The Potential for Offshore Sand Sources to Offset Climate Change Impacts on Sydney's Beaches

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Abstract
Beach nourishment is a potential adaptive option to offset the adverse impacts of sea level rise and increased storminess on Sydney's ocean front assets, both public and private, while at the same time retaining a public beach. The volumes required to effectively utalise this option over a 100 year period are substantial. As a by-product of past studies on the Sydney shelf, sediment deposits have been identified that could be harvested for this purpose. The volume of deposits that is available, without incurring possible adverse impacts from offshore sand harvesting, is limited. Further, a number of beaches are already experiencing distress so, if the nourishment option is to be considered, it is essential that an Authority be established immediately to coordinate the program, establish a funding mechanism, obtain the necessary approvals, reserve the offshore sources and commence nourishing threatened beaches.

1 Introduction

A range of options exists for managing the coastal impacts of climate change in developed areas of the coast. The appropriateness of any one option depends on a number of factors in regard to what is at risk and what the consequences are as compared with the costs (NCCOE 1991, 2004). Of the available options most are mutually exclusive. For example, a seawall option means progressive loss of public beach as against an asset retreat option which maintains a beach but results in the loss of assets. When dealing with a shoreline that is fully developed with high value assets the available options, given the social, economic and political realities, is significantly limited. For the Sydney Coastline the assets at risk include not only high value private property but also beach front parks, parking areas, amenities, surf clubs and infrastructure such as water, sewerage, power and roads. The one option that can maintain all aspects of the current configuration of the Sydney coastline, certainly in the short to medium term (say 100 years), and cope with climate change impacts is beach nourishment. Sydney's coastline, both open ocean and estuary, features iconic beaches backed by valuable public and private assets. It would be intergenerational negligence to adopt a "do nothing" approach to climate change impacts on the Sydney shoreline. A well structured nourishment program would provide an effective solution that could be progressively implemented on a "needs" basis. Given the extent of beaches in the Sydney area the quantity of nourishment material required, in say a 100 year period, would be substantial and, although such a program would require significant funding, it is likely to be cost competitive and more effective than other options, provided sufficient nourishment material is readily available.

During the 1970's and 1980's a number of studies were undertaken on the Sydney shelf and on the beach systems. The data collected in these various studies has been revisited and brought together to identify the likely requirements and the potential sources for a major beach nourishment program to combat the adverse impacts of climate change on Sydney's coastline.

2 Background

By the early 1970's there was a growing awareness that Sydney's operational source of construction sand, the Kurnell Peninsula, was a limited resource. It was also becoming apparent that the potential life of the resource was coming under further pressure from State Government initiatives included in the Sydney Regional Outline Plan published in 1968. In 1974, Sutherland Council called for a moratorium on sand mining on the peninsula. A subsequent inquiry into sand extraction (Woodward, 1986) canvassed the progressive phasing out of sand extraction at Kurnell. The market place responded to the developing situation by investigating alternate sources of construction sand. Given that there were limited on-shore deposits in the immediate vicinity of Sydney, attention was directed to potential offshore sources. By 1977 investigations commenced into the potential extraction of sand offshore from Broken Bay (Wright et al, 1980; Hoffman et al, 1980). At the time the studies raised concerns regarding the impacts of the various proposals given that the available dredges were limited to a maximum of 24m water depth. Hence the dredging would be within the active zone of the beaches coastal process systems and therefore could result in shoreline recession.

The severe storms on the NSW coast of 1974 (Foster et al, 1975) and their associated beach erosion resulted in Public Works NSW examination of the potential for beach nourishment as an option for beach restoration. In 1977 Public Works, in combination with Sutherland Council, commenced a two year re-nourishment of the Cronulla Beaches (Gordon, 1992). The sand source was the Wanda dunes on Kurnell Peninsula. As with the quest for construction sand, it soon became apparent that the volume of on-shore sand available was insufficient to consider on-going nourishment as a management option. Hence the potential for offshore sand sources required exploration.

The 1974 storms also highlighted the need to obtain a better understanding of the coastal processes of Sydney's coastline. As a result during the 1970's and 1980's studies were undertaken on most of Sydney's beach systems from Palm Beach in the north to Cronulla in the south. As a result of these studies, and others on NSW beaches, the first tentative link was made between coastal recession and sea level rise (Gordon, 1988).

By the early1970's it had also become apparent that the three major Sydney cliff based sewerage outfalls at North Head, Bondi and Malabar, needed to be moved offshore. Design and construction considerations along with requirements to achieve environmental performance criteria resulted in a detailed seabed study being commenced for a significant portion of the Sydney shelf. The outfall design and performance considerations required both seabed mapping and an understanding of seabed currents and sediment movements.

These four separate initiatives resulted in a series of studies covering 62 km of the Sydney coast, from 33km north of Sydney Heads at Bouddi Point in Broken Bay to 29 km south of the Heads at Port Hacking Point in Bate Bay. The study extended from the coast out to 7km (60m depth) in the north to 4km (85m depth) in the south.

3 Seabed Mapping

The first seabed mapping commenced in 1979 with beach and seabed profile data collection on shore normal profile lines, at 1 km spacing utilizing a 6m catamaran capable of operating in the surf zone and equipped with a Raytheon 719B sounder and Motorola Mk3 Miniranger microwave tracking system. In the smaller embayments additional lines were run from the surf zone to offshore to ensure there were at least 3 profiles per beach. Tidal, bar checks, salinity and position fixing corrections were applied to all data. Because of the weather dependency of this work it was staged over 2 years. In total the reconnaissance project involved 500km of catamaran operation.

The second seabed study used the reconnaissance from the first to design and carry out a major seabed mapping exercise. The work was undertaken utilizing a 25m trawler hulled vessel, the "Sieglinde", equipped with twin 450 hp engines. The twin engine/propeller configuration provided excellent maneuverability at the low speeds required for quality side scan records. An Atlas Deso twin frequency (30 kHz/210kHz, simultaneous) sounder was used to obtain depth data with a Klein 521 side scan sonar for seabed mapping. A 100kHz fish was used for a majority of side scan work. It was generally set to provide a 150m wide scan on either side of the vessel. The survey tracks were coast parallel starting in 5m of water or 100m off cliffs. The tracks were spaced 200m apart thereby providing overlapping records. A 500kHz fish set at 75m sweep either side was used for detailed on-lapping work in areas of specific interest such as the outfall locations and on the major offshore sand bodies. The detail of the operation was described by Gordon and Hoffman (1986). This work was also very weather dependent and could only be undertaken during the extended periods of light westerly conditions. Over a period of 4 years approximately 5,000kms of side scan records were collected and analysed. Data reduction took a further 3 years because of the sheer volume of information and requirement for manual analysis and interpretation of the side scan records.

4 Sub Seabed mapping

The sub sea bed mapping was undertaken using the same vessel as the side scan however it was fitted with a "boomer" and "sparker" array to obtain the seismic profile of the sub sea bed strata, including the underlying rock interface with the sediment deposits. It was not possible to operate the seismic equipment in conjunction with the side scan due to competing towing arrangements and signal interference. Further, the seismic equipment did not require the close spaced shore parallel survey lines of the side scan and sounder. Hence a separate cruise program was undertaken using the side scan results, as they became available, to determine the layout of the seismic work. The seismic program and results were presented by Albani et al (1985).

5 Seabed Sampling

The side scan sonar not only delineated the rocky areas of seabed but also seabed sediment types. Sediments with differing properties produced clearly observable differences in sonic reflectivity. This showed up on the side scan record as changes in hue on the chart. Rather than a gradation of hue the interfaces between differing sediment types was often surprisingly marked. To interpret the varying sonic densities a seabed sampling program was undertaken. This was further supported by diving out to 25m depth and then, with the use of an ROV, out to 80m. In all 750 seabed sediment samples were collected covering the entire project area. 720 of these were surface samples obtained using a small drag dredge, 19 were Box core samples and 31 were obtained using a vibrocore. All samples were described in the field and selected, representative samples were analysed for sediment size and shell content.

6 Seabed Movements

Seabed movements were evaluated using 20 years of beach and surf zone profiling (including the impacts of the 1974 event) and long term observations of bed movements at stakes driven into the seabed out to 30m (Gordon, 1990). Data was also collected at 24m, 60m and 80m by deploying seabed instrumentation packages consisting of a Marsh McBirney electromagnetic current meter, a time lapse camera and a vertical array of sediment traps (Gordon and Hoffman, 1985). ROV operations over 2 years provided data on bed forms and movements in 40m to 60m water depth.

7 Seabed Maps

The seabed maps were published as a series of 3 maps (82310-575, 576 and 577) by the Department of Public Works (PWD, 1989). This mapping was later augmented with a 4th map extending 14km further northward (83042-1001, PWD, 1989). These coloured seabed maps were constructed from the sounding, side scan and sediment data. They included 2m seabed contours, rocky reef areas and they delineated four clearly identifiable zones of sediment type: a medium to fine grained golden sand typically with a d50 of 0.3mm and a shell content of between 10% and 30% and generally found in water depths of 0 to 20m, but in some embayments only out to 6m whereas in others out to 30m; a fine fawn coloured sand with a typical d50 of 0.16mm and a shell content of 30% generally found in water depths of 14m to 24m, but in some embayments 6m and 30m and in others not occurring at all as a recognizable feature; a medium to coarse grained orange sand with a d50 of 0.6mm but very poorly sorted and a shell content of 25% generally found in water depths of 24m to 50m but inshore as shallow as 10m and offshore as deep as 60m in areas with extensive reef; a fine grained grey muddy sand with a typical d50 of 0.16mm and a shell content of 30% generally found in water depths greater than 50m but sometimes as shallow as 40m. The distribution of Sydney shelf sediments appears to be far less well ordered and does not form the distinctive shore parallel sediment zone structure observed elsewhere on the NSW coast (Roy, 1984). The significant three dimensional wave induced currents and turbulence caused by the extensive offshore reefs are believed to be a major factor in creating these anomalies.

Both the seabed and seismic maps clearly define the four major drowned ancient river valleys that are now in filled with sediment, the Hawkesbury, Parramatta, Botany and Georges/Hacking Rivers; cut into the underlying rock during a lower sea level phase. In each case the depth of the rock base of the river valley is approximately 100m below the present day sea level (Albani et al, 1985). Between these major systems there is a complex series of incised creeks. Whereas the intersections of the ancient river systems with the present day coast are defined by the Broken Bay, Port Jackson, Botany Bay and Port Hacking entrances, each of Sydney's beaches represents the intersection of a lesser river or creek valley with the coast. These were also established at a lower sea level; the present day beaches representing the landward extent of sand plug that was transported shoreward during the 130m sea level rise that occurred between 15,000 and 8,000 years before present. The steepness of this ancient topography and the extensive exposure of eroded rock structures, now featuring as seabed reefs, has resulted in fan like beach/surf zone regions at the top of the ancient valleys, in the current embayments. The beach embayments are connected by rocky sided underwater valleys of varying width to the shelf sediments in 50 to 60m of water.

8 Volume of Nourishment Required

The order of magnitude of beach nourishment quantity required in the next 100 years for Sydney, assuming a sea level rise of say 0.9m during this period, has been estimated based on a simple model of lifting open coast beach profiles from 18m water depth (approximately 1km offshore) by 0.9m and allowing for an additional 100m width of beach). Within the estuaries a similar calculation was undertaken based on the 5m depth contour (10m Broken Bay) but with more site specific estimates of profile and beach width: only the lower estuary foreshores were included. It is suggested that a "storm safety" allowance for possible increased storminess be included as a reserve. The figures adopted to obtain an order of magnitude reserve are heuristic estimates based on an additional severe storm of the magnitude of the 1974 event. These estimates are 250m^3/m run on the open coast, 10m^3/m in sheltered estuaries and 40cum/m for Broken Bay. The results are presented in Table 1.

It should be noted that 44% of the "Northern Suburbs" coastline between Broken Bay and the North Head of Port Jackson, 87% of the "Eastern Suburbs" coast between the South Head and Cape Banks (Botany Bay) and 50% of the "Southern Suburbs" coast between Botany Bay and Port Hacking Point (Bata Bay) is rocky and therefore not requiring beach nourishment.

From Table 1 it can be seen that the total volume required to nourish Sydney's sandy coast to cater for a 0.9m sea level rise is therefore of the order 34,950,000m^3 with an additional 5,790,000m^3 for "storm safety". Allowing for about 30% losses the total volume required would be of the order

53,000,000m^3, this quantity would be increased if all beaches within the estuaries were to be included in the nourishment.

Table 1. Volume of Nourishment required

Location	Beach Length km	Volume cu m $\times 10^6$	Storm Safety cu m $\times 10^6$
Pittwater	5	1.1	0.05
Broken Bay	4	2.16	0.16
Northern Beaches	15	14.85	3.7
Harbour Beaches	8	3.8	0.08
Eastern Suburbs	2.5	2.48	0.63
Botany Bay	12	5.5	0.12
Bate Bay	4	3.96	1.0
Port Hacking	5	1.1	0.05
Total	**55.5**	**34.95**	**5.79**

9 Availability of Nourishment Material

Off Broken Bay (for the purpose of this paper taken as seaward of a line between Barrenjoey and Box Heads) there is large deposit of sediment that has in-filled the ancient Hawkesbury River valley. Although there is limited data on the sub surface sediments, given their depositional environment, it is considered likely they would reflect the surface sediments and therefore be suitable for beach nourishment. The available information indicates that the seabed material off Broken Bay is medium to course sand (0.4 to 0.6mm with some coarse material of 1.5mm typical mean diameter), is a fawn/orange colour (orange associated with iron staining) and has between 5% and 30% shell (the northern beaches typically are 30% shell). As such it would be a suitable material for beach nourishment although possibly slightly coarser and more iron stained than the sand on some of the beaches. As this is a moderate to high energy coastal environment, wave stirring and seabed mobility is a major consideration when delineating possible extraction areas. The high value of onshore assets located on unconsolidated sediment deposits both within and in the immediate vicinity of Broken Bay means that any offshore extraction would need to be sufficiently remote to ensure their safety. Based on the work by Gordon (1990), the side scan records, the seabed current meter and camera studies and the ROV footage, it would appear that harvesting by bed skimming in water depths greater than 45m could be considered. Skimming 1m off the seabed between 6km and 7km off Broken Bay over the 6km directly off the entrance would yield, excluding losses, 12,000,000m^3. Given that any beach nourishment program would likely be staged over many years, an associated monitoring program could be used to manage the rate and location of the harvesting operation.

Of the 27 km Broken Bay to Port Jackson 12km is rocky headland. The valleys forming the beach embayments extend offshore rapidly narrowing past 20m water depth. Only 11% of the region between 20m and 40m in this area is exposed sediment, generally located in the sinuous valley floors; 89% of the seabed is reef. Further, for 44% of the shelf of this coastline the reef area dominates 85% of the seabed from 40m out to 60m. With the exception of a sand lobe off Bangalley Head there is no significant identifiable source of potential beach nourishment material. The Bangalley lobe is located in 16m to 35m water depth and although it is of a similar material as Avalon and Whale Beaches, it does contain angular material suggesting recent supply from the nearby cliffs. Its location within the mobile seabed zone and its proximity to a narrow valley connecting to Whale Beach cautions against consideration of its use. There is therefore little prospect of an offshore nourishment source from deposits directly off this 27km of coast.

Between Port Jackson and Ben Buckler, immediately north of Bondi, the seismic profiles show that the deeply incised Parramatta River valley exits Sydney Heads and turns southward to just north of Ben Buckler, where it then heads directly east out across the shelf. For the 6 km between South Head and Ben Buckler the channel runs shore parallel with its deepest part being about 1.5 km offshore and varying from 60m below sea level at South Head to 110m down off Ben Buckler. While the underlying rock base descends steeply from 20m at the cliff base to 110m offshore, the present day sedimentary seabed is somewhat flatter starting at 26m and descending to only 48m at 1.5km offshore. The thickness of the sediment deposit in this area varies on average from 6m to 52m. Further offshore than 1.5km, past dumping of dredged spoil and construction waste from Sydney foreshore and harbour works makes consideration of this section of the offshore area somewhat problematic. The side scan identified areas of debris that suggested random dumping of waste material over many years. Vibrocoring of the sediments inshore of 1.5km indicated the top 5m was typically medium (d50 typically 0.2 to 0.4) fawn coloured sand with some course particles and between 5% and 20% shell with some whole shell. The grains were commonly angular suggesting that at least some of the material may have originated from erosion of the adjacent sandstone cliffs thereby making it ideal nourishment sand. While the inshore limit, at 26m, is within the active profile depth, a shore-normal reef 1.5km south of South Head acts as a containment groin towards the northern end separating the deposit from the sediment structure leading into Port Jackson. An extensive reef off Ben Buckler provides containment to the south. The potential volume that could be harvested at this location, between the natural containment reefs, assuming a realistic extraction depth of say 3m, is of the order 24,000,000m^3.

To the south of Port Jackson and excluding the area between South Head and Bondi, the 18 km down to Bate Bay is 79% reef between 20m and 40m with extensive reef areas out to 50m and again outcrops between 65m and 80m. The seismic data in this area indicates rock shallowly underlying the surface sediments between 40m and 80m. There is an anomalous sand body in this region off Malabar (Albani et al, 1985 and Roy, 1984). Albani estimated that this sand body contains 112M cu m of unconsolidated sediment. Based on the vibrocoring, Roy's (1984) analysis, side scan records, the fact that the lobe is directly connected to Maroubra Beach and considerations of profile matching with other similarly exposed beaches, the potential to harvest this source needs to be balanced against the potential for adverse impacts. It is felt that the shape of the profile does not necessarily represent the presence of excess material, rather the offshore ramp necessary to maintain the beach at this exposed location. Hence the volume available at this source is only suggested to be 10,000,000m^3 at this point in time. Further studies are recommended before this figure is accepted. As with Broken Bay there is the potential to gradually harvest this source and monitor seabed response.

There are extensive sand lobes off Cape Banks and Cape Solander, either side of the entrance to Botany Bay. The side scan, sampling and seismic studies indicate these lobes are in water depths from 45 to 72m depth and sampling suggests they contain sand suitable for beach nourishment including angular sand from cliff erosion. These lobes could yield in the order 60,000,000m^3 and are remote from any sandy shorelines or active zones. The limited subsurface coring in this area dictates that further work be carried out to prove-up both the quality and quantity of material available from these lobes for beach nourishment.

Finally, the Bate Bay area features similar seabed surface material to that found off Broken Bay. However underlying ancient river valley is far more sinuous and considerably narrower resulting in much of the seabed being either rocky or having only shallow sediment cover. The current sedimentary seabed slopes relatively gently out to the 40m contour which is located approximately 4km off Cronulla Beach. The slope then steepens significantly to achieve a depth of 70m only 1km further offshore. The change in slope at 40m is believed further evidence that the present day open coast active profile terminates in a depth of between 40 and 50m. The steepness of the profile past 40m and the increasing seabed activity in lesser depths combined with the shallow underlying rock over much of the bay, precludes consideration of this area as a potential major sand harvesting area with the exception of a strip area approximately 1sq km in 45 to 50m of depth in the centre of the Bay. It may be possible to harvest this area to a depth of 1m thereby yielding 1,000,000 cu m.

As a general observation it is interesting to note that where offshore sand deposits are near sandstone cliff foreshores, sampling showed a significant content of angular material likely generated by cliff erosion. Further, offshore and beach sands in areas where there are extensive shallow reef systems comprise approximately 30% shell.
Table 2 presents the potential sources and order of magnitude of material available, minimizing the risk of undesirable side effects.

Table 2. Volume of available Offshore Material

Location	Quantity (cu m ×10^6)
Off Broken Bay	12 #
Northern Suburbs	0
Ben Buckler	24*
Eastern Suburbs (Malabar)	10#*
Cape Banks/Solander	60*
Off Bate Bay	1#
Total	**107**

Designates sources that require further assessment as to viability and potential,
* Designates sources that may have greater potential than indicated.

10 Dredging

At the depths contemplated to minimize the potential for adverse shoreline impacts, generally greater than 40m, except off Ben Buckler, harvesting would likely require a large trailer suction dredge equipped to pump onshore. Given the dredge depth, the volumes to be harvested, the travel times from the sources to the beaches, the establishment/disestablishment costs and the 100 year time frame, the most viable nourishment program would involve importation of a large dredger for periods of months say every 5 years to move some 2,500,000m^3 at a time. Such a program would commence with the most vulnerable beach(s) and provide say 20 years of nourishment, meaning that each beach would be nourished 5 times in the 100 years. This approach would also enable extraction at source areas to be monitored and programmed so that there was time for the areas to readjust and the impacts assessed.

11 Environmental Considerations

Studies undertaken to determine the environmental impacts on fish and benthic organisms resulting from construction and operation of the three Sydney deepwater ocean outfalls demonstrated that there was limited marine life activity associated with the seabed in the water depths being contemplated for harvesting of nourishment material. Further, given that a trailer suction dredge could harvest in controlled tracks, and that the harvesting would consist of a series of operations spaced years apart, there would be opportunities for benthic organisms to migrate and re-colonize disturbed areas. Further, dredge patterns during any one operation could be designed to assist this. On-shore, the pumping of nourishment onto the beach and into the surf zone can be expected to cause considerable disruption during the operation and may result in inconvenience, discoloration of the beach for a time and increased turbidity. Generally however, experience in Australia and overseas has shown that such disruption is short lived with beaches recovering within a matter of weeks, depending on the wave climate at the time. Detailed studies will be required prior to implementation and adverse impacts weighed up against the long term benefits.

12 Comments

This paper scopes the scale of a nourishment option for managing the impacts of climate change on Sydney's beaches. For a 100 year sea level rise of 0.9m the volume of material required would be of the order 53Mm^3 equating to a present day cost of between $500M and $800M, depending on the economies of scale that can be achieved. That is of the order of $5M to $8M per year or $25M to $40M for each 5 year program. The advantage of a nourishment option is that it would protect private and public assets while also retaining the beaches. Further, it has the flexibility to cope with the uncertainties of the current climate change scenarios as it can be undertaken in progressive stages, as required. The disadvantage is the complexity and uncertainty of the operating environment including the stability of the organisation managing the program and the political/economic vulnerability of a flexible program extending over a 100 year time frame. However the value of private and public assets that would be lost if some form of protection is not put in place is substantial and the economic and social impact of Sydney loosing its beaches if a hard protection option were selected is difficult to estimate, but would be major. Some insight into the potential financial impact of doing nothing to combat climate change induced sea level rise and increased storminess can be obtained from an assessment of the value of private and public oceanfront assets at risk. Gordon (1989) estimated the value, excluding indirect values such as commercial, tourism and recreational benefits, was of the order $1,200M in 1989 dollars. Taking into account property inflation by a factor of 3 and infrastructure inflation by a factor of 2 and including the public and private assets within the estuaries (but only associated with beaches towards the entrances) this figure is now closer to $5,000M. Hence the estimated nourishment project cost is 10% of the asset value alone without considering the commercial and recreational benefits.

An alternative option to a structured long term nourishment solution would to be to adopt the laissez-faire approach of leaving it to individual property owners to progressively undertake hard protective works as their properties come under threat. Interestingly, such protective works are likely to be of the same order of cost as nourishment. Further, they will require on-going maintenance as sea level rises and storm exposure increases and will result in the progressive loss of any beach amenity and the resulting commercial losses in tourism and for beach dependant businesses; a sad legacy for future generations.

The scale of a major nourishment project, both in size and timeframe, dictates that a special purpose major project authority would be required to be established, similar to the Snowy Mountains Authority, to implement the nourishment program. This is no different from what is occurring overseas; Holland being an example where the scale and costs of addressing climate change are orders of magnitude greater than the Sydney situation.

The immediate actions that authority would need to take are: the reservation of the offshore sources required for nourishment for the future; establishing funding mechanisms; a detailed program of proving-up sources; impact assessments; the obtaining of the necessary approvals and; developing nourishment contracts. The funding mechanism would need to take into consideration that the assets to be protected include private property, public property, public infrastructure the public beach amenity and the commercial activity associated with the coast including tourism. Given the current threat to some Sydney beaches and the magnitude of the task at hand the establishment of such an authority is already overdue. The link between long term beach recession in NSW and climate change induced sea level rise was recognised, and published, over 20 years ago (Gordon, 1988).

13 References

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