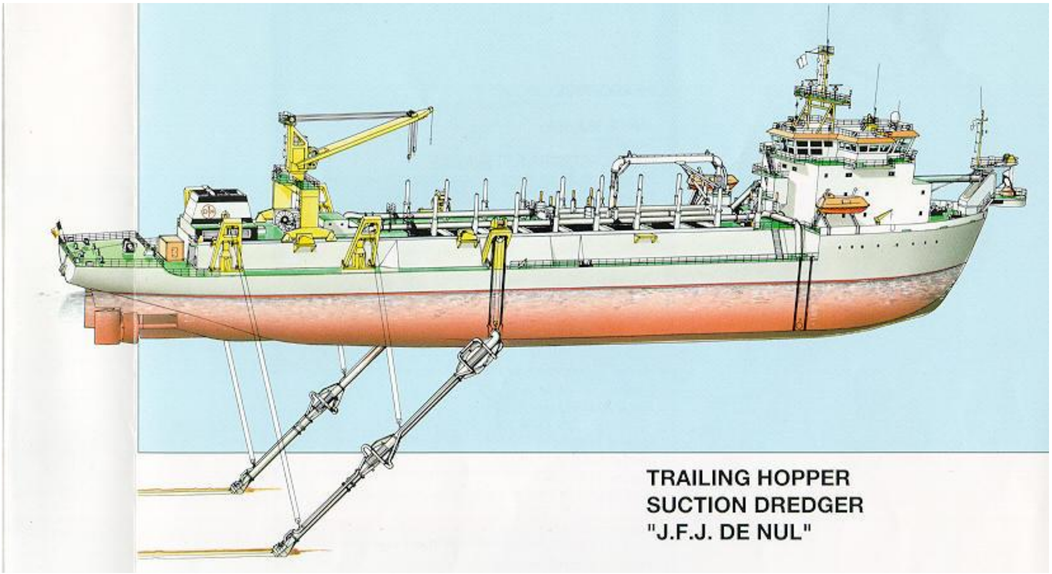


Figure 4.5: Trailing Suction Hopper Dredger (Jan de Nul Group)

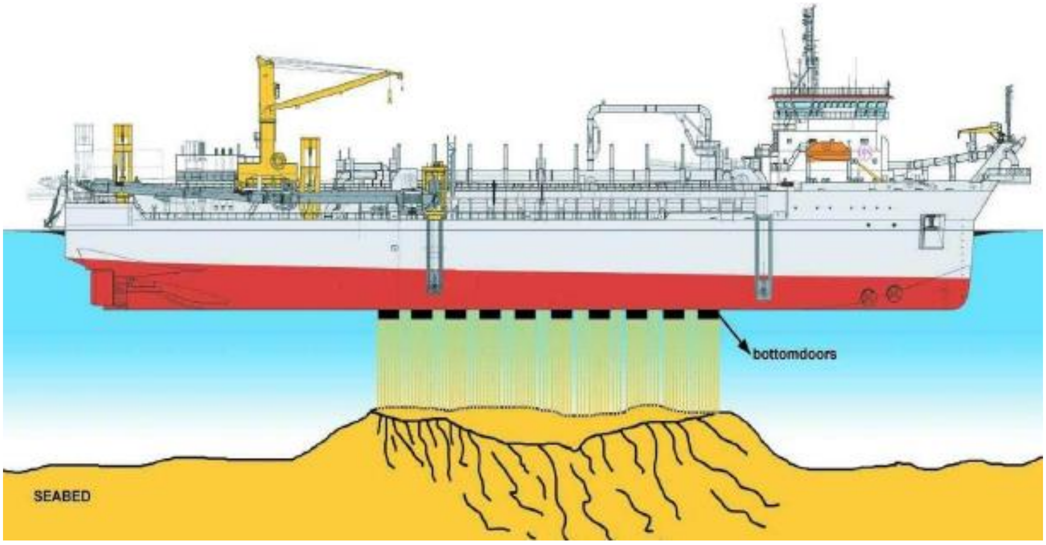


Figure 4.6: Trailing Suction Hopper Dredger Bottom Placement (Jan de Nul Group)

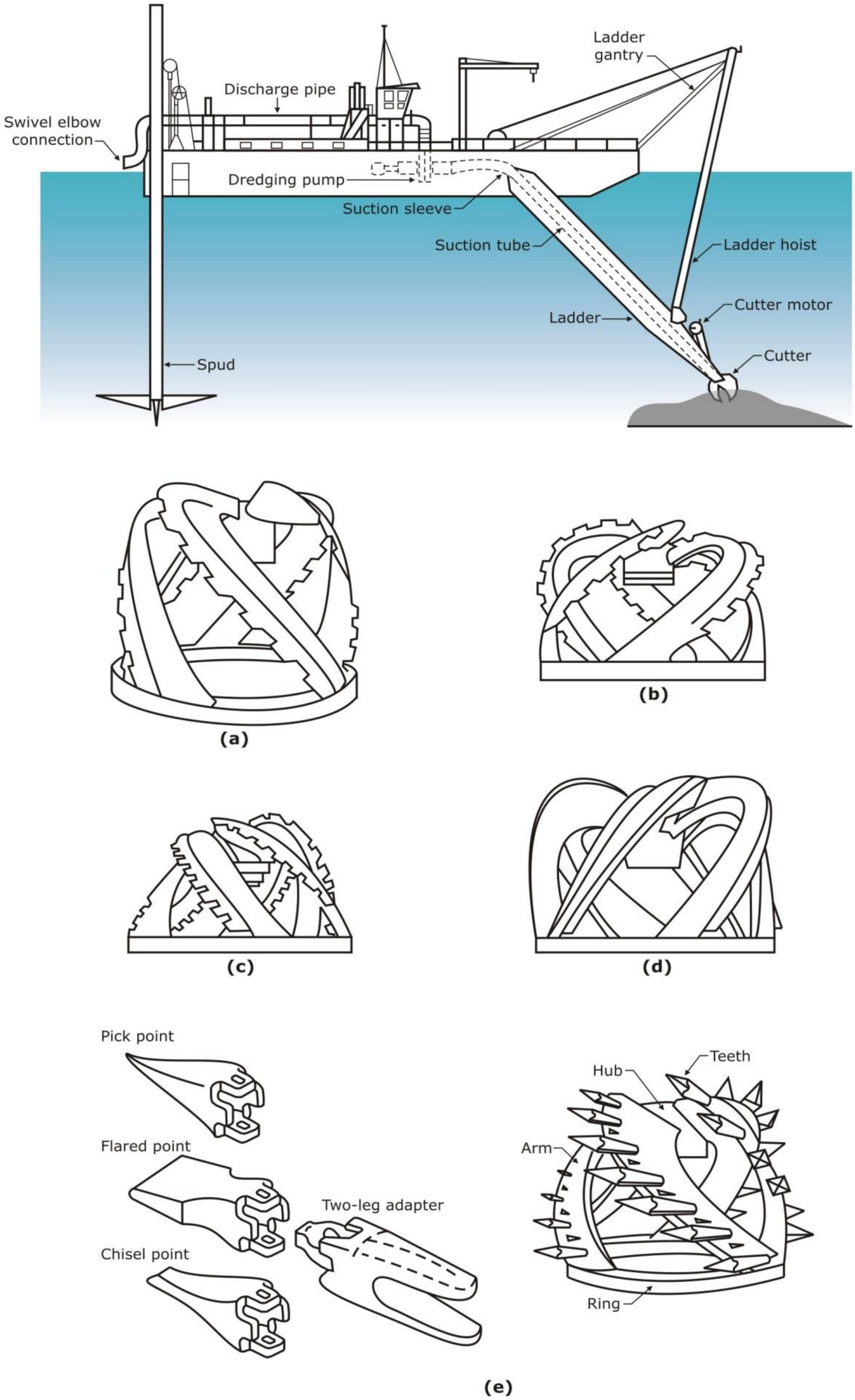
Figure 4.7: Trailing Suction Hopper Dredger Rainbowing (Van Oord Australia)

4.4.3 Pipeline Dredgers

Pipeline dredgers transport their sand slurry from the extraction site by means of a pipeline. The dredger consists of a floating barge and a 'ladder' which is mounted at the bow of the barge. The ladder supports the intake pipe and is articulated vertically so that it can move up and down thereby accessing the borrow area. The sand/water mixture (slurry) is carried up to the barge where the main pump creates enough pressure to move the slurry mixture through a pipeline to the nourishment location.

Additionally, pipeline dredgers can be classified as 'cutter head' and/or 'suction head' dredgers. Suction head dredgers are the most effective for very mobile, fine sediments.

Cutter head dredgers include a rotating feature called a 'cutter head' at the lower end of the intake pipe. This is equipped with steel teeth or blades which mobilise the sediments, enhancing the flow of sediments into the pipe (Dean, 2002). The principles behind a cutter suction dredger are illustrated in Figure 4.8. These vessels are generally classified as small (<3,200 m^3/day output).



(Based on Bray, 1979)

Figure 4.8: Cutter Suction Dredger

4.5 Placement Geometry

Sand may be placed in the following positions/configurations (Figure 4.9, modified from Smith and Jackson, 1990):

- Dune zone;
- Visible beach;
- Swash and wave zone;
- Full profile nourishment (distributed nearshore);
- Offshore berm bar; and
- Subaqueous.

The placement method is somewhat dependent on the extraction method, or may require the incorporation of additional steps at additional expense.

4.5.1 Dune Zone

The purpose of this method is to build up the sand reserves or strengthen existing dunes against future storms. For small scale projects this may simply involve raising low points in the dune to prevent overtopping or breaches, or to reform beach access ways following storm events.

4.5.2 Visible Beach

This method aims to broaden and steepen the existing beach zone with the maximum visual impact. However, this may rapidly erode in the first storm, with public perceptions of failure.

4.5.3 Swash and Wave Zone

The objective is to widen the visible beach by moving the wave breaking zone seaward. The "losses" occur slowly and in a manner more consistent with a natural beach.

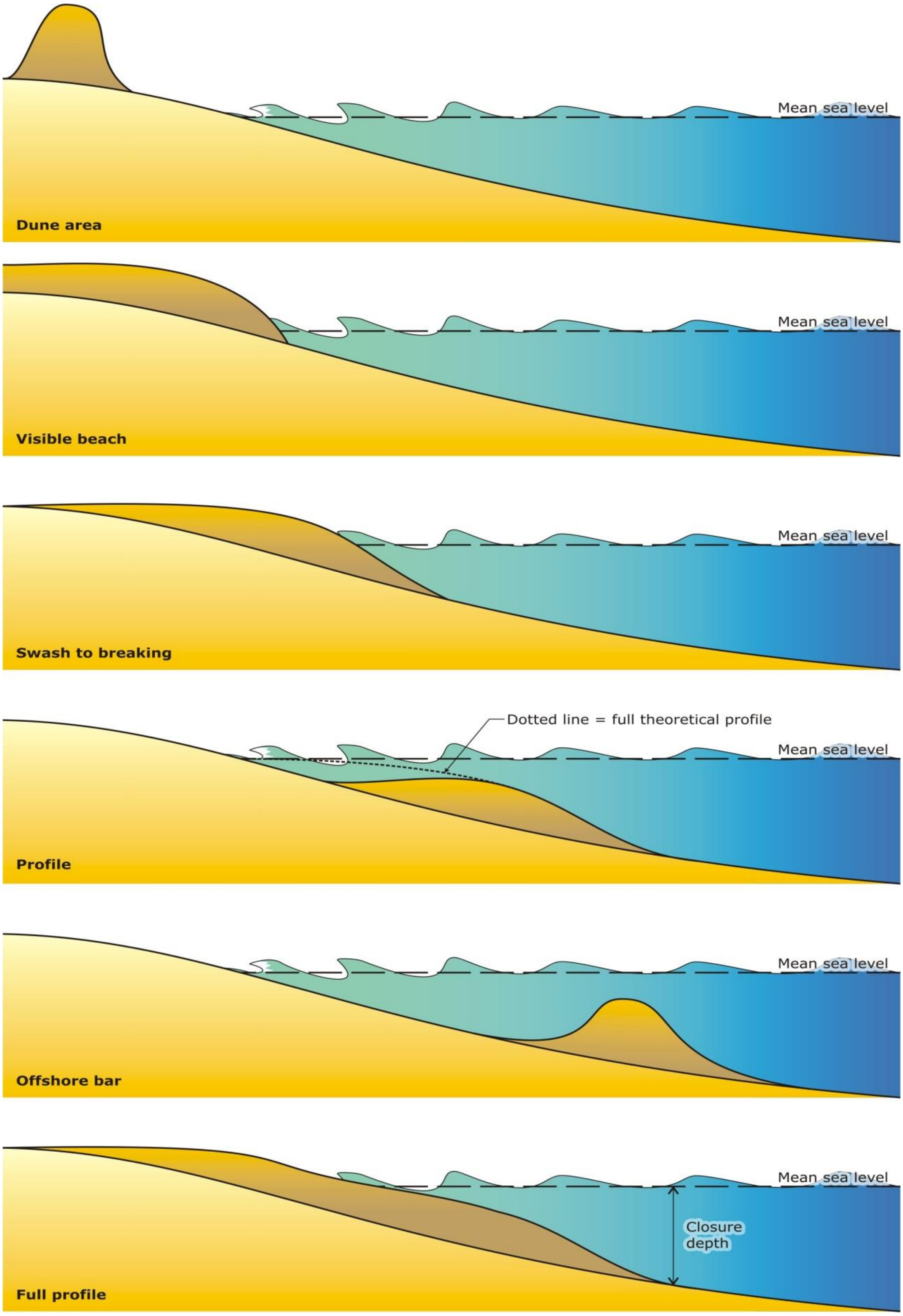
4.5.4 Full Profile Nourishment (Distributed Nearshore)

This method is sometimes referred to as "profile nourishment" and is aimed at placing the sand in a stable configuration. The drawbacks are that it is more expensive to place and requires specialised plant.

4.5.5 Offshore Berm Bar

The aim of this method is to place the beach fill in 6 m to 10 m of water to form an artificial storm bar and emulate a natural storm bar formation. If a storm arrives soon after beach nourishment, wave break may be triggered and thereby help protect the coast. However, if no storm arrives, the waves will redistribute the sand onshore. This placement location is generally not viewed favourably by the public due to the small perceived change.

Recent trials have been undertaken with placement in shallower water (2 to 5 m deep) to provide enhanced sand banks for surfing (the "sand slug") at Cronulla. This could be termed configuration placement. While careful shaping would involve higher costs, offshore placement can be undertaken with less equipment.



(Modified from Smith and Jackson, 1990)

Figure 4.9: Alternative Beach Fill Placement Locations

4.5.6 Depth Limitations on Dredger Placement

Figure 4.10 (after Corbett and Salyer, 2014 and Pro Dredging, 2013) shows potential placement zones for a range of dredger types.

Figure 4.10: Placement Depths for Various Dredger Sizes (Corbett and Salyer, 2014)

4.6 Longevity and Maintenance

Nourishment sand may be moved from the project area through cross shore processes, alongshore processes or currents (e.g. estuary mouths or rips). Each project needs specific analysis, however, some broad tendencies exist on the NSW coast.

Net northward littoral drift generally prevails on the NSW coast north of about Newcastle (Section 2.5; Mariani et al., 2013; Gordon, 1987), which will generally transport nourishment sand northward over the longer term. This does not necessarily make nourishment unfeasible, but rather may reduce the life of the nourishment in the project area and increase the desired renourishment frequency, which needs to be considered in assessing a project.

South of about Newcastle, most coastal embayments are reasonably closed littoral compartments between headlands, so nourishment sand is more likely to remain within the compartment, notwithstanding transport into estuaries. It is feasible and common to nourish portions of coastal compartments, however, alongshore losses of sand from the project area will be greater. Nevertheless, this may still be more economical than nourishing the entire compartment.

For nourishment schemes undertaken by dredging in the USA and Netherlands, typical renourishment frequencies are 5 to 10 years (Verhagen, 1992; Kraus et al., 1998), however, longer lives may prevail with compatible sand in closed compartments. Bypassing plants on littoral drift coasts operate semi-continuously subject to wave conditions. Specific project design is needed to determine the expected nourishment longevity and any required renourishment frequency.

5. Environmental Impacts

Environmental impacts can be classified as:

- Physical, which may include:
    - Changes to wave refraction;
    - Beach impacts;
    - Burial of shipwrecks and reefs.

- Ecological, which may include:
    - Burial of reefs;
    - Disturbance of habitats.

Much of the literature on impacts is generic or international. Limited studies or investigations have been undertaken to date which are specific to NSW beaches and their unique ecology.

5.1 Ecological Impacts

Dean (2002) suggested ecological impacts can be divided into short-term and long-term impacts. Short-term impacts may include:

- Direct burial of the creatures that reside in the area;
- Lethal or damaging doses of turbidity; and
- Direct effects of equipment used in the beach nourishment process.

Long-term impacts may include:

- Beaches that are altered in their natural state;
- A long-term source of turbidity affecting light penetration; and
- Altered sediment compositions which may affect the types of biota of the area.

There are three specific beach sections that are likely to be impacted by a beach nourishment project involving dredging (Committee on Beach Nourishment and Protection, 1995). Potential impacts differ in each of the three zones. The three zones outlined below are:

- The subaerial beach;
- The sub-tidal beach
- The borrow source areas.

Careful project design can assist recolonisation in extraction and placement areas. The generally aggressive environment in the surf zone means that with appropriate design studies and placement configuration, the placement of nourishment sand may be less ecologically disruptive than normal surf zone processes (Dean, 2002). Large placement depths over large areas may create higher disruption.

5.1.1 Subaerial Beach Impacts

The subaerial beach comprises two components: the supralittoral (dry) portion of the beach and the intertidal zone. As a purpose of beach nourishment may be to increase the volume of sand in this area, substantial amounts of nourishment sand is added to these sections of the beach. Obvious positive impacts of a beach nourishment program on the subaerial beach include protection of coastal property and infrastructure and improvement of the beach for recreational purposes.

Possible negative ecological impacts include:

- Disturbance of the indigenous biota inhabiting the subaerial zones, in turn possibly affecting the foraging patterns of the species that feed on those organisms; and
- Disruption to species that use subaerial beach habitats or adjacent areas for nesting, nursing and breeding areas (Committee on Beach Nourishment and Protection, 1995).

Several studies have shown that even when beach-compatible materials are used, the nourished beach may be physically altered when compared to unnourished beaches with respect to sand compaction, shear resistance, moisture content, grain size and shape, and other factors (Committee on Beach Nourishment and Protection, 1995).

5.1.2 Sub-tidal Beach Impacts

Aquatic habitats adjacent to the subaerial beach, in the near shore zone, are affected by beach nourishment projects through nourishment of the active profile. These areas often support a diverse array of biota.

Ecological consequences of beach nourishment projects can include:

- Burial of habitats in the surf zone as the beach is widened;
- Increased sedimentation in areas seaward of the surf zone as the fill material redistributes to a more stable profile;
- Changes in the near shore bathymetry and associated changes in wave action; and
- Elevated turbidity levels, particularly in the vicinity of pipeline effluent (Committee on Beach Nourishment and Protection, 1995).

Movement of sediment away from the designated nourishment area can have both beneficial and detrimental effects. Littoral drift may benefit beaches adjacent to the nourishment area by providing additional sand material. However, it may also have adverse effects on neighbouring vulnerable communities.

Biological effects resulting from alteration of the near shore zone have not been well documented (Committee on Beach Nourishment and Protection, 1995). However, mobile invertebrates and fishes found in this region should be able to avoid the major direct effects of beach nourishment. Surveys of fish populations off a nourished beach in Florida showed no evidence of adverse effects to the fish (Committee on Beach Nourishment and Protection, 1995). It has been suggested that hard-bottom reef habitats or seagrass beds, may be the most adversely affected by elevated turbidity surrounding beach nourishment. High turbidity and silt loads in these environments can smother organisms, inhibit filter-feeding processes and/or significantly decrease photosynthetic activity, potentially resulting in long-term damage to these resources (Courtenay et al., 1974; 1980; Goldberg, 1989).

Surfing, wave breaking, beach safety and rips may all be altered by the introduction of additional sand into the surf zone.

5.1.3 Borrow Area

The primary biological effect of dredging to obtain beach nourishment material is removing benthic vegetation and creatures present on the sediments. The area and magnitude of impacts are dependent on the extraction method adopted (Section 4). These impacts can be reduced by careful design of the dredging configuration, such as a chequerboard pattern, which allows more rapid recolonization.

Dredging can also increase turbidity in the borrow area. There is the potential for deep holes in tranquil areas to alter water quality, potentially decreasing dissolved oxygen levels or increasing hydrogen sulphide levels. However, this is less likely to occur on the open coast. Dredging operations have also been known to damage reef habitats in areas adjacent to the borrow area when buffer zones have been inadequate (Grober, 1992). However, with adequate buffer zones and the use of accurate positioning systems this can be avoided.

Noise, increased ship movements and potential spills may adversely impact fish and marine mammals.

There is potential for contamination of sediment from heavy metals or other contaminants when sand is sourced from the seabed or contamination from weeds when sourced terrestrially. Test samples from the borrow source area are required to confirm the presence (or absence) of heavy metals and other contaminants.

Regular monitoring of the beach, revegetation, and removal of any weeds following completion of the nourishment program will reduce ecological impact from terrestrial sand.

5.2 Impacts and Limitations Specific to Nourishment Methods

5.2.1 Beach Scraping

Beach scraping may cause changes to nearshore bathymetry and changed banks for surfing. It is uncertain whether this change would be positive or negative, and may be difficult to attribute to the scraping within a dynamic high energy system.

As stated above, beach scraping has been undertaken regularly at New Brighton, NSW. Environmental monitoring of beach scraping has been reported in Smith et al., (2011), who could find no negative ecological impacts. As with sand nourishment, it has been postulated that this is because of the aggressive environment present within the surf zone and the relatively small extraction and deposition zone.

The operation of machinery will have noise and air pollution impacts.

5.2.2 Sand Transfer

Extraction below the water may cause local deepening which may cause additional hazard for swimmers. It may alter the sand banks for surfing, however, there are insufficient cases and high uncertainty as to whether this would be positive or negative.

There is usually increased turbidity at deposition sites.

The use of trucks for sand transfer has negative community impacts, but these may be justifiable for trial or intermittent sand transfer projects. The operation of machinery will also have noise and air pollution impacts.

Beach nourishment operations can disrupt existing biological communities both above and below the waterline. Placement of large quantities of sediment within the near shore zone, as is the case with beach nourishment, can have substantial effects on the biota residing in this area. Additionally, dredging of material for fill placement will also have ecological impacts. However, the active beach zone is dynamic, with the seasonal relocation of large quantities of sand from portions of the subaerial beach and near shore zone. Subsequently the animals residing in this region tend to be well-adapted to highly dynamic conditions (Dean, 2002).

5.2.3 Large Scale Nourishment

If sand is extracted in an unfavourable configuration or water depth, incident waves reaching the beach may be altered and consequently change the shoreline. This can be avoided with appropriate project design studies to determine a benign extraction pattern and depth.

There is usually increased turbidity at both the extraction and deposition sites, however, recent advances in dredging technology can reduce turbidity to acceptable levels.

Organisms living in the extraction zone may be killed, while organisms living in the placement zone may be buried, however, these impacts can be reduced through careful project design such as chequerboard extraction patterns which allow recolonisation. While sandy foreshores are generally perceived positively, placed sand may bury nearshore reefs or archaeological relics such as shipwrecks.

6. Costing and Economics

6.1 Costing

6.1.1 Overview of Costing

For projects involving large dredges, the upfront cost is strongly determined by the mobilisation proximity. Substantial savings or premiums are possible depending on the travel distance for the dredge.

As a guide, all-inclusive unit rates for placed nourishment sand range from \$5 to \$50 per cubic metre in Australia. If a single rate is required, the following are typical plausible estimates:

- Beach scraping: \$5 per cubic metre;
- Sand bypassing: \$10 per cubic metre;
- Dredging offshore: \$20 per cubic metre (noting that costs could be as high as \$50 cubic metre)

6.1.2 Reported Costs on NSW Projects

Moses and Ling (2010) reported indicative costs for a range of projects administered by the then Land and Property Management Authority. These costs are generally for dredging of navigation channels, and do not necessarily include additional transport, placement and shaping costs for beach nourishment, however, Moses and Ling presented other scenarios for this.

They classified projects into three size and cost categories, namely:

- Major: 60,000 m^3: \$10 to \$13 per cubic metre;
- Medium: 30,000 m^3: \$13 to \$17 per cubic metre;
- Minor: 20,000 m^3: \$15 to \$20 per cubic metre.

Within scenarios for cost sharing and value adding, Moses and Ling (2010) also presented indicative unit rates for components of dredging and nourishment. These included:

- Dredge and load barges: \$3 per cubic metre;
- Deliver to stockpile and unload: \$3 per cubic metre;
- Load and transport for offsite disposal: \$5 per cubic metre;
- Final shaping to surrounding profile: \$2 per cubic metre.

If the dredged sand was to be sold, they estimated revenue of \$3 per cubic metre.

6.1.3 Mobilisation Costs

For large projects and/or those requiring sand extraction in deep water, the mobilisation/demobilisation costs for a large international dredger will be a significant component. AECOM (2010) estimated these to be \$15 million for a hypothetical Sydney project. PBP (2006) estimated these to be \$4 million in a feasibility study for Byron Bay. Substantial savings would be possible if the international component could be shared between multiple domestic projects.

Pro Dredging (2013) estimated the following mobilisation/demobilisation costs for the Gold Coast, with the international vessels travelling from Singapore:

- Small TSHD (475 m^3) Bottom dumping: $60,000

- Medium TSHD (5,800 m^3):
  - Bottom dumping: $3.8 million
  - Rainbowing: $3.8 million
  - Pump ashore: $4.9 million

- Large TSHD (11,600 m^3):
  - Bottom dumping: $5.6 million
  - Rainbowing: $5.6 million
  - Pump ashore: $6.7 million

6.1.4 Factors Affecting Costing

CIRIA (1996) listed the following factors as affecting nourishment costs:

- Project size and consequent economies of scale
- Bathymetry of borrow area and site – determinant of dredger size
- Distance between dredge and target sites
- Recharge material – coarser material causes greater equipment wear and tear which is likely to be passed on to customers
- Estimated material losses
- Availability (and size) of dredgers
- Degree of site exposure – determinant of type of dredger to be used
- Third party requirements

6.1.5 International Cost Comparisons

IPCC CZMS (1990) published unit rates for a range of coastal adaptation options including sand nourishment. They provided cost factor for all coastal nations relative to an index of 1.0 for the Netherlands. For sand nourishment, the cost factor ranged globally from 0.8 to 2.0, with Australia having a cost factor of 1.5.

IPCC CZMS (1990) reported sand nourishment costs in 2009 US dollars (Linham et al., 2010) of: US$4.21 to 8.43 per m^3. WRL indexed these to 2016 (108.6/92.9), Australian dollars (1/0.75) and multiplied them by the Australian cost factor (1.5). This gives approximate rates of:

- AUD$10 to 20 per m^3.

Linham et al., (2010) undertook a worldwide survey of beach nourishment costs, primarily in developed countries. They also considered work in the IPCC CZMS (1990) and indexed the 1990 values to 2009 dollars. Through extensive research, for ten developed countries (Australia, France, Germany, Italy, Netherlands, New Zealand, South Africa, Spain, UK, USA), they found that actual beach nourishment costs varied from 2009 US$3.0 to US$73 per m^3.

Isolated high costs were from shingle nourishment in the UK, and some locations in New Zealand where no dredge sites were available and beach managers were compelled to pay the same market rate as for construction sand. Where dredge sites for sand were available, Linham et al. found more reasonable New Zealand costs of 1990 US$8.80 per m^3.

Linham et al. found that the average nourishment costs in the ten countries analysed ranged from 2010 US$4.09 to US$7.40 per m^3. This equates to 2016 AU$6.40 to $11.50 per m^3. This range is lower, but broadly consistent with the typical Australian values presented above.

6.2 Economics

As stated above, nourishment projects may be undertaken for erosion protection or to enhance beach amenity. A project is considered to be economically viable if its net present value (NPV) exceeds zero and/or of its benefit-cost ratio exceeds 1.

6.2.1 Australian Examples

AECOM (2010) estimated the following benefit to cost ratios for hypothetical beach nourishment case studies in NSW undertaken for the Sydney Coastal Councils Group.

For Collaroy-Narrabeen a net present value of $42M and a benefit-cost ratio of 1.6.

The main quantified benefits for Collaroy-Narrabeen were the avoided loss of:

- Residential property values attributable to beach amenity (45% of total quantified benefits).
- Value of residential properties located within hazard lines (38%).
- Expenditure by beach visitors (8%).
- Rates revenue from residential property values within walking distance of the beach as a result of lower property values (4%).

For Manly Ocean Beach a net present value of $48M and a benefit-cost ratio of 2.4.

The main quantified benefits for Manly Ocean Beach were the avoided loss of:

- Residential property values attributable to beach amenity (49% of total quantified benefits).
- Expenditure by beach visitors (23%).
- Rates revenue from businesses in the Manly Business District as a result of lower property values (13%).
- Non-traded value (consumer surplus) associated with beach visits (9%).

For Bate Bay (Cronulla), a net present value of $13M and a benefit-cost ratio of 1.2.

The main quantified benefits for Bate Bay, Cronulla were the avoided loss of:

- Residential property values attributable to beach amenity (73% of total quantified benefits).
- Expenditure by beach visitors (13%).
- Rates revenue from residential property values within walking distance of the beach as a result of lower property values (5%).
- Non-traded value (consumer surplus) associated with beach visits (5%).

6.2.2 USA Examples

Dean (2002) noted that economic benefits can be in the form of:

- Storm protection;
- Property value increase;
- Recreational benefits.

Dean presented examples from the USA for which these benefits arising from beach nourishment exceeded the cost of nourishment. Secondary benefits included increased government revenue from property rates/taxes, which extended into improved schools in some areas.

6.3 Cost Sharing

Projects involving dredging and/or nourishment may have multiple beneficiaries and opportunities for cost sharing, which could result in individual parties spending less than the gross amounts stated in this report.

Examples include a dredging project where navigation is improved, with the dredged sand being used for beach nourishment. In some states in the USA, beachfront home owners who construct seawalls are required to contribute towards beach nourishment, based on an explicit formula which considers the volume of sand their seawall is locking up (Dean, 1986; Lester, 2014). Schemes have been postulated whereby offshore commercial sand extraction for industry is allowed in exchange for providing a proportion of the extracted sand for beach nourishment.

7. Monitoring

7.1 Overview

Monitoring will involve both physical and ecological components. The scope of monitoring needs to be tailored to the scale of the project. Advances in remote sensing and computing means that monitoring can increasingly be undertaken to a higher standard at lower cost (Turner et al., 2016). Establishing an appropriate monitoring program is an important component of project design and approvals.

7.2 Physical Monitoring

Physical monitoring involves measuring a nourished area to ascertain its physical performance against predictions and any thresholds which may trigger further adaptive actions. Recent work on monitoring includes (Turner et al., 2016) and Harley et al., (2007).

Available methods include:

- Aerial photos and photogrammetry;
- Coastal imaging;
- LIDAR;
- Quad bike GPS-RTK surveys;
- Manual surveys;
- Hydrographic/bathymetric surveys.

Spatial and temporal specifications for these need to be established. Examples could include surveys at weekly or monthly intervals over a predetermined area, with additional data collected after major storms (say H_s above 3 or 5 m).

Analysis of data is as important as its collection. Unanalysed data is less likely to uncover problems in both its collection, and the monitoring program.

7.3 Ecological Monitoring

The major objectives in ecological monitoring include (Committee on Beach Nourishment, 1995):

- Determine baseline conditions;
- Characterise temporal and spatial variability (pre project);
- Evaluate post nourishment change.

Aquenal (2011) suggested that at predetermined sampling locations, three random box cores (30 cm x 30 cm x 30 cm) should be collected within a 2 m radius of the location and sieved to 1 mm to retain all macrofauna. This can be analysed later in a laboratory.

8. Local Precedent

8.1 Beach Scraping

Beach scraping is undertaken at numerous beaches in NSW to improve beach access, accelerate beach recovery following storms and to bury hard material such as toe aprons which may be associated with seawalls. Some locations may have insufficient sand for beach scraping.

8.2 Sand Mining

Beach face mining of sand was once widely undertaken in NSW. It is now only undertaken at Boambee, Coffs Harbour, which is an accreting beach due to the presence of the harbour breakwaters. Other sand mining operations target either sand that has been removed from the active beach system (such as wind-blown sand deposits at Anna Bay), or relict deposits.

8.3 Maintenance Dredging

Maintenance dredging is undertaken at numerous river and port channels in NSW. Some of this dredged material is used for nearby beach nourishment (e.g. Lake Macquarie, Coffs Harbour and Tweed River), while some is sold as a commercial product.

Numerous lake and lagoon entrance berms are excavated for flood control purposes (e.g. Narrabeen). This material is usually retained within the littoral system by transferring with trucks.

8.4 Sand Bypass Plants

A major sand bypass plant exists at the mouth of the Tweed River. The Tweed River Sand Bypassing Project (TRESBP) commenced operations in 2001. Details can be found at http://www.tweedsandbypass.nsw.gov.au/ A similar sand bypass plant transfers sand across the Gold Coast Seaway, 30 km north of Tweed Heads. Only sites with a surplus of sand (e.g. training walls on littoral drift coasts and/or infilling channels) are suitable for such plants.

8.5 Offshore Extraction

While common in other states and countries, there is presently no extraction of offshore sand for beach nourishment (or other purposes) in NSW. This path is probably the only viable one for large scale beach nourishment on the open coast.

Two commercial sand mining ventures have been proposed off the coast of Sydney (Nielsen et al., 2011). The first was by Goldfields in the 1980s (off Broken Bay) and the second by Metromix in the 1990s (off southern Sydney). The water depths proposed for the sand extraction were greater than 20 m in the case of the Goldfields proposal and greater than 25 m (off rocky headlands) and greater than 35 m (off sandy beaches) in the case of the Metromix proposal. These depths were chosen by the proponents on the basis of ensuring that there would be no significant impacts on adjacent beaches. Neither proposal proceeded due to community and Government concern regarding the potential environmental impacts.

9. Policy and Legal Framework

9.1 Overview

A range of Commonwealth and NSW Acts may apply to any proposal to extract sand for beach nourishment. These may include:

Commonwealth

- Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)
- Telecommunications and Other Legislation Amendment (Protection of Submarine Cables and Other Measures) Act 2005

NSW

- Coastal Management Act 2016
- Offshore Minerals Act 1999 No 42
- Environmental Planning and Assessment Act 1979 (EP&A Act)
- Marine Estate Management Act 2014 No 72 and Marine Estate Management Regulation 2009

Other NSW Acts

- Protection of the Environment Operations Act 1997
- Threatened Species Conservation Act 1995
- Fisheries Management Act 1994
- Crown Lands Management Act 2016
- National Parks and Wildlife Act 1974

9.2 NSW Legislation

9.2.1 (NSW) Offshore Minerals Act 1999 No 42

Sand or marine aggregate is a mineral under Section 22 of the (NSW) Offshore Minerals Act 1999. An entity is required to hold a mining licence under Part 2.4 of the Act in order to recover marine aggregate from the seabed within the 3 nautical mile limit.

9.2.2 (NSW) Marine Estate Management Act 2014 No 72

The Marine Estate Management Act 2014 No 72 contains the following clauses which prohibit sand mining within marine parks and aquatic reserves except in limited circumstances such as "conservation purposes":

Division 6 Development and activities within marine parks and aquatic reserves 54 Mining in marine parks and aquatic reserves prohibited

> (1) It is unlawful to prospect or mine for minerals in a marine park or an aquatic reserve.
> (2) The Offshore Minerals Act 1999, the Mining Act 1992, the Petroleum (Onshore) Act 1991 and the Petroleum (Offshore) Act 1982 do not apply to or in respect of any area within a marine park or an aquatic reserve.
> (3) This section does not apply to or in respect of any licence, permit, authorisation or lease in force under any of those Acts:
>
>> (a) in relation to a marine park—as at 1 August 1997, and Note. Section 18 of the Marine Parks Act 1997 (the predecessor of this provision in relation to marine parks) commenced on 1 August 1997.

> (b) in relation to an aquatic reserve—as at 31 March 2002. Note. Section 197B of the Fisheries Management Act 1994 (the predecessor of this provision in relation to aquatic reserves) commenced on 31 March 2002. However, no renewal or extension of such a licence, permit, authorisation or lease may be granted after those dates except as expressly authorised by an Act of Parliament.
>
> (4) This section does not apply to or in respect of **sand extraction within a marine park for conservation purposes** or for the purpose of preventing the risk of serious injury to a person or harm to the environment that is carried out in accordance with a consent granted under this section and any other authorisation required under any other Act.
>
> (5) The relevant Ministers may grant consent (with or without conditions) to the carrying out of sand extraction within a marine park but only if satisfied that the sand extraction is for a purpose referred to in subsection (4).
>
> (6) In deciding whether to grant consent, the relevant Ministers must have regard to the assessment criteria (if any) prescribed by the regulations.

In Clause (4) above "sand extraction within a marine park for conservation purposes" could be construed as sand extracted for beach nourishment. Ministerial consent for this would consider assessment criteria under the Marine Estate Management Regulation 2009.

9.3 NSW Policy

As stated above, while the Offshore Minerals Act was gazetted on 31 March 2000, no regulations have been gazetted or promulgated that will allow an entity to apply for a mining licence off the NSW coast.

9.4 Beach Scraping

Beach scraping could be undertaken under State Environmental Planning Policy (Infrastructure) 2007 as a foreshore management activity. It would generally be undertaken under Part 5 matter with the local government authority being both the proponent and approval authority. Depending on the scale of the works, generally a *Review of Environmental Factors* (REF) or *Statement of Environmental Effects* (SEE) would be undertaken as part of the approval. A range of other assessments and permits may be required in NSW depending on the specific work location, including:

- Crown Lands;
- Aboriginal Cultural Heritage Assessment/Surveys and/or Aboriginal Heritage Impact Permit;
- Permit for destruction of marine vegetation;
- Species Impact Statement.

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