Horton Coastal Engineering
Coastal & Water Consulting

Coastal Engineering Advice on Mona Vale Beach Amenities and Lifeguard Facilities Building, Including Consideration of Tolerable Risk

Prepared by Horton Coastal Engineering Pty Ltd

for Northern Beaches Council

Issue 2

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Picture on Front Cover:

View of existing Mona Vale Beach amenities building on 26 February 2020, looking north-east

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EXECUTIVE SUMMARY

It is proposed to demolish the existing amenities building and to construct a new amenities and lifeguard facilities building at the northern end of Mona Vale Beach. Probabilistic coastal hazard modelling for coastal erosion/recession, using a full Monte Carlo probability simulation procedure, has been undertaken for this site.

The proposed building is found to be at a tolerably low risk of damage from coastal erosion/recession over a reasonable 40 year design life, as it is to also be founded on deep piles with allowances for sand slumping and wave forces. Operational management measures are outlined to further reduce the erosion/recession risk, namely:

1. the dune volume seaward of the building should generally be maintained by Council over the building design life, by restoring and revegetating the dune after damaging storm events;
2. if the building is ever undermined or nearly undermined, land levels under and surrounding the building must be restored; and
3. storm events at the site must be monitored by Council, and if threatened by erosion, the building must be barricaded off to prevent public access.

Risk of damage from coastal inundation can be managed in construction through the following measures:

1. using floor finishes and wall materials that would withstand inundation, such as concrete and tiles, up to a level of at least 1m above the finished floor level;
2. allowing for wave forces on exposed elements of the building;
3. placing electrical fittings and outlets that could be damaged by inundation at least 1m above the floor level, or waterproofing them below this; and
4. designing cross-falls over the building footprint to ensure that inundation would drain away from the building, where possible.

Risk of damage from coastal inundation can be managed during operation through the following measures:

1. storing items that could be damaged by inundation, or become polluting due to inundation, at least 1m above the floor level; and/or
2. relocating items that could be damaged by inundation prior to a storm; and/or
3. using sand bags as required to reduce the extent of inundation into the building.

With implementation of the above measures as appropriate, the proposed building could be constructed and maintained at an acceptably low risk of damage from coastal inundation.

The proposed development satisfies the coastal engineering matters in Chapter B3.3 of *Pittwater 21 Development Control Plan*, the *Coastline Risk Management Policy for Development in Pittwater*, *State Environmental Planning Policy (Coastal Management) 2018*, Clause 7.5 of *Pittwater Local Environmental Plan 2014*, and the "Coastal Management Strategy, Warringah Shire" prepared in 1985.

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1. INTRODUCTION

It is proposed to demolish the existing amenities building and to construct a new amenities and lifeguard facilities building at the northern end of Mona Vale Beach. In February 2020, a revised concept design for this building was released following community feedback.

Northern Beaches Council has requested coastal engineering advice from Horton Coastal Engineering Pty Ltd on this revised concept design, with this advice set out herein. This includes consideration of:

- whether the building location is at tolerably low risk from a coastal engineering perspective (including probabilistic coastal hazard modelling for coastal erosion/recession, using a full Monte Carlo probability simulation procedure);
- how and if any risks of undermining of the building (from erosion/recession) and damage (from ocean inundation) can be managed; and
- a merit assessment of the development in relation to coastal engineering matters in Chapter B3.3 of *Pittwater 21 Development Control Plan*, the *Coastline Risk Management Policy for Development in Pittwater*, *State Environmental Planning Policy (Coastal Management) 2018*, Clause 7.5 of *Pittwater Local Environmental Plan 2014*, and the "Coastal Management Strategy, Warringah Shire" prepared in 1985.

The report author, Peter Horton [BE (Hons 1) MEngSc MIEAust CPEng NER], is a professional Coastal Engineer with 28 years of coastal engineering experience. He has postgraduate qualifications in coastal engineering, and is a Member of Engineers Australia and Chartered Professional Engineer (CPEng) registered on the National Engineering Register. He is also a member of the National Committee on Coastal and Ocean Engineering (NCCOE) and NSW Coastal, Ocean and Port Engineering Panel (COPEP) of Engineers Australia.

In previous employment, Peter was the main author of the *Coastal Zone Management Plan for Bilgola Beach (Bilgola) and Basin Beach (Mona Vale)* prepared for Pittwater Council in 2016, and the *Coastal Erosion Emergency Action Subplan for Bilgola Beach (Bilgola) and Basin Beach (Mona Vale)* prepared for Pittwater Council in 2012. He has also prepared coastal engineering assessments for public buildings at numerous Northern Beaches locations over the last decade, including an acceptable risk assessment of Mona Vale SLSC in 2017. Peter has inspected the area in the vicinity of the subject site on several occasions in the last decade, including specific recent inspections on 26 February 2020 and 31 May 2020.

The report herein is set out as follows:

- the existing site is described in Section 2;
- the proposed development is described in Section 3;
- historical beach profiles are described and analysed in Section 4, to assist with understanding coastal processes and coastal hazards at the subject site;
- previous reports on the subject site are outlined in Section 5;
- subsurface conditions at the subject site are outlined in Section 6, including consideration of how subsurface clay and bedrock affects the probabilistic coastal hazard definition and structural design;
- the tolerable risk assessment methodology is outlined in Section 7, including consideration of design life, likelihood, consequences, and the probabilities defining tolerable risk for the adopted consequences;

- a probabilistic coastal hazard definition is carried out as outlined in Section 8, to determine the probabilities associated with each consequence level over the design life;
- coastal inundation coastline hazards at the site are described in Section 9, along with measures to reduce the risk of inundation damage to the proposed building;
- a merit assessment of the proposed development from a coastal engineering perspective is provided in Section 10; and
- conclusions and references are provided in Section 11 and Section 12 respectively.

Note that all levels given herein are to Australian Height Datum (AHD). Zero metres AHD is approximately equal to mean sea level at present.

2. EXISTING SITE DESCRIPTION

Photographs of the existing amenities building at the time of the site inspection on 26 February 2020 are provided in Figure 1 to Figure 3. From a 2020 survey provided by Council, ground elevations near the building are between about 6.6m and 6.8m AHD, reducing to the NE to about 6.4m AHD at outdoor showers, and increasing to about 6.9m AHD about 50m to the SW.

Figure 1: View of existing amenities building (at arrow) from Mona Vale Beach, looking NNW

Figure 2: View of existing amenities building from reserve to NE, looking SSW

Figure 3: View of existing amenities building from reserve to SW, looking ENE

Seaward of the amenities building, a fenced and vegetated dune area extends about 20m cross-shore, with the sandy beach seaward of the dune vegetation landward edge (grassed reserve fence) typically about 70m wide to the shoreline at mean sea level (0m AHD). As evident in Figure 1, the dune vegetation coverage was sparse at the time of the site inspection. From occasional site observations and review of aerial photography since 2003, the vegetation coverage has been sparse since about December 2015.

Beach width varies over time due to varying water levels, plus erosion of the beach in response to large waves and elevated water levels, and subsequent recovery (accretion) in calmer periods. An example of an erosion scarp seaward of the amenities building in 2015 is provided in Figure 4.

Figure 4: Erosion seaward of amenities building evident on 6 June 2015

3. PROPOSED DEVELOPMENT

It is proposed to demolish the existing amenities building and to construct a new amenities and lifeguard facilities building. The proposed layout of the new building is depicted in Figure 5.

The current amenities building is understood to have been constructed in 1975. Prior to this, there was an amenities building with the approximate outline shown in yellow in Figure 5 (as derived from an aerial photograph taken in 1961). Based on discussions with Ian Usher and Russell Sheppard, long-term residents of Mona Vale, the amenities building suffered some damage in the major coastal storm of May-June 1974 (as observed by these residents).

Historical beach profile locations are also shown in Figure 5, as discussed further in Section 4.

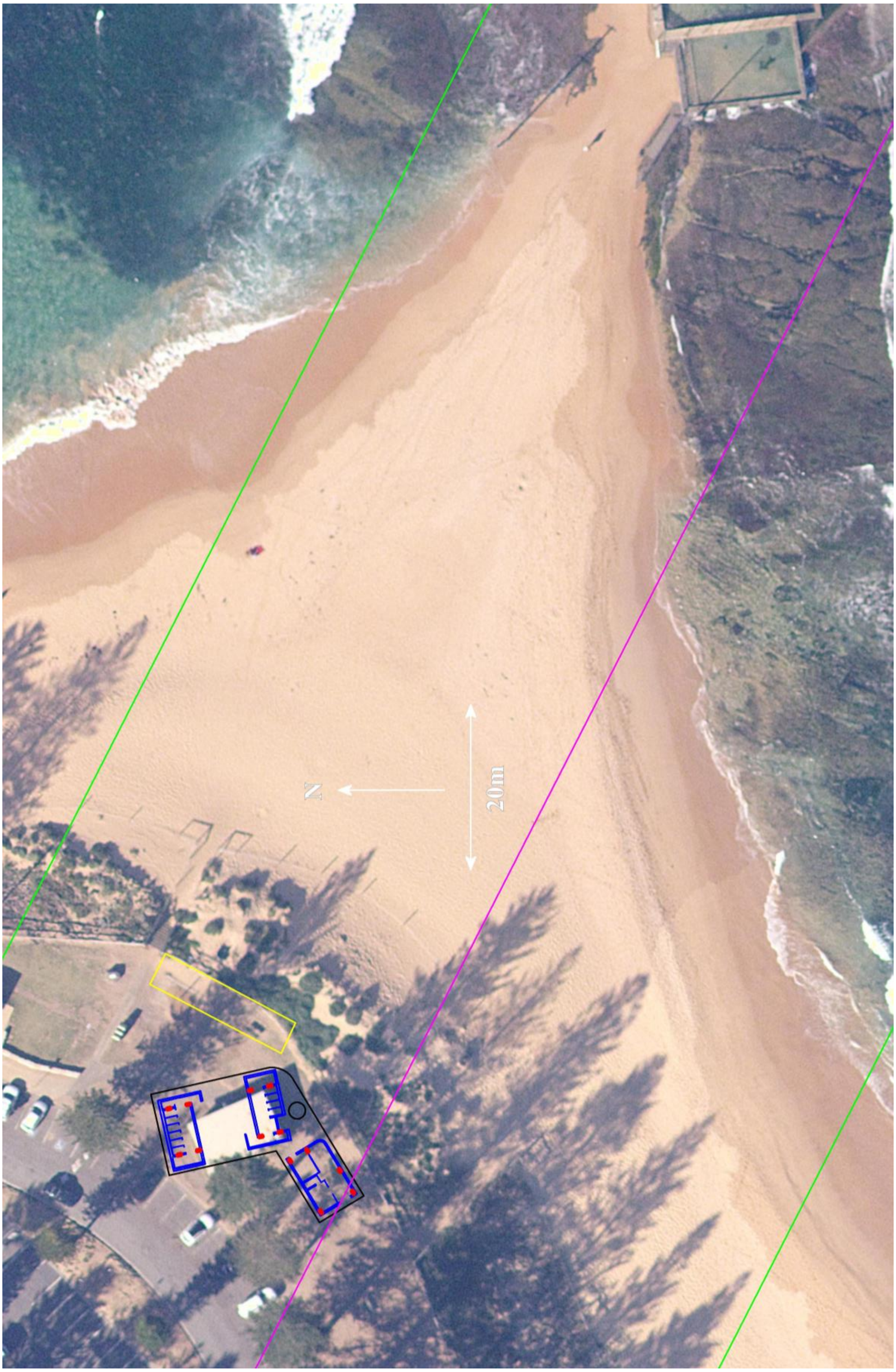

Figure 5: Proposed layout of new amenities and lifeguard facilities building, with supporting columns in red, walls in blue, and roof outline in black (aerial photograph taken 17 August 2018). An outline of the previous amenities building (before 1975) is shown in yellow, with historical beach profile locations in magenta and green

4. HISTORICAL BEACH PROFILES

The NSW Government has recorded historical beach profiles at Mona Vale Beach and Basin Beach, derived from photogrammetric analysis of aerial photography (or directly from LiDAR[1] data collection in recent years) for 13 dates from 1951 to 2019 inclusive. The alongshore profile spacing in this data set is 50m, with 3 profiles depicted in Figure 5. A plot of the historical beach profiles at the magenta profile in Figure 5, which passes through the southern corner of the proposed amenities and lifeguard facilities building, is provided in Figure 6. Note that the section is not perpendicular to the beach contours (that is, it is not shore-normal).

It is evident in Figure 6 that at this cross section, the proposed building is at a location that has not been subject to erosion/recession in the beach profile record from 1951 to 2019. It is also evident that prior to 1970, ground levels in the vicinity of the proposed building were about 1m to 2m lower. By 1970, the car park had been formed landward of the proposed building, and this area was presumably filled as part of these works. The significant erosion in 1974 is evident, with a general trend of accretion (increase in beach volume) after that time to 2011, and some recession (loss in beach volume) in 2017 and 2018.

The trend in beach volumes over time at this section, seaward of the proposed building, is depicted in Figure 7 (full record) and Figure 8 (1970 onwards, after artificial filling). It is evident that there is a mild trend of accretion over both the full record and from 1970 onwards. These accretion rates are 1.4 and 0.7m^3/m/year respectively.

The trend in 3m AHD contour position seaward of the proposed building over time at this section is depicted in Figure 9 (full record) and Figure 10 (1970 onwards). The chainages in these figures are relative to zero at the landward edge of the profile, and to convert to equivalent chainages to Figure 6, subtract 164.7m. It is evident that there is a very mild (essentially insignificant) trend of accretion over the full record (equal to 0.03m/year) and a very mild trend of recession from 1970 onwards (equal to -0.02m/year). Overall, these Figures indicate a general long-term stability, whereby sand that is eroded off the visible beach in storms then returns to the beach in calmer periods.

It is recognised that only one profile has been considered herein, but the same overall mild accretion trend or long-term stability is generally evident by analysing all profiles at Mona Vale Beach and Basin Beach, eg as per the 2017 reports *Coastal Zone Management Plan for Bilgola Beach (Bilgola) and Basin Beach (Mona Vale)*, and *Risk Assessment to Define Appropriate Beachfront Development Setback in Relation to Coastline Hazards for Redevelopment of Mona Vale SLSC*.

[1] LiDAR, which stands for Light Detection and Ranging, uses light in the form of a pulsed laser (typically supported on a flying object such as a plane or drone) to measure distances to the Earth.

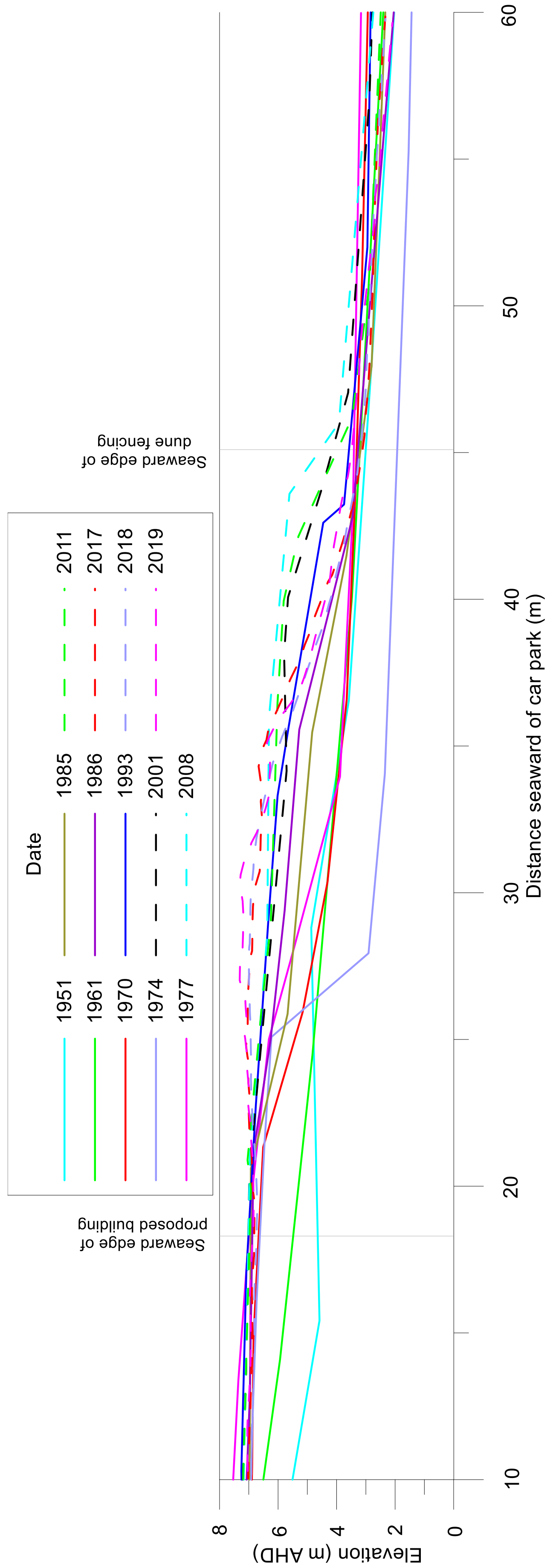

Figure 6: Historical beach profiles at proposed building location from 1951 to 2019

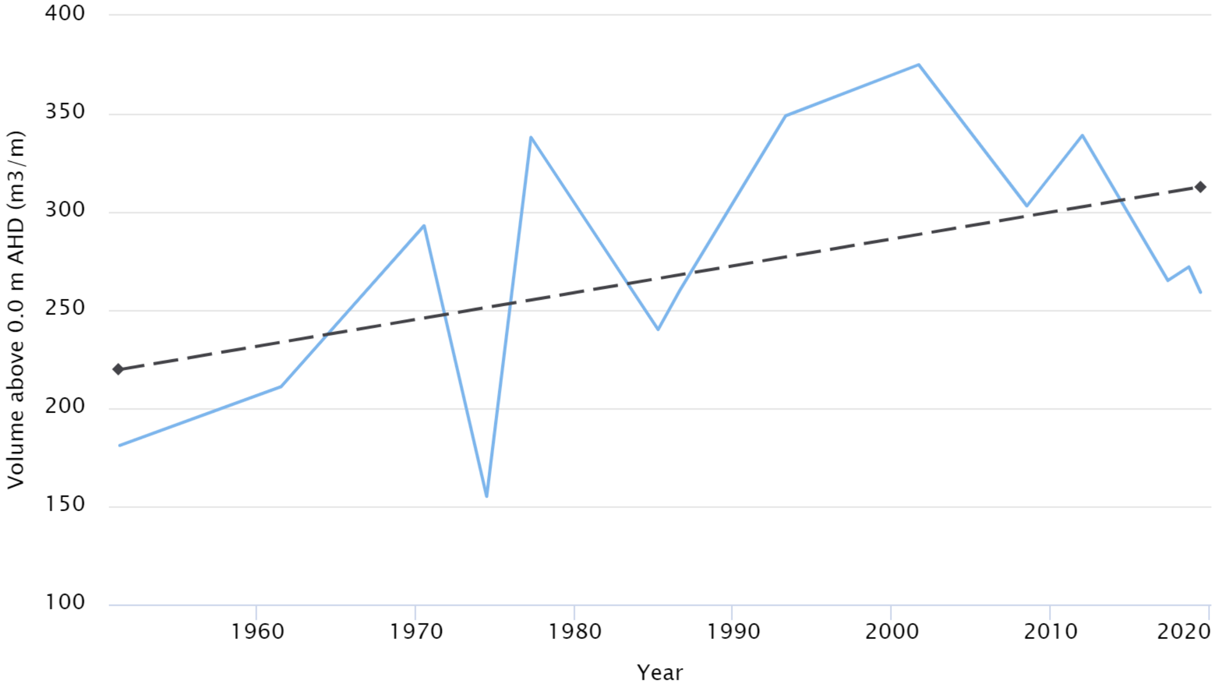

Figure 7: Trend in breach volume seaward of proposed building from 1951 to 2019

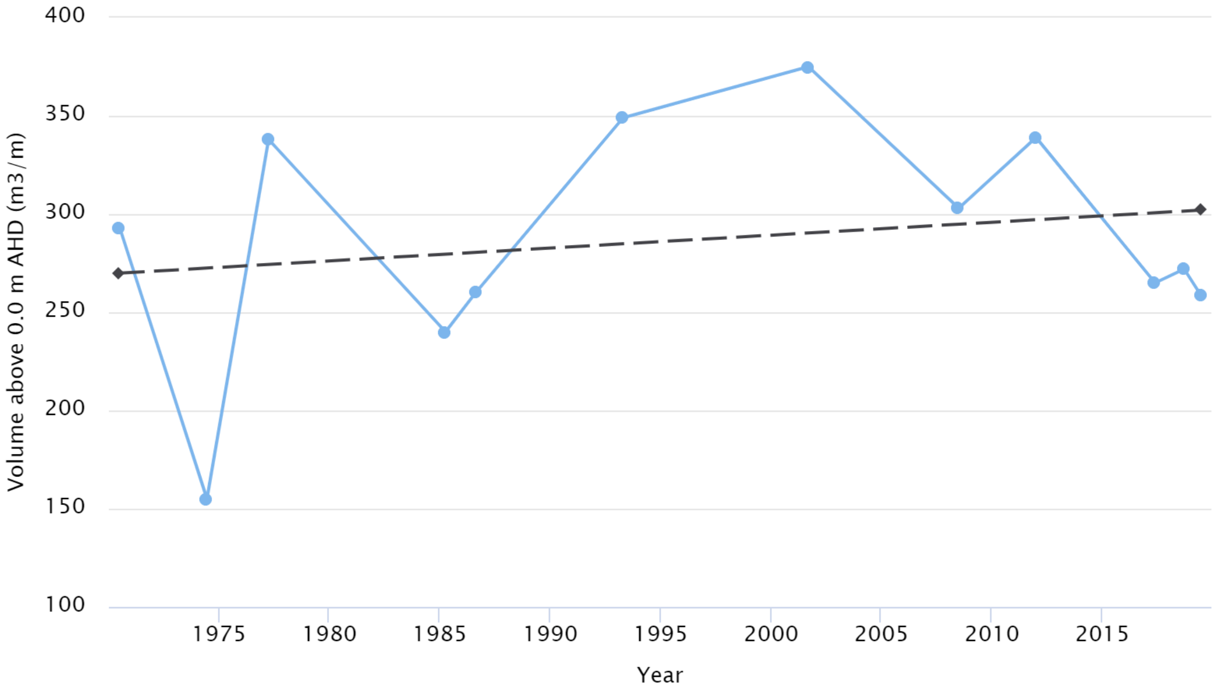

Figure 8: Trend in breach volume seaward of proposed building from 1970 to 2019

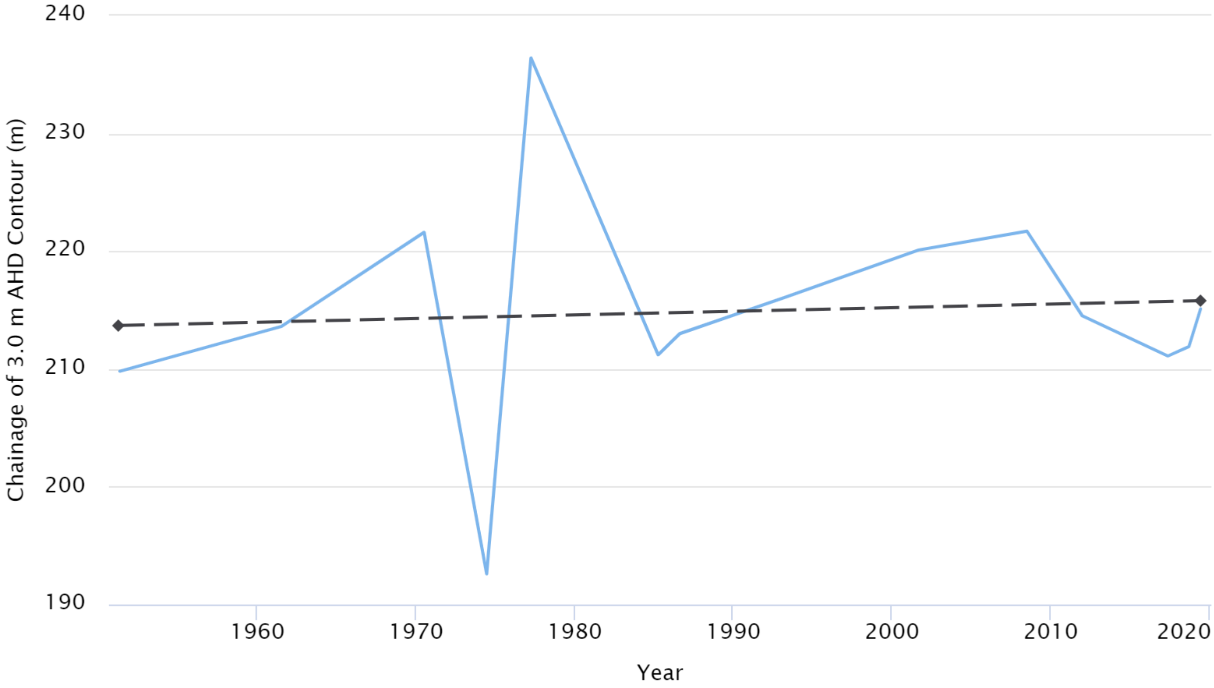

Figure 9: Trend in 3m AHD contour position seaward of proposed building from 1951 to 2019

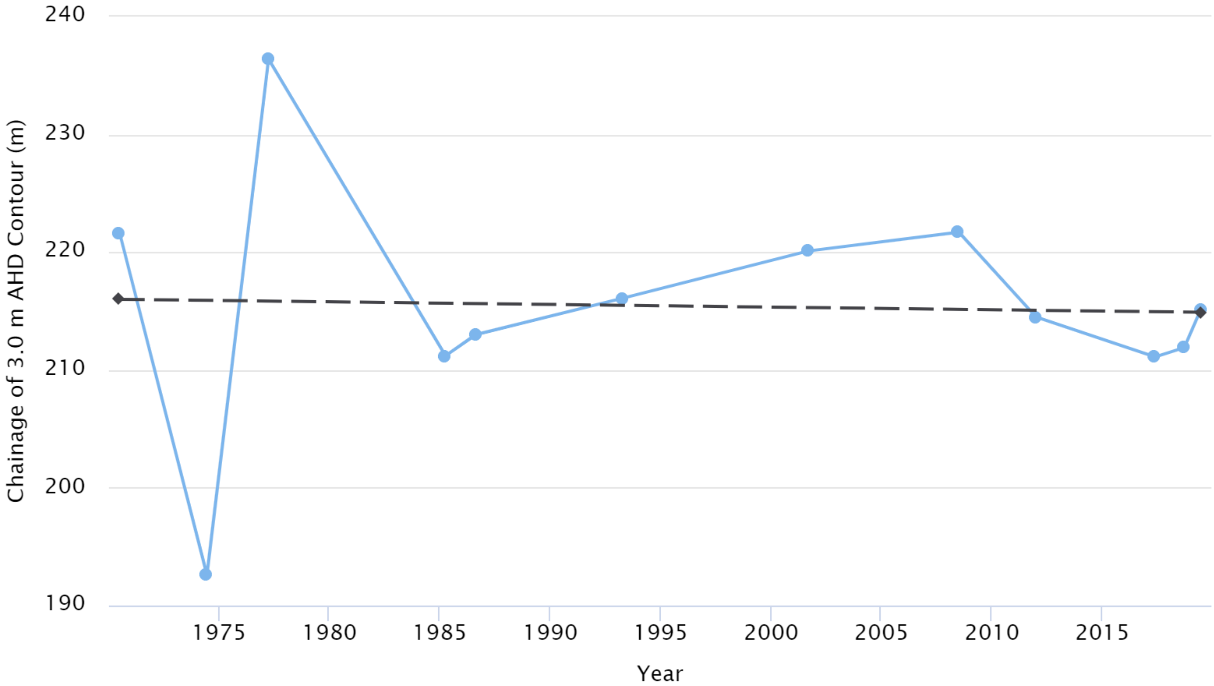

Figure 10: Trend in 3m AHD contour position seaward of proposed building from 1970 to 2019

5. PREVIOUS REPORTS ON SITE

In a 2 December 2014 report (prepared by Peter Horton in previous employment with Royal HaskoningDHV) entitled "Coastal Engineering Advice in Relation to Potential Redevelopment of Mona Vale SLSC", the relative merits of two locations (denoted as "Site 1" and "Site 2" respectively) for the redevelopment of Mona Vale SLSC were considered from a coastal engineering perspective. Site 1 was at the current SLSC (as has been adopted for the currently proposed redevelopment of the SLSC, as per Development Application DA2018/1771), while Site 2 was just north of the current amenities building at the northern end of Mona Vale Beach.

The 2 December 2014 report was updated by a 20 February 2015 report entitled "Additional Coastal Engineering Advice in Relation to Potential Redevelopment of Mona Vale SLSC (Including Consideration of New Geotechnical Information)" (again prepared by Peter Horton in previous employment), in which geotechnical information[2] derived from boreholes at each site was considered. The subsurface conditions at Site 2 (near the proposed amenities building) are discussed in Section 6.

[2] As documented in JK Geotechnics (2015).

6. SUBSURFACE CONDITIONS

6.1 JK Geotechnics Investigations

As noted in Section 5, JK Geotechnics drilled a borehole in the vicinity of the proposed building in 2015. The location of this borehole is depicted in green as "2015 BH" in Figure 11. At this location, medium dense sand was found from the surface at 6.6m AHD down to 1.6m AHD, and then very stiff silty clay down to -1.2m AHD, where weathered shale bedrock was encountered.

As discussed in JK Geotechnics (2019), four additional boreholes were drilled in the vicinity of the proposed building in October 2019, with the location of these boreholes depicted in green in Figure 11 as BH1 to BH4. The subsurface conditions at these four boreholes are listed in Table 1, along with surface levels derived from the 2020 survey provided by Council. These four 2019 boreholes were not extended down to bedrock, ie the termination of the boreholes was within the continuing clay layer.

Table 1: Surface and subsurface levels (m AHD) at four boreholes of JK Geotechnics (2019)

Material	Location			
	BH1	BH2	BH3	BH4
Surface level	6.4	6.7	6.6	6.8
Fill down to	6.1	6.3	5.2	4.7
Medium dense sand down to	1.2	1.5	1.7	1.6
Silty clay[3] down to	-0.1	0.2	0.1	0.3

JK Geotechnics undertook additional geotechnical investigations in May 2020, with probing to determine rock levels at 9 locations on the beach near the waterline, and the drilling of 4 boreholes on the beach seaward of the proposed building. The locations of the boreholes, (BH205 to BH208) are depicted in yellow in Figure 11, with subsurface conditions listed in Table 2. Bedrock was encountered at the lowest level listed at each borehole, eg bedrock was encountered at -1m AHD at BH205.

Table 2: Surface and subsurface levels (m AHD) at four boreholes of JK Geotechnics in May 2020

Material	Location			
	BH205	BH206	BH207	BH208
Surface level	2.5	2.4	2.0	3.0
Sand down to	0.5	-0.6	0.0	0.0
Silty sandy clay down to	-1.0	-3.6	-2.5	-1.5

JK Geotechnics undertook additional geotechnical investigations in June 2020, with 3 boreholes drilled over the proposed building footprint. The locations of the boreholes, (BH301 to BH303) are depicted in white in Figure 11, with subsurface conditions listed in Table 3. Bedrock was not encountered at BH301, and was encountered at -1.9m AHD at BH302 and BH303 (ie, bedrock was encountered at the base of the silty clay layer at BH302 and BH303).

Table 3: Surface and subsurface levels (m AHD) at three boreholes of JK Geotechnics in June 2020

Material	Location		
	BH301	BH302	BH303
Surface level	6.6	6.6	6.6
Sand down to	1.1	1.1	1.1

[3] Stiff to very stiff silty clay at all boreholes, except firm at BH4 down to 0.8m AHD, then very stiff below this.

Material	Location		
	BH301	BH302	BH303
Silty clay down to	-2.9	-1.9	-1.9
End of borehole	-2.9	-2.7	-8.4

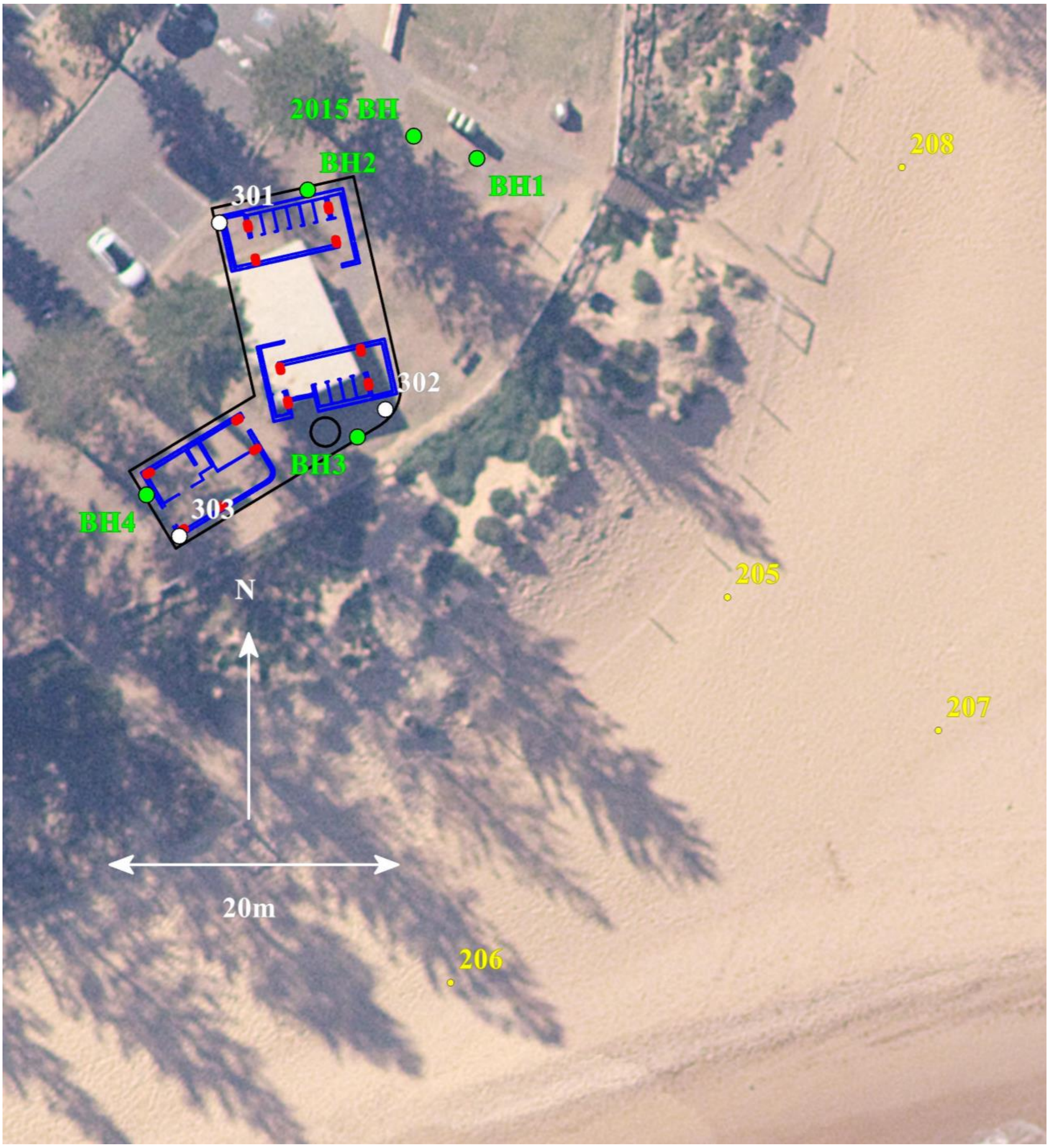

Figure 11: Locations of JK Geotechnics (2015, 2019) boreholes in green, May 2020 boreholes in yellow and June 2020 boreholes in white (17 August 2018 aerial photograph)

In Figure 12, the AHD levels of the clay and bedrock layers at the boreholes are depicted in light blue and orange colours respectively. The locations of the probing sites are also depicted in Figure 12 in dark blue, along with the AHD rock levels at these locations.

Figure 12: AHD levels of top of clay (light blue) and top of bedrock (orange) in boreholes, and probed bedrock AHD levels (dark blue) in JK Geotechnics geotechnical investigations, with proposed building roof outline in black (17 August 2018 aerial photograph)

6.2 Implications for Probabilistic Coastal Hazard Definition and Structural Design

The active coastal erosion zone extends above about -1m AHD at beaches with an entirely sandy subsurface. The probing depicted in Figure 12 indicated rock levels between 0m AHD and 0.7m AHD at the waterline, with an average of 0.3m AHD over the 9 locations probed. To the south of the proposed building, the prevailing critical storm wave direction for maximum erosion near the building, rock levels varied from 0.3m to 0.7m AHD. For the report herein, the bedrock level near the waterline was taken to be 0.3m AHD. This bedrock 'sill' would be expected to dissipate some wave energy and reduce wave erosion compared to a fully sandy subsurface down to a typical scour level of -1m AHD.

It is evident in Figure 12 that bedrock levels dip moving landward of the probing locations (to about -2.5m to -3.6m AHD), before rising again to about -2m ±1m AHD in the vicinity of the proposed building. Therefore, bedrock would not be expected to constrain beach erosion landward of the probing locations, although it is reiterated that the bedrock sill near the typical waterline would be expected to reduce erosion (compared to a fully sandy beach) due to dissipation of wave energy and providing some protection from direct wave attack at the lower elevations below the sill.

The upper surface level of clay near the proposed building is in the vicinity of 1.1m to 1.7m AHD, with an average of 1.4m AHD over 6 locations. It is expected that this clay would be significantly more resistant to erosion and slumping than sand. The upper surface level of clay in the mid-beach area was found to be about 0m ± 0.5m AHD, which may also be somewhat resistant to erosion.

For analysis purposes, it was assumed that beach erosion at the subject site would be reduced by (0.3-(-1)) ÷ (6.6+1), that is by 17%, where 0.3m AHD is the bedrock sill level, -1m AHD is a typical sandy beach scour level, and 6.6m AHD is the ground level in the vicinity of the proposed building. That is, the reduction in beach erosion has been assumed to be proportional to the vertical portion of the profile that is inerodible at the sill[4]. This analysis ignores any effect of clay in reducing erosion.

Note that the May and June 2020 investigations of JK Geotechnics are documented in JK Geotechnics (2020). This investigation also included Emerson Class Number testing of selected residual clay samples, namely:

- at 0.2m to 0.6m AHD in BH301, which was slightly dispersive to non-dispersive with an Emerson Class Number of 4, indicating a low potential for dispersive behaviour;
- at -2.4 to -2.9m AHD in BH301, which was slightly to non-dispersive with an Emerson Class Number of 5, indicating a low potential for dispersive behaviour; and
- at -0.9 to -1.4m AHD in BH303, which was dispersive with an Emerson Class Number of 2, indicating a moderate potential for dispersive behaviour.

The more dispersive the clay, the more likely it is that that it would break down when subject to inundation and wave action. If there was an entirely sandy subsurface, the 'default' scour level (maximum vertical erosion extent) for structural design would be -1m AHD. With stiff clay at a minimum level of 1.1m AHD and an average level of 1.4m AHD under the proposed building, this would be expected to reduce the vertical extent of scour. In consultation with JK Geotechnics and TTW (the structural engineer for the proposed building) and considering the generally low potential for dispersive behaviour in the clays, it was agreed that a scour level of 1m below the lowest clay level was reasonable for design (that is, a design scour level of 0.1m AHD was considered to be reasonable).

That is, the deep foundation piles for the proposed building should extend into bedrock to support the building if undermined down to a level of 0.1m AHD. Horton Coastal Engineering also supplied TTW with sand slumping and wave forces to allow for on the foundation piles,

[4] Note that this methodology has been used at other sites, eg Hyams Beach in the Shoalhaven City Council Local Government Area, including peer review by Lex Nielsen from Advisian.

wave uplift forces on the slab, and wave runup forces on the building face to assist with their structural design.

To take account of the clay in reducing erosion under the proposed building in probabilistic coastal hazard definition, it was assumed that landward of the current fenceline that is located seaward of the proposed building, there would be a reduction in beach erosion in addition to the 17% reduction due to the bedrock sill. With average clay levels at about 1.4m AHD, this reduction due to clay was assumed to be (1.4-(-1)) ÷ (6.6+1), that is about by 32%, where -1m AHD is a typical sandy beach scour level and 6.6m AHD is the ground level in the vicinity of the proposed building. That is, the reduction in beach erosion due to clay has been assumed to be proportional to the vertical portion of the profile where clay is present (landward of the fenceline position). This does not contradict the structural design allowance of scour down to 0.1m AHD, which is for a different purpose and where conservatism is justified given that the consequences of foundation failure could be catastrophic damage to the building. The reduction of 32% is for the purpose of probabilistic coastal hazard definition, where best estimates of input parameters are required.

7. TOLERABLE RISK ANALYSIS FOR EROSION/RECESSION

7.1 Framework

In 2013, the author (with assistance of other peer reviewers) developed a methodology to define the appropriate setback for new beachfront development on the basis of 'acceptable risk' to property, as described in Horton et al (2014) and Horton and Britton (2015).

In the interest of conciseness, detailed background information on the development of the acceptable risk methodology is not included herein. The framework of the adopted risk assessment methodology came from Australian Geomechanics Society (AGS) procedures for landslide risk management (AGS 2007a, b), modified to be appropriate for "sandy beach" coastline hazards. Various reports completed in 2017 can be referred to for that background, including the *Coastal Zone Management Plan for Collaroy Narrabeen Beach and Fishermans Beach*, the *Coastal Zone Management Plan for Bilgola Beach (Bilgola) and Basin Beach (Mona Vale)*, and *Risk Assessment to Define Appropriate Beachfront Development Setback in Relation to Coastline Hazards for Redevelopment of Mona Vale SLSC*.

Note that the AGS (2007a, b) procedures were developed over a period of more than a decade via a Working Group of experts, and have been widely applied in geotechnical engineering practice since 2000[5]. The AGS procedures were also subject to peer review and discussion through the AGS Landslides Taskforce, with 23 members. That is, the AGS procedures can be considered to be an established, recognised and peer reviewed methodology for defining landslide risk for development assessment. With modification to be appropriate for 'sandy beach' coastline hazards, it is considered that the same principles of the AGS procedures can be applied to define 'tolerable risk' for beachfront development, as has been undertaken herein.

In the AGS methodology, there is a distinction between "acceptable risk" and "tolerable risk". As stated in AGS (2007a):

> It is important to distinguish between "acceptable risks" and "tolerable risks". "Tolerable risks" are risks within a range that society can live with so as to secure certain benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable. "Acceptable risks" are risks which everyone affected is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort[6]. AGS suggests that for most development in existing urban area[s,] criteria based on "tolerable risks" levels are applicable because of the trade-off between the risks, the benefits of development and the cost of risk mitigation.

That is, adopting a "tolerable risk" standard for the proposed building is allowable, and has been adopted herein.

The terms "acceptable", "tolerable" and "allowable" are essentially synonymous by dictionary definition. However, for the report herein, specific and distinct definitions were applied to describe "acceptable risk", "tolerable risk" and "allowable risk", as described above. To reiterate, it is considered to be appropriate to adopt a "tolerable risk" standard for the proposed building. A tolerable risk analysis for the proposed building is set out below.

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[5] Using preceding AGS documents as discussed in AGS (2007a).
[6] As also defined in AGS (2007a), "acceptable risk" is a risk for which, for the purposes of life or work, we are prepared to accept as it is with no regard to its management. Society does not generally consider expenditure in further reducing such risks justifiable.

The tolerable risk analysis herein is based on coastal erosion caused by meteorological events ('coastal storms') leading to large waves and elevated water levels, and recession due to net sediment loss and sea level rise. Tsunamis, which have rarer frequencies of occurrence and different driving processes to coastal storms[7], have not been considered.

The probabilistic assessment herein followed a full Monte Carlo probability simulation procedure, enhancing the more approximate procedures used in the studies listed above. Monte Carlo simulation uses estimated potential ranges in input parameters (along with their estimated probability distributions) sampled randomly over many simulations (over 1.4 million in this study for each year simulated) to obtain a range of outputs that can then be assigned probabilities based on their percentage occurrence in the output range.

7.2 Probability Terminology

The following terminology has traditionally been used to describe event probabilities in past engineering practice, for example as described in the Third Edition of *Australian Rainfall and Runoff* in 1987 (Pilgrim et al, 1987) and previous editions in 1958 and 1977:

- "Average Recurrence Interval" (ARI), the average time period between occurrences equalling or exceeding a given value; and
- "Annual Exceedance Probability" (AEP), the probability of an event being equalled or exceeded within a year.

For example, a 100 year ARI event has a 1% AEP. With release of the most recent edition of *Australian Rainfall and Runoff* (Ball et al, 2019a), there were the following recommendations:

1. avoiding the use of "ARI" altogether;
2. events equal to or more frequent than 1 year ARI (which is 63.2% AEP) being expressed as X Exceedances per Year (EY), eg 2 EY is equivalent to the former 0.5 year ARI term ($EY = 1/ARI$);
3. a preference of expressing events of 1% AEP and rarer as "1 in X AEP", where $100/X$ would be the equivalent percentage probability (eg 1% AEP is the same as 1 in 100 AEP); and
4. an acceptance of using the AEP % terminology for 63.2% AEP events and rarer.

Given that the focus herein was on events rarer than 60% AEP, and the clear understanding of AEP as a probability, the AEP % terminology has generally been adopted herein to enable use of a consistent and meaningful term. The relationship between ARI, EY and AEP for various events is listed in Table 4.

Table 4: Relationship between Average Recurrence Interval (ARI), Exceedances per Year (EY) and Annual Exceedance Probability (AEP)

ARI (years)	EY	AEP (%)
0.5	2	86.5
1	1	63.2
2	0.5	39.3
5	0.2	18.1

[7] Tsunamis are typically driven by earthquakes, landslides, large scale collapse of volcanic islands, or asteroid impacts, with earthquakes being the dominant tsunami source in NSW for events more frequent than 500 year average recurrence interval (Somerville et al, 2009).

ARI (years)	EY	AEP (%)
10	0.1	9.5
20	0.05	4.9
50	0.02	2.0
100	0.01	1.0
1,000	0.001	0.1
10,000	0.0001	0.01
100,000	0.00001	0.001

The relationship between AEP and ARI is defined by the so-called Langbein formula (Ball et al, 2019b), originally defined by Langbein (1949), defined as follows and as depicted in Figure 13:

$$AEP = 1 - e^{-\frac{1}{ARI}} \quad (1)$$

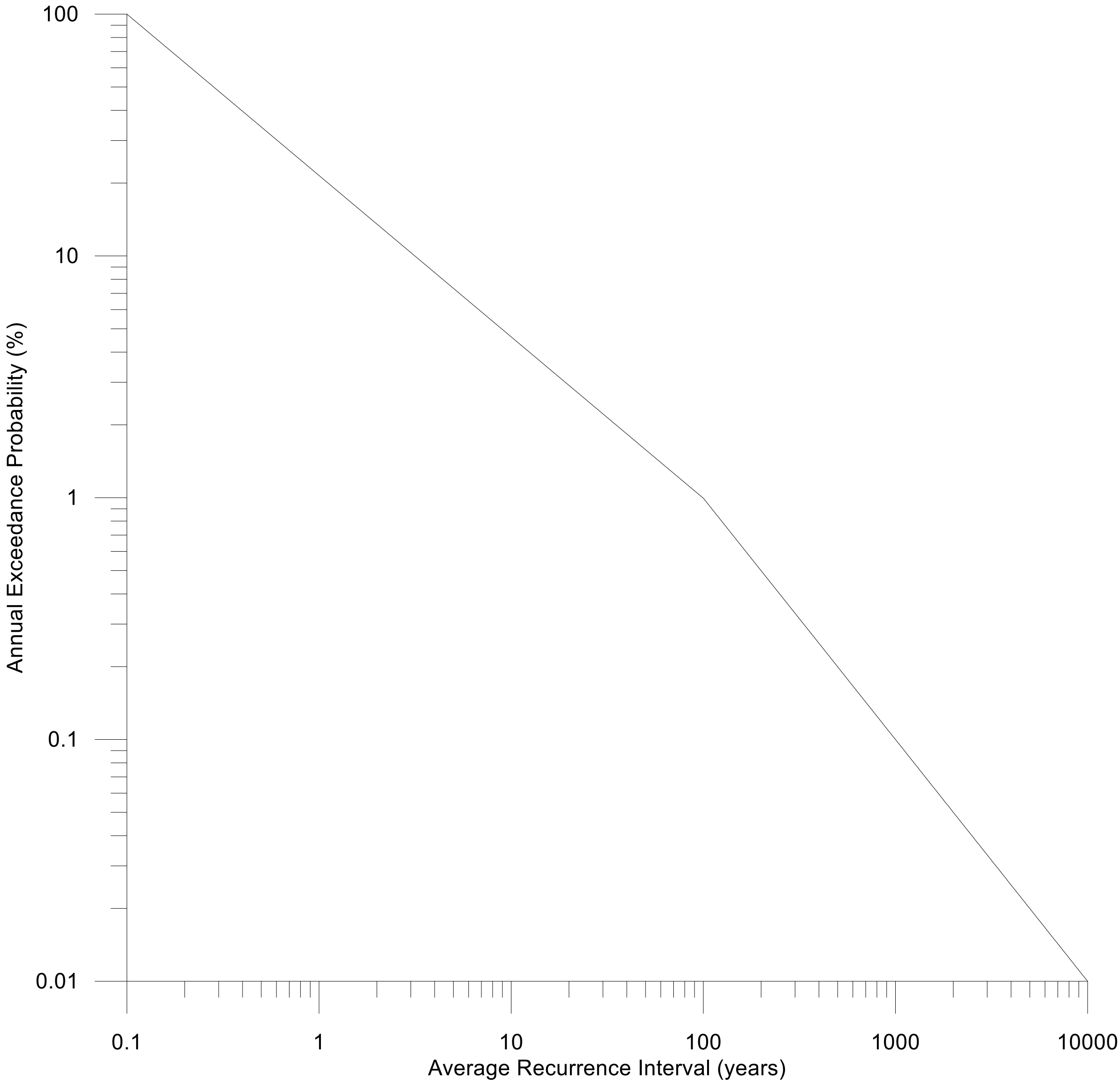

Figure 13: Relationship between AEP and ARI based on the Langbein formula

7.3 Generic Explanation of Hazard Zones

Nielsen et al (1992) has delineated various coastline hazard zones as discussed below and depicted in Figure 14, assuming an entirely sandy (erodible) subsurface above -1m AHD.

The *Zone of Wave Impact* (ZWI) delineates an area where any structure or its foundations would suffer direct wave attack during a severe coastal storm. It is that part of the beach which is seaward of the beach erosion escarpment.

A *Zone of Slope Adjustment* (ZSA) is delineated to encompass that portion of the seaward face of the beach that would slump to the natural angle of repose of the beach sand following removal by wave erosion of the design storm demand. It represents the steepest stable beach profile under the conditions specified.

A *Zone of Reduced Foundation Capacity* (ZRFC) for building foundations is delineated to take account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. Nielsen et al (1992) recommended that structural loads should only be transmitted to soil foundations outside of this zone (ie landward or below), as the factor of safety within the zone is less than 1.5 during extreme scour conditions at the face of the escarpment. In general (without the protection of a terminal structure such as a seawall), dwellings/structures not piled and located within the ZRFC would be considered to have an inadequate factor of safety.

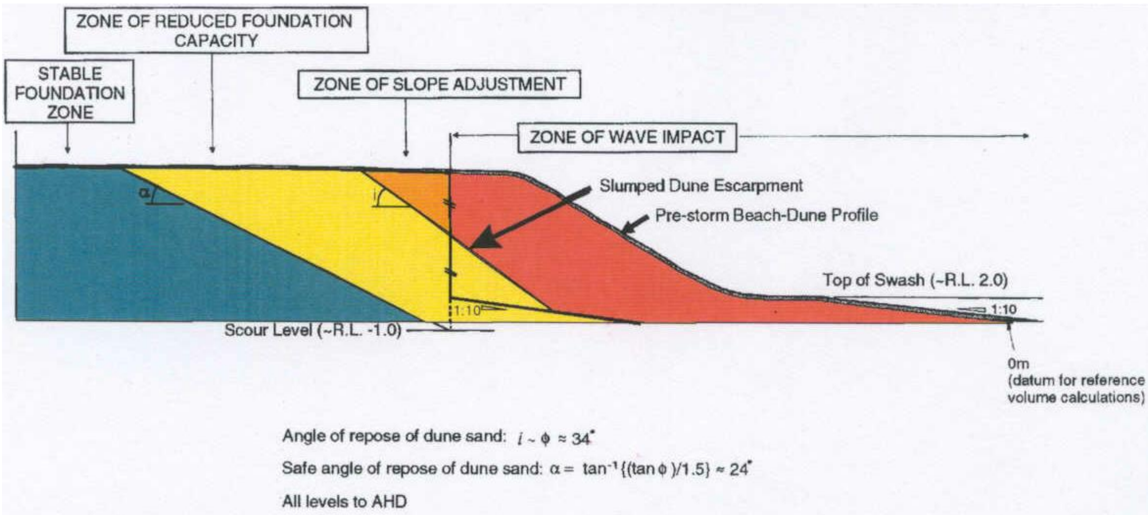

Figure 14: Schematic representation of coastline hazard zones (after Nielsen et al, 1992)

All coastal hazard line positions herein were defined at the landward edge of the Zone of Slope Adjustment as per the methodology in Nielsen et al (1992).

7.4 Design Life

A design life of 40 years has been adopted herein, as agreed with Council. This is considered to be acceptable for the non-habitable structure proposed, and is consistent with the design life used in various Australian Standards, including *AS 3600 - Concrete Structures*.

Therefore, probabilistic coastal hazard (Monte Carlo) simulations were undertaken over a 40 year period extending to 2060, with 41 years of simulations undertaken including 2020 as an immediate simulation.

That stated, structural design of the building is being undertaken for a 50 year life, and the conservative foundation design (see Section 6.2) is considered to be such that the building is likely to be remain supported on its deep foundations if undermined by coastal erosion over a period well beyond 2060.

7.5 Definition of Tolerable Risk

7.5.1 Preamble

Risk is defined as the product of likelihood and consequences, with likelihood discussed in Section 7.5.2, and consequences discussed in Section 7.5.3.

Only risk to property is evaluated herein, not risk to life. In the coastal beach context, risk to life related to development at the Mona Vale Amenities Building was considered to be acceptably low as:

- coastal storms (large waves and elevated water levels) are generally foreseeable at least 24 hours in advance, with warnings issued by the Bureau of Meteorology;
- a large component of elevated water level is astronomical tide, which can be accurately predicted into the future;
- erosion would generally be expected to be greatest for a few hours near the peak of the tide;
- the progress of erosion on a beach is visible and perceptible, and would not generally be expected to proceed undetected to undermine development without warning;
- it is highly unlikely that a person would be occupying the building and would be unaware (or would not have been made aware) that the building was at imminent threat of undermining;
- the State Emergency Service (SES), if mobilised, has powers to warn and evacuate people if required (as does NSW Police);
- Council could request that the SES takes on a Combat Agency role if an actual emergency was occurring and it had not already been mobilised; and
- even if undermined, the proposed building would not be expected to be significantly damaged, as it is proposed to be founded on deep piles, as discussed in Section 6.2.

These factors mean that people would have a low probability of occupancy and/or loss of life during an actual storm event that could threaten the building, and hence have a low risk to life in such an event, which would satisfy the acceptance criteria given in AGS (2007a).

7.5.2 Likelihood

Using probabilistic coastal hazard definition, any coastal hazard position has a probability (likelihood) associated with it. For example, a particular position along a shore-normal cross-section may have a 1.5% probability of being reached by erosion/recession in the year of 2032, or a cumulative probability of 64% of being reached by erosion/recession at least once over the design life from 2020 to 2060.

AGS (2007a, b) used six likelihood descriptors, as set out in Column 1 of Table 5[8], along with associated indicative annual exceedance probabilities (AEP's) as per Column 2. For a design life of 40 years and assessment over 41 years (with the immediate year of 2020 also included),

[8] The heading of each column shows the column number.

the cumulative probability of an event of a particular AEP occurring at least once over 41 years was determined as per Column 3 of Table 5, using the formula[9]:

$$J = 1 - (1 - P)^L \tag{2}$$

where P is the AEP, L is the design life (years) and J is the cumulative probability of the event with an AEP of P occurring at least once over the design life.

Table 5: Likelihood descriptors and associated probabilities used by AGS (2007a, b)

(1) Descriptor	(2) AEP (%)	(3) Cumulative probability over 41 years (%)
Almost Certain	10	98.7
Likely	1	33.8
Possible	0.1	4.0
Unlikely	0.01	0.41
Rare	0.001	0.041
Barely Credible	0.0001	0.0041

7.5.3 Consequences

AGS (2007a, b) used five consequence descriptors. These descriptors were related to the percentage of damage caused to a property due to a landslide event, relative to the improved value of the property (land plus structures), as listed in Table 6.

Table 6: Consequence descriptors from AGS (2007a, b)

Descriptor	Approximate cost of damage	Description
Catastrophic	200%	Structure(s) completely destroyed and/or large scale damage requiring major engineering works for stabilisation. Could cause at least one adjacent property major consequence damage.
Major	60%	Extensive damage to most of structure, and/or extending beyond site boundaries requiring significant stabilisation works. Could cause at least one adjacent property medium consequence damage.
Medium	20%	Moderate damage to some of structure, and/or significant part of site requiring large stabilisation works. Could cause at least one adjacent property minor consequence damage
Minor	5%	Limited damage to part of structure, and/or part of site requiring some reinstatement stabilisation works
Insignificant	0.5%	Little damage

For a coastal erosion/recession event, with the proposed building on deep piled foundations (see Section 6.2), there would not be significant building damage expected for such an event or sequence of events. Therefore, if the proposed building is undermined by coastal erosion/recession events in the future, the consequences of these events would be related to the erosion of the land and the required stabilisation of the land that would result, not building damage. Land erosion is a much less significant consequence than building damage, as erosion can be restored through relatively low cost and simple earthmoving techniques.

For the report herein, particular locations along a shore-normal cross-section were designated for each of the 5 consequence descriptors, as depicted in Figure 15. Note that the red line in Figure 15 is the section location adopted for all analysis.

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[9] For example, see Laurenson (1987).

The “insignificant” consequence was designated as the erosion/recession hazard line (landward edge of the ZSA, see Section 7.3) that reached the seaward edge of the proposed building.

The “minor” consequence was designated as the erosion/recession hazard line that undermined about one-third of the proposed building, whereby part of the site would require some reinstatement stabilisation works.

The “medium” consequence was designated as the erosion/recession hazard line that undermined about two-thirds of the proposed building, whereby a significant part of the site would require reinstatement stabilisation works.

The “major” consequence was designated as the erosion/recession hazard line that undermined landward of the entire proposed building, whereby land reinstatement beyond the building footprint would be required and access to the building would be lost until that reinstatement had been carried out.

The “catastrophic” consequence was designated as the erosion/recession hazard line that extended well landward of the proposed building into the car park, whereby major land reinstatement stabilisation works would be required.

It is recognised that there is some subjectivity to the consequence designations in Figure 15, but it is considered that they are conservative, with the cost of damage unlikely to reach the value of the property (land plus structures) percentage levels listed in Table 6 for each consequence (given that damage would be to the land, and not expected to be to the building).

Figure 15: Designated consequence locations to match five AGS (2007a, b) consequence descriptors (aerial photograph taken 2 August 2020)

7.5.4 Probabilities Defining Tolerable Risk for Adopted Consequences

A risk matrix is presented in AGS (2007a, b), as shown in Figure 16. For example, if the consequences of a particular "unlikely" event were "major", then the risk would be considered "medium".

Likelihood	Consequence				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost Certain	Very High	Very High	Very High	High	Medium
Likely	Very High	Very High	High	Medium	Low
Possible	Very High	High	Medium	Medium	Very Low
Unlikely	High	Medium	Low	Low	Very Low
Rare	Medium	Low	Low	Very Low	Very Low
Barely Credible	Low	Very Low	Very Low	Very Low	Very Low

Figure 16: AGS (2007a, b) risk matrix

A key aspect of the AGS (2007a, b) approach is that they defined the tolerable level of risk as being "medium" as per the matrix in Figure 16. Therefore, each consequence level has an associated likelihood and probability, as listed in Table 7.

Table 7: Probabilities of each consequence level to achieve tolerable risk

Consequence	Likelihood to achieve medium (tolerable) risk from Figure 16	Cumulative probability (not to be exceeded) to achieve tolerable risk over design life from Table 5 (%)
Catastrophic	Rare	0.041
Major	Unlikely	0.41
Medium	Possible	4.0
Minor	Likely	33.8
Insignificant	Almost Certain	98.7

Probabilistic coastal hazard definition is carried out in Section 8, to determine the cumulative probabilities of each consequence level position being realised over the design life, and thus assess whether the proposed building is at a tolerably low level of risk.

8. PROBABILISTIC COASTAL HAZARD DEFINITION FOR EROSION/RECESSION

8.1 Preamble

The Monte Carlo analysis procedure adopted for probabilistic coastal hazard definition herein is described in Section 8.2. There are various coastal hazard definition components and considerations, including storm demand (Section 8.3), the base profile for hazard definition (Section 8.4), long term recession due to net sediment loss (Section 8.5), sea level rise (Section 8.6), and long term recession due to sea level rise (Section 8.7).

In Section 8.8, the Monte Carlo analysis results are summarised. In undertaking the analysis, consequences were devised assuming that the building was supported on deep piles, as discussed in Section 6.2 and Section 7.5.3. Other risk minimisation measures for erosion/recession besides piling are described in Section 8.9.

8.2 Monte Carlo Analysis

The normal distribution is a useful continuous probability distribution to represent variables that can be described by a likely range (maximum and minimum to represent two standard deviations or 95% of the range), but the exact form of the probability distribution is not known. This applies to many of the variables used to define coastal hazard lines for future planning periods.

If engineering judgement can be used to define the range of a variable, for the normal distribution this in turn defines a mean (the average of the two standard deviations maximum and minimum values) and standard deviation (quarter of the difference between the two standard deviations maximum and minimum).

The following parameters were assumed to be described by a normal distribution in the analysis:

- long term recession due to net sediment loss (see Section 8.5);
- sea level rise (see Section 8.6); and
- part of the distribution for inverse slope, a parameter used in the calculation of long term recession due to sea level rise (long term recession due to sea level rise was determined by the product of sea level rise and inverse slope, see Section 8.7).

In the Monte Carlo analysis, the probability distribution for each parameter was randomly sampled 1,048,576 times. The resulting results were then analysed to determine percentiles of exceedance for each of the five consequence locations. The steps were as follows for each of these 1.05 million scenarios. For the particular year under consideration:

1. randomly assign storm AEP between 0 and 100%;
2. determine storm demand for random AEP based on relationships in Section 8.3;
3. determine chainage of landward edge of ZSA (C) for this storm demand;
4. randomly sample from the inverse of the cumulative normal distribution function for the rate of long term recession due to net sediment loss as per Section 8.5;
5. determine long term recession due to net sediment loss ($LTRNSL$) by multiplying by the years elapsed in the simulation (as explained in Section 8.5);
6. randomly sample from the inverse of the cumulative normal distribution function for sea level rise as per Section 8.6;

7. determine the inverse slope from its adopted probability distribution, for a random probability, as discussed in Section 8.7;
8. multiply sea level rise (Step 6) with inverse slope (Step 7), to determine long term recession due to sea level rise ($LTRSLR$);
9. determine chainage of hazard line for this scenario as $C–LTRNSL–LTRSLR$; and
10. with these steps repeated 1.05 million times, a probability distribution of hazard line chainage can be developed, and hence the probability of erosion/recession reaching a particular consequence location can be determined.

The above steps were repeated 41 times, for each year from 2020, 2021, etc to 2060. To calculate the cumulative probability at a particular consequence location, each yearly AEP to reach that location was applied as a value loss function, as used in cost benefit analysis. For example, if the initial 'value' of the proposed building and land was 100%, and the probability of a particular consequence line being reached in 2020 was 0.23%, then its remaining value at the start of 2021 would be 99.77%. Then, in 2021, if the probability of a particular consequence line being reached was 0.24%, then 99.53% would be remaining at the end of 2021, continuing using the same methodology for every year until the end of 2060. At the end of 2060, if the remaining value was 86.36%, then the cumulative probability of the particular consequence line being reached over the design life would be 13.64%.

8.3 Storm Demand

During storms, large waves, elevated water levels and strong winds can cause severe erosion to sandy beaches. Storm demand represents the volume of sand removed from a beach (defined herein as the volume lost above 0m AHD) that could be expected due to a severe storm or from a series of closely spaced storms.

Based on measurements at NSW beaches, Gordon (1987) derived relationships between storm demand and average recurrence interval (ARI), at both "high demand" (at rip heads) and "low demand" (away from rip heads) areas. The rip head relationship is depicted in solid black in Figure 17.

Gordon (1987) estimated that the storm demand above 0m AHD was about 220m^3/m for the 100 year ARI event, for exposed NSW beaches at rip heads, and depicted a relationship between storm demand (plotted vertically) and the logarithm of ARI (plotted horizontally) that was linear (as evident in Figure 17). With the preference for use of AEP over ARI herein, an AEP axis has also been added to Figure 17, applicable to the dashed lines. Note that for rarer than 100 year ARI (1% AEP), linear-log extrapolation has been used in Figure 17.

Applying the 17% reduction in erosion due to the bedrock sill and 32% reduction in erosion due to underlying clay landward of the fenceline, as described in Section 6.2, the revised Gordon (1987) relationship applying at the subject site is as depicted in red in Figure 17.

Although the entire beach is unlikely to be eroded uniformly in a coastal storm (erosion tends to be concentrated at rip heads, which are typically a few hundred metres apart), it was conservatively assumed that the subject site would experience the full rip-head storm demand in all storms. In the method of Nielsen et al (1992), a ϕ value (natural angle of repose of sand, also known as the friction angle) of 33° was adopted, as per WorleyParsons (2012).

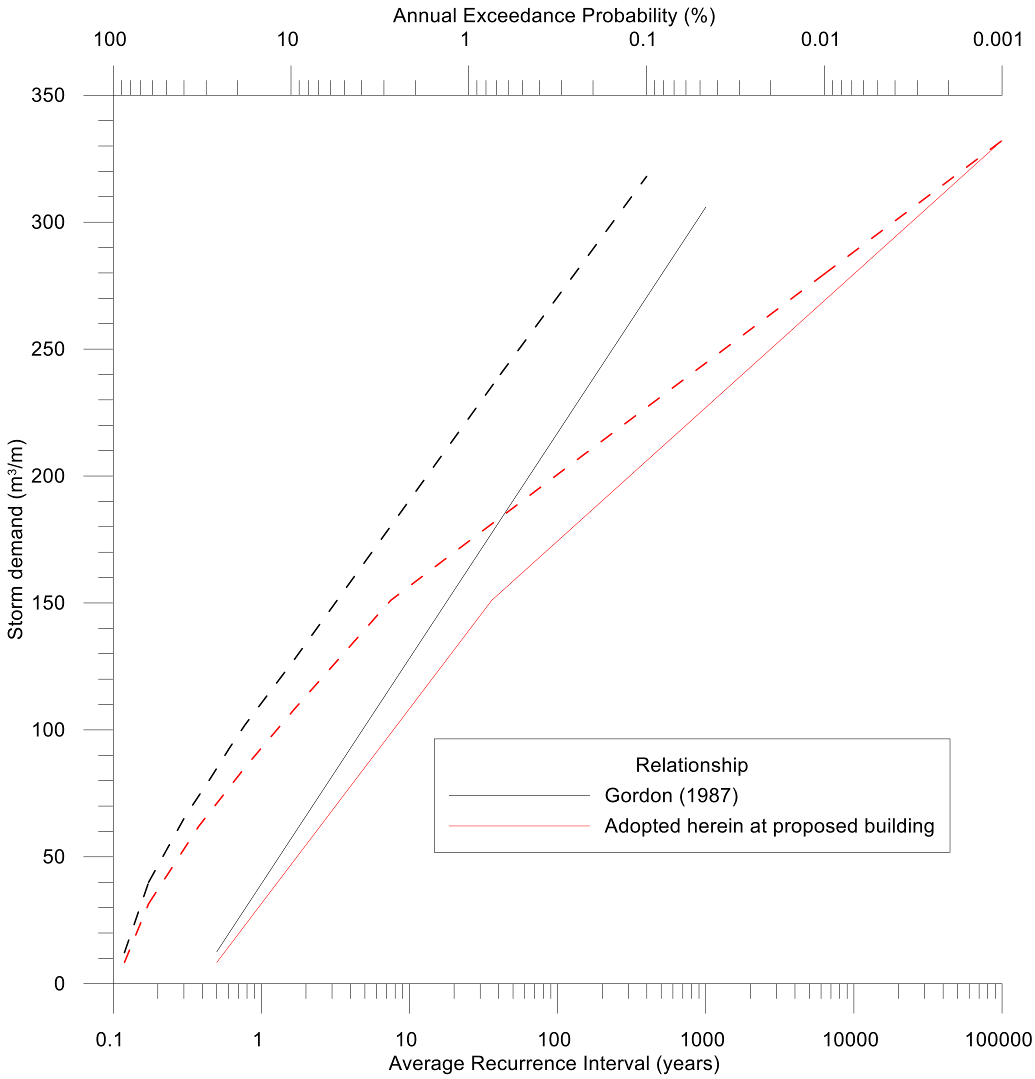

Figure 17: Relationship between storm demand and ARI or AEP as developed by Gordon (1987) for rip-head areas (black), along with adopted relationship for investigation herein in red, with ARI relationships as solid lines and AEP relationships dashed

8.4 Application of Storm Demand to Beach Profiles

In applying a storm demand volume at a particular beach profile to determine the position of a hazard line (for example, defined at the landward edge of the ZSA, see Section 7.3), the hazard line position can vary depending on the profile date used. This is because beach volumes constantly change in the study area as a result of short-term erosion/accretion cycles.

A key to appropriately defining the limit of erosion for a particular storm demand volume is the selection of a pre-storm profile (beach state). It is most appropriate to select a relatively accreted profile as the base (pre-storm) profile for hazard definition, typically known as an "average beach-full" profile in NSW coastal engineering practice, as storm demands in the order of 220m^3/m (ignoring bedrock) would only be expected to occur at accreted beach profiles. This is because eroded profiles have lower storm demands due to dissipation of wave energy on offshore bars (Harley et al, 2009). It is also advantageous to select a recent profile, where possible, such that the base profile is relatively similar to the current general shape of the beach.

Unfortunately, the beach profile data analysed in Section 4 is not perpendicular to the beach contours, so cannot be used for base profile definition. However, Horton Coastal Engineering holds LiDAR data covering the subject site for dates in 2007, 2011 and 2018, which was used to generate a cross section for each date at the red location in Figure 15.

The difference in using these three profiles represents only a 3m difference in the chainage of the 1% AEP immediate coastal hazard line. The 2018 date was adopted for analysis as it is the most recent profile, and was volumetrically the middle profile of the three. It is considered to be a conservative "average beach-full" profile. The storm demand volume removed from the beach profile was calculated using the method of Nielsen et al (1992) to determine the position (landward edge) of the ZSA for each Monte Carlo simulation.

8.5 Long Term Recession due to Net Sediment Loss

The beach profile analysis outlined in Section 4 indicated mild accretion or long-term stability of the subject site. That is, adoption of a best estimate zero long term recession rate due to net sediment loss would be reasonable in the study area. However, this rate (net stability) may not continue, and cannot necessarily be expected in the future as the beach recedes due to sea level rise (thus diminishing the width of dune vegetation and hence the capacity of the dune to capture sand) and due to other climate change effects such as ocean acidification (that may affect sediment production and structure).

To be conservative herein, a two standard deviations minimum rate of zero was adopted, with a two standard deviations maximum (recession) rate of -0.05m/year adopted, and a mean of -0.025m/year. This means that after applying the normal distribution, the percentiles for the long term recession due to net sediment loss rate were as follows:

- standard deviation of 0.0125, so 68.3% of values between -0.0125 and -0.0375m/year; and
- two standard deviations of 0.025, so 95.4% of values between 0 and -0.05m/year.

Given that the base beach profiles for hazard definition were dated in 2018, to project long term recession due to net sediment loss into the future gives a period of 2 years at 2020, 3 years at 2021, etc, to 42 years at 2060.

8.6 Sea Level Rise

In Intergovernmental Panel on Climate Change [IPCC] (2013), global mean sea level rise projections were presented for 4 representative concentration pathways (RCP) scenarios and the so-called Special Report on Emissions Scenarios (SRES) A1B scenario. The projections were based on results from 21 Atmosphere-Ocean Global Circulation Models for each scenario, with median, 95% and 5% exceedances reported (based on the range of model results). These 95% and 5% exceedances can be converted into 97.7% and 2.3% exceedances (two standard deviations minimum and maximum values respectively) by normal distribution analysis, if the mean sea level rise is assumed to be the average of the 95% and 5% exceedances.

Herein, the normal distribution parameters for sea level rise at each year from 2020 to 2060 (relative to 2018, with the base profile dated in 2018) inclusive were determined by averaging the median, 95% and 5% exceedances over the five scenarios in IPCC (2013). A selection of adopted global mean sea level rise values (at 2020, 2040 and 2060) derived from IPCC (2013) are presented in Table 8 (note that the analysis was undertaken on an annual basis).

Table 8: Global mean sea level rise values (relative to 2018) derived from IPCC (2013) for selected years of 2020, 2040 and 2060

Year	Sea level rise (m) averaged from 5 scenarios		
	95% exceedance	Median	5% exceedance
2020	0.006	0.008	0.010
2040	0.08	0.10	0.13
2060	0.15	0.22	0.28

It is also relevant to consider regional sea level rise variation, that is, how the study area sea level rise may vary from the global mean. From Figure 13.21(a) of IPCC (2013), although the resolution is coarse, it can be estimated that sea level rise in NSW is projected to be 10-20% larger than the global mean at 2081-2100 (compared to 1986-2005). Assuming these increases also apply from 2020 to 2060, the 95% exceedance, median and 5% exceedance global mean sea level rise values were increased by 10%, 15% and 20% respectively. The sea level rise scenarios in Table 9 were thus adopted herein (again, for selected years of 2020, 2040 and 2060).

Table 9: Adopted sea level rise values (relative to 2018) considering regional sea level rise variation, for selected years of 2020, 2040 and 2060

Year	Sea level rise (m)		
	95% exceedance	Median	5% exceedance
2020	0.007	0.009	0.013
2040	0.08	0.12	0.16
2060	0.17	0.25	0.34

From analysis of the normal distribution, 97.7% and 2.3% exceedances (two standard deviations minimum and maximum values respectively), mean, and the standard deviations of sea level rise are as listed in Table 10.

Table 10: Adopted two standard deviations minimum and maximum sea level rise values for selected years of 2020, 2040 and 2060

Year	Sea level rise (m)			
	97.7% exceedance	Mean	2.3% exceedance	Standard deviation
2020	0.0060	0.0095	0.013	0.0018
2040	0.076	0.12	0.16	0.022
2060	0.15	0.25	0.36	0.052

Using the mean and standard deviation in Table 10 (and determined for other years not shown in Table 10), the sea level rise for any probability of exceedance can be determined for each year.

8.7 Long Term Recession Due to Sea Level Rise

Bruun (1962) proposed a methodology to estimate shoreline recession due to sea level rise, the so-called Bruun Rule. It can be described by the equation (Morang and Parson, 2002):

$$R = \frac{S \times B}{h + d_c} \tag{3}$$

where R is the recession (m), S is the long-term sea level rise (m), h is the dune height above the initial mean sea level (m), d_c is the depth of closure of the profile relative to the initial mean sea level (m), and B is the cross-shore width of the active beach profile, that is the cross-shore distance from the initial dune height to the depth of closure (m). Equation 3 is a mathematical expression that the recession due to sea level rise is equal to the sea level rise multiplied by the average inverse slope of the active beach profile, with the variables as illustrated in Figure 18.

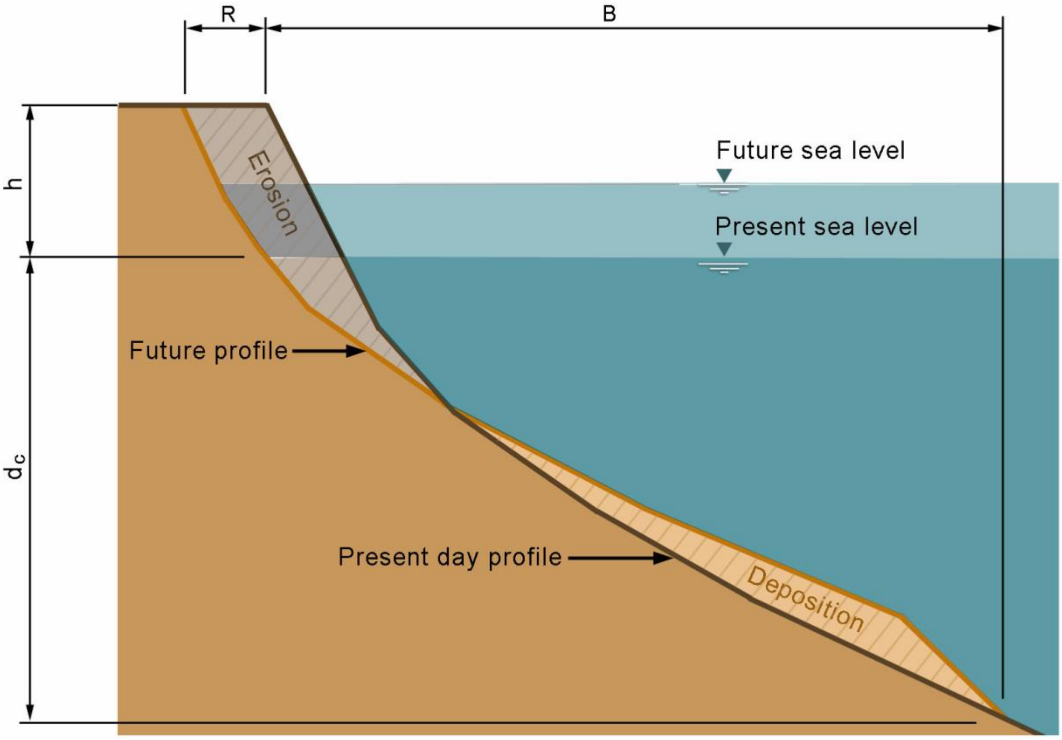

Figure 18: Illustration of variables in the Bruun Rule (not to scale)

At the subject site, the beach is perched above a bedrock platform, so the appropriate inverse slope for use in the Bruun Rule is considered to be the inverse slope of the beach face above this bedrock[10]. Analysing LiDAR profiles from 2007, 2011 and 2018, and taking the top of the beach face as being at either 4m AHD or 5m AHD, the average inverse slope of the beach face was 10.5 up to 4m AHD and 9.1 up to 5m AHD. Averaging over all dates and elevations (6 data points) the mean inverse slope was 9.8, with a standard deviation of 1.5.

To define a probability distribution for inverse slope, a normal distribution was assumed between one standard deviation below the mean and two standard deviations above the mean (between inverse slopes of 8.0 and 12.7, and corresponding range of values from 11.7% to 97.7%). For the lower 11.7% of values, a constant inverse slope of 8.0 as assumed (that is, the minimum inverse slope in the distribution was defined to be 8.0, to be conservative). For the values above 97.7%, the inverse slope was linearly interpolated between a value of 12.7 at 97.7% and 28 at 100%, where 28 was the best estimate inverse slope determined at Mona Vale SLSC in 2017[11]. This larger inverse slope value would apply in areas unconstrained by bedrock, and given the proximity of these areas to the subject site, an allowance for these larger inverse slopes was included in the analysis to extend the tail of the normal distribution.

[10] This is consistent with the approach in numerous other studies, including Bettington and Nielsen (1996) at Hargraves Beach on the NSW Central Coast, and Horton Coastal Engineering (2018) at Campbells Beach near Coffs Harbour in NSW (with this latter report reviewed by then Office of Environment and Heritage staff).
[11] In the report *Risk Assessment to Define Appropriate Beachfront Development Setback in Relation to Coastline Hazards for Redevelopment of Mona Vale SLSC* that was completed in 2017. This value of 28 was based on a depth of closure at the inner Hallermeier depth at -12m AHD.

For the mean sea level rise of 0.25m at 2060 (relative to 2018), and for the mean inverse slope of 9.8 for the normal distribution component of the inverse slope probability distribution, that would give 2.5m of long term recession due to sea level rise at 2060.

8.8 Analysis Results

The Monte Carlo analysis results at 2060, for the five consequence levels, are summarised in Table 11, compared to the tolerable risk probabilities listed in Table 7.

Table 11: Cumulative probabilities of reaching five consequence level positions, compared to tolerable risk probability, at 2060

Consequence	Cumulative probability (not to be exceeded) to achieve tolerable risk over design life (%)	Probability to reach consequence position determined from Monte Carlo analysis
Catastrophic	0.041	0.023
Major	0.41	0.18
Medium	4.0	2.8
Minor	33.8	15.5
Insignificant	98.7	72.5

It is evident in Table 11 that the calculated probabilities of erosion/recession reaching each of the five consequence positions are less than the maximum allowable probabilities to achieve tolerable risk. That is, the proposed development can be considered to be at tolerable risk in its adopted location, as it is also to be founded on deep piles designed assuming a scour level of 0.1m AHD, and allowing for sand slumping and wave forces, as outlined in Section 6.2. From the analysis, the cumulative probability of the building being undermined over its design life is less than about 15%.

Note that in the report herein, the acceptability of the proposed development is only considered in terms of risk of damage from coastal processes. There are other considerations that must also be made to assess if the proposed design and location is acceptable, including its required functions and likely number of users, visual amenity, effects on views, required sight lines from the building, design life, impacts on trees, ease of access for lifesaving equipment on to the beach and linkages (to the car park, beach and grassed reserve) for beach users.

8.9 Other Measures (Besides Piling) to Minimise Erosion/Recession Risk

Although the proposed building is at a tolerably low risk of damage from erosion/recession if constructed on deep foundation piles (a construction measure), if "tolerable risk" is applied as the standard, it is necessary to include risk mitigation measures beyond the fact that the development is piled, given that the land around the building can erode. Such operational management measures comprise the following:

1. the dune volume seaward of the building should generally be maintained by Council over the building design life, by restoring and revegetating the dune after damaging storm events;
2. if the building is ever undermined or nearly undermined, land levels under and surrounding the building must be restored; and
3. storm events at the site must be monitored by Council, and if threatened by erosion, the building must be barricaded off to prevent public access.

With regard to maintaining a vegetated dune seaward of the building, this is important to reduce the potential for windblown sand to impact on the building, as well as to maintain sand volumes as an erosion/recession buffer seaward of the building.

9. COASTAL INUNDATION COASTLINE HAZARDS

Some inundation of the proposed building could be expected for a severe storm over the design life. This would be expected to be a high-velocity shallow-depth flow, in the order of up to 0.5m deep, if it occurs. This issue could be managed by implementing construction and operational measures. Construction measures comprise:

1. using floor finishes and wall materials that would withstand inundation, such as concrete and tiles, up to a level of at least 1m above the finished floor level;
2. allowing for wave forces on exposed elements of the building;
3. placing electrical fittings and outlets that could be damaged by inundation at least 1m above the floor level, or waterproofing them below this; and
4. designing cross-falls over the building footprint to ensure that inundation would drain away from the building, where possible.

The most exposed southern face of the building generally presents a solid face to the prevailing wave action, which is suitable from a coastal engineering perspective. Raising finished floor levels above natural ground would be another construction measure that would reduce the risk of inundation damage, but this has not been adopted due to practicality of maintaining universal accessibility[12], and can be accepted.

Operational measures to reduce inundation risk comprise:

1. storing items that could be damaged by inundation, or become polluting due to inundation, at least 1m above the floor level; and/or
2. relocating items that could be damaged by inundation prior to a storm; and/or
3. using sand bags as required to reduce the extent of inundation into the building.

It is considered that with implementation of the above measures as appropriate, the proposed building could be constructed and maintained at an acceptably low risk of damage from coastal inundation.

[12] It is understood that the proposed floor level is to be flush with natural ground.

10. MERIT ASSESSMENT

10.1 Chapter B3.3 of *Pittwater 21 Development Control Plan*

Chapter B3.3 of the *Pittwater 21 Development Control Plan* (DCP) does not actually apply at the subject site, but has been considered in general terms for consistency with coastal planning in the area[13]. Based on Chapter B3.3 of the DCP (numbered for convenience herein):

1. all development on land to which this control applies must comply with the requirements of the *Coastline Risk Management Policy for Development in Pittwater* (Part B, Appendix 6 of the DCP);
2. development must be designed and constructed to ensure that every reasonable and practical means available is used to remove risk to an acceptable level for the life of the development;
3. the development must not adversely affect or be adversely affected by coastal processes nor must it increase the level of risk for any people, assets and infrastructure in the vicinity due to coastal processes;
4. the Statement of Environmental Effects [is to include] a statement in relation to the proposed development outlining how it has been designed and will be constructed to address the Coastal (Beach) Hazard;
5. the application is to be accompanied by a report prepared by a NPER Engineer with coastal engineering as a core competency and having an appropriate level of professional indemnity insurance;
6. the report is to provide an assessment of the risk and should demonstrate that the proposal is designed and has been located to achieve the control requirements; and
7. the report should also provide management procedures to be carried out during construction and over the life of the development to achieve an acceptable level of Risk Management.

With regard to Item 1, see Section 10.2.

For Item 2, the proposed development is at a tolerably low risk of damage from coastal erosion/recession over a reasonable 40 year design life, as it is to also be founded on deep piles with allowances for sand slumping and wave forces. Furthermore, operational measures to minimise erosion/recession risk have been outlined, as discussed in Section 8.9, which it is assumed will be adopted.

Further to Item 2, the proposed building could be constructed and maintained at an acceptably low risk of damage from coastal inundation if the measures outlined in Section 9 are adopted.

For Item 3, the proposed development is unlikely to have a significant impact on coastal hazards nor increase the risk of coastal hazards in relation to any other land over its design life, as it is to be supported on deep piles above and landward of typical coastal processes. That is, it would not be expected to adversely affect coastal processes nor increase the level of risk for any people, assets and infrastructure in the vicinity due to coastal processes over its design life.

For Item 4, it is reiterated that the proposed building has been designed to be supported on deep piles if undermined, which along with the operational measures outlined in Section 8.9, and measures to reduce the risk of coastal inundation outlined in Section 9, would satisfactorily address the Coastal (Beach) Hazard over the design life.

[13] The DCP version up to Amendment 25 (effective from 1 December 2019) was considered herein.

For Item 5, the report herein, and its author, meet these requirements.

For Item 6, risk has been comprehensively assessed herein, and the proposed development meets the control requirements (Items 1-7) as described in this Section.

For Item 7, management measures for erosion/recession have been outlined in Section 8.9, and measures to reduce the risk of coastal inundation have been outlined in Section 9.

The proposed development thus satisfies Chapter B3.3 of the DCP.

10.2 *Coastline Risk Management Policy for Development in Pittwater*

Based on Section 8.2(i) of the *Coastline Risk Management Policy for Development in Pittwater*:

a) all structures below the Coastline Planning Level shall be constructed from flood compatible materials;
b) all development must be designed and constructed so that it will have a low risk of damage and instability due to wave action and/or oceanic inundation hazards;
c) all development and/or activities must be designed and constructed so that they will not adversely impact on surrounding properties, coastal processes or the amenity of public foreshore lands;
d) all uncontaminated dune sand excavated during construction operations shall be returned to the active beach zone as approved and as directed by Council;
e) wherever present, remnant foredune systems shall be appropriately rehabilitated and maintained for the life of the development to stabilise an adequate supply of sand (as determined by a coastal engineer) that is available to buffer erosion processes and/or minimise the likelihood of oceanic inundation;
f) all vegetated dunes, whether existing or created as part of coastal protection measures shall be managed and maintained so as to protect the dune system from damage both during construction of the development and as a result of subsequent use during the life of the development;
g) all electrical equipment, wiring, fuel lines or any other service pipes and connections must be waterproofed to the Coastline Planning Level;
h) the storage of toxic or potentially polluting goods, materials or other products, which may be hazardous or pollute waters during property inundation, will not be permitted below the Coastline Planning Level;
i) for existing structures, a tolerance of up to minus 100mm may be applied to the Coastline Planning Level in respect of compliance with these controls;
j) building heights must not exceed 8.0 metres above the Coastline Planning Level or 8.5 metres above existing ground level, whichever is higher; and,
k) where land is also subject to the provisions of the Flood Risk Management Policy for Development around Pittwater, the higher of the Coastline Planning Level and Flood Planning Level shall apply.

The Coastline Planning Level can be assumed to be 1m above the finished floor level of the building.

For Item (a), it was recommended in Section 9 that floor finishes and wall materials that would withstand inundation be used up to at least the Coastline Planning Level.

For Item (b), the development is at a tolerably low risk of damage from coastal erosion/recession over a reasonable 40 year design life, as it is to also be founded on deep piles with allowances for sand slumping and wave forces. Operational measures to minimise erosion/recession risk have been outlined, as discussed in Section 8.9. With adoption of the measures outlined in Section 9, the risk of damage from inundation would be minimised.

For Item (c), it has been noted previously that the proposed development would not be expected to adversely impact on surrounding properties or coastal processes.

Item (d) would be achievable and appropriate during construction, although significant excavation would not be expected.

For Items (e) and (f), existing vegetated dune areas seaward of the building are to be maintained.

For Item (g), a recommendation was provided in Section 9 that electrical fittings and outlets that could be damaged by inundation were placed above the Coastline Planning Level, or waterproofed below this, where practical.

For Item (h), a recommendation was provided in Section 9 that items that could be damaged by inundation, or become polluting due to inundation, be stored above the Coastline Planning Level.

Item (j) is not a coastal engineering matter and hence is not addressed herein.

For Item (k), the subject site is not mapped as being significantly affected by catchment flooding.

In the *Coastline Risk Management Policy for Development in Pittwater*, it is noted that a Coastline Management Line must be defined. It is considered that the probabilistic approach adopted herein supersedes that requirement, which was developed at a time when probabilistic coastal hazard definition had not been established.

Based on 8.2(iii) of the Policy, "new development and major additions to existing development must be sited on the landward side of the 100 year Coastline Management Line". It is considered that given the proposed development satisfies tolerable risk criteria at five different consequence levels over a reasonable 40 year design life, the principles of this requirement have been met (note that adoption of a 100 year line is not mandatory).

Completed Forms 1 and 1(a) as given in the *Coastline Risk Management Policy for Development in Pittwater* are provided in Attachment A.

The proposed development thus satisfies the *Coastline Risk Management Policy for Development in Pittwater*.

10.3 *State Environmental Planning Policy (Coastal Management) 2018*

10.3.1 Preamble

Based on *State Environmental Planning Policy (Coastal Management) 2018* (SEPP Coastal) and its associated mapping, the subject site is partly within the "coastal environment area" (see Section 10.3.2), and is in the "coastal use area" (see Section 10.3.3).

10.3.2 Clause 13

Based on Clause 13(1) of SEPP Coastal, "development consent must not be granted to development on land that is within the coastal environment area unless the consent authority has considered whether the proposed development is likely to cause an adverse impact on the following:

(a) the integrity and resilience of the biophysical, hydrological (surface and groundwater) and ecological environment,
(b) coastal environmental values and natural coastal processes,
(c) the water quality of the marine estate (within the meaning of the *Marine Estate Management Act 2014*), in particular, the cumulative impacts of the proposed development on any of the sensitive coastal lakes identified in Schedule 1,
(d) marine vegetation, native vegetation and fauna and their habitats, undeveloped headlands and rock platforms,
(e) existing public open space and safe access to and along the foreshore, beach, headland or rock platform for members of the public, including persons with a disability,
(f) Aboriginal cultural heritage, practices and places,
(g) the use of the surf zone".

With regard to (a), the proposed development would not be expected to adversely affect the biophysical, hydrological (surface and groundwater) and ecological environments, as it is replacing a building in an already developed area. For the proposed development, a rainwater tank to capture stormwater and reuse for toilet flushing is proposed, or alternatively stormwater drainage will discharge to a stormwater infiltration trench (note that the current building has a single downpipe on the landward side). Either way, significant impacts on the hydrological environment are not expected.

With regard to (b), the proposed development would not be expected to adversely affect coastal environmental values or natural coastal processes over a reasonable design life, as it is at a tolerably low risk of being damaged by coastal erosion/recession over a reasonable life, and is designed to be supported above and landward of typical coastal processes. It is also in an already developed area.

With regard to (c), the proposed development would not be expected to adversely impact on water quality, as long as appropriate construction environmental controls are applied. No sensitive coastal lakes are located in the vicinity of the proposed development.

With regard to (d), the proposed development would not impact marine vegetation, native vegetation and fauna and their habitats of significance (which are assumed not to exist at the site), and undeveloped headlands and rock platforms, with none of these items in proximity. No significant impacts on marine fauna and flora would be expected as a result of the proposed development, as the development would not interact with subaqueous areas for a tolerably rare storm over a reasonable life.

With regard to (e), it can be noted that the proposed development will not affect public access to Mona Vale Beach and Basin Beach, with existing beach accessways to the north and south of the building being maintained.

With regard to (f), this is not a coastal engineering matter so has not been considered herein.

With regard to (g), the proposed development would not interact with the surf zone for a tolerably rare storm over a reasonable life, so would not significantly impact on the use of the surf zone.

Based on Clause 13(2) of SEPP Coastal, "development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that:

(a) the development is designed, sited and will be managed to avoid an adverse impact referred to in subclause (1), or
(b) if that impact cannot be reasonably avoided—the development is designed, sited and will be managed to minimise that impact, or
(c) if that impact cannot be minimised—the development will be managed to mitigate that impact".

The proposed development has been designed and sited to avoid any potential adverse impacts referred to in Clause 13(1).

10.3.3 Clause 14

Based on Clause 14(1) of SEPP Coastal, "development consent must not be granted to development on land that is within the coastal use area unless the consent authority:

(a) has considered whether the proposed development is likely to cause an adverse impact on the following:
    (i) existing, safe access to and along the foreshore, beach, headland or rock platform for members of the public, including persons with a disability,
    (ii) overshadowing, wind funnelling and the loss of views from public places to foreshores,
    (iii) the visual amenity and scenic qualities of the coast, including coastal headlands,
    (iv) Aboriginal cultural heritage, practices and places,
    (v) cultural and built environment heritage, and
(b) is satisfied that:
    (i) the development is designed, sited and will be managed to avoid an adverse impact referred to in paragraph (a), or
    (ii) if that impact cannot be reasonably avoided—the development is designed, sited and will be managed to minimise that impact, or
    (iii) if that impact cannot be minimised—the development will be managed to mitigate that impact, and
(c) has taken into account the surrounding coastal and built environment, and the bulk, scale and size of the proposed development".

With regard to Clause (a)(i), the proposed development will not affect public beach access.

Clauses (a)(ii), a(iii), a(iv) and a(v) are not coastal engineering matters so are not considered herein.

With regard to (b), the proposed development has been designed and sited to avoid any potential adverse impacts referred to in Clause 14(1) for the matters considered herein.

Clause (c) is not a coastal engineering matter so is not considered herein.

10.3.4 Clause 15

Based on Clause 15 of SEPP Coastal, "development consent must not be granted to development on land within the coastal zone unless the consent authority is satisfied that the proposed development is not likely to cause increased risk of coastal hazards on that land or other land".

The proposed building is unlikely to have a significant impact on coastal hazards or increase the risk of coastal hazards in relation to any other land, as it is at a tolerably low risk of being damaged by coastal erosion/recession over a reasonable life, and is designed to be supported above and landward of typical coastal processes.

10.3.5 Clause 16

Based on Clause 16 of SEPP Coastal, "development consent must not be granted to development on land within the coastal zone unless the consent authority has taken into consideration the relevant provisions of any certified coastal management program that applies to the land".

No certified coastal management program applies at the subject site.

10.3.6 Synthesis

The proposed development satisfies Clause 13, 14, 15 and 16 of *State Environmental Planning Policy (Coastal Management) 2018* for the matters considered herein.

10.4 *Pittwater Local Environmental Plan 2014*

Clause 7.5 of *Pittwater Local Environmental Plan 2014* (LEP 2014) does not strictly apply at the subject site, as it is not identified as a "Coastal erosion / wave inundation" area on the Coastal Risk Planning Map (Sheet CHZ_018). However, for consistency with coastal planning for adjacent private development, Clause 7.5 of LEP 2014 has been considered herein.

Based on Clause 7.5(3) of LEP 2014, "development consent must not be granted to development on land to which this clause applies unless the consent authority is satisfied that the development:

- (a) is not likely to cause detrimental increases in coastal risks to other development or properties, and
- (b) is not likely to alter coastal processes and the impacts of coastal hazards to the detriment of the environment, and
- (c) incorporates appropriate measures to manage risk to life from coastal risks, and
- (d) is likely to avoid or minimise adverse effects from the impact of coastal processes and the exposure to coastal hazards, particularly if the development is located seaward of the immediate hazard line, and
- (e) provides for the relocation, modification or removal of the development to adapt to the impact of coastal processes and coastal hazards, and
- (f) has regard to the impacts of sea level rise, and
- (g) will have an acceptable level of risk to both property and life, in relation to all identifiable coastline hazards".

With regard to (a) and (b), the proposed development would not increase coastal risks nor alter coastal processes and the impacts of coastal hazards over its design life, as it is at a tolerably low risk of being damaged by coastal erosion/recession over a reasonable life, and is designed to be supported above and landward of typical coastal processes.

With regard to (c) and (g), founding the proposed development on piles, along with adoption of the measures outlined in Section 8.9 and Section 9, are appropriate to achieve a tolerably low risk to property from coastal risks. As noted in Section 7.5.1, risk to life related to development at the proposed building is considered to be acceptably low.

With regard to (d), founding the proposed development on piles also minimises the adverse effects from the impact of coastal processes and the exposure to coastal hazards for the proposed development. The Immediate Hazard Line is not applicable in a probabilistic coastal hazard definition framework. Given that the proposed development is at a tolerably low risk of damage for a reasonable life, (e) is not necessary.

With regard to (f), sea level rise has been considered herein, with the probabilistic coastal hazard definition incorporating sea level rise projections in a rigorous manner. Sea level rise has also been considered with regard to the recommendations on coastal inundation in Section 9.

The proposed development thus satisfies Clause 7.5 of LEP 2014.

10.5 Coastal Management Strategy, Warringah Shire

In 1981, a working party was established comprising Warringah Council and Public Works Department (PWD) staff at that time, with the aim of integrating Council's management and planning with coastal engineering advice to produce an overall strategy for coordination of beach reserves management and identification of areas of the coastal zone that required specific development controls (PWD, 1985).

This resulted in the completion of an investigation by PWD (1985), entitled "Coastal Management Strategy, Warringah Shire" in which coastline management strategies were developed for the beaches and headland areas of the entire Warringah Shire Council Local Government Area (LGA), which extended from Freshwater to Palm Beach at that time (thus covering the former Pittwater and Warringah LGA's).

For the subject site, it was noted "Maintain the protective works in front of the car park. If serious storm damage occurs, review design of revetment and investigate possibility of relocating change rooms away from the active beach zone".

Given that no coastal protection works are known to have been constructed in the vicinity of the proposed building, the reference to "protective works" above must be to dune stabilisation and vegetation works that were carried out in the 1970's and 1980's. It has been recommended herein (Section 8.9) that the dune volume seaward of the building should generally be maintained by Council over the building design life, by restoring and revegetating the dune after damaging storm events, consistent with PWD (1985).

As the proposed building is to be founded on deep piles, serious damage to the building is not to be expected over the design life, and there is no requirement to consider revetment protection of the site nor relocation of the building at this time.

11. CONCLUSIONS

It is proposed to demolish the existing amenities building and to construct a new amenities and lifeguard facilities building at the northern end of Mona Vale Beach. Probabilistic coastal hazard modelling for coastal erosion/recession, using a full Monte Carlo probability simulation procedure, has been undertaken for this site.

It was found that the proposed building was at a tolerably low risk of damage from coastal erosion/recession over a reasonable 40 year design life, as it is to also be founded on deep piles with allowances for sand slumping and wave forces. Operational management measures have been outlined to further reduce the erosion/recession risk, as described in Section 8.9.

Risk of damage from coastal inundation can be managed through the measures outlined in Section 9. With implementation of these measures as appropriate, the proposed building could be constructed and maintained at an acceptably low risk of damage from coastal inundation.

The proposed development satisfies the coastal engineering matters in Chapter B3.3 of *Pittwater 21 Development Control Plan*, the *Coastline Risk Management Policy for Development in Pittwater*, *State Environmental Planning Policy (Coastal Management) 2018*, Clause 7.5 of *Pittwater Local Environmental Plan 2014*, and the "Coastal Management Strategy, Warringah Shire" prepared in 1985, as has been outlined.

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ATTACHMENT A: FORMS 1 AND 1(A) FROM *COASTLINE RISK MANAGEMENT POLICY FOR DEVELOPMENT IN PITTWATER*

COASTLINE RISK MANAGEMENT POLICY FOR PITTWATER

FORM NO. 1 – To be submitted with Development Application

Development Application for Northern Beaches Council
Name of Applicant

Address of site Mona Vale Beach Reserve (amenities building)

Declaration made by a Coastal Engineer as part of a Coastal Risk Management Report

I, Peter Horton on behalf of Horton Coastal Engineering Pty Ltd
(Insert Name) (Trading or Company Name)

on this the 9 September 2020
(date)

certify that I am a Coastal Engineer as defined by the Coastline Risk Management Policy for Pittwater and I am authorised by the above organisation/company to issue this document and to certify that the organisation/company has a current professional indemnity policy of at least $2 million.

I have:

Please mark appropriate box

- ☑ Prepared the detailed Coastal Risk Management Report referenced below in accordance with the Pittwater Council Coastline Risk Management Policy
- ☐ Am willing to technically verify that the detailed Coastal Risk Management Report referenced below has been prepared in accordance with the Pittwater Council Coastline Risk Management Policy
- ☐ Have examined the site and the proposed development/alteration in detail and, as detailed in my report, am of the opinion that the Development Application only involves Minor Development/Alterations or is sited such that a detailed coastal hazard analysis or risk assessment is not required.
- ☐ Provided the coastal hazard analysis for inclusion in the Coastal Risk Management Report

Coastal Risk Management Report Details:

Report Title: Coastal Engineering Advice on Mona Vale Beach Amenities and Lifeguard Facilities Building, Including Consideration of Tolerable Risk

Report Date: 9 September 2020

Author: Horton Coastal Engineering Pty Ltd

Documentation which relate to or are relied upon in report preparation:

See Section 12 of report

I am aware that the above Coastal Risk Management Report, prepared for the above mentioned site is to be submitted in support of a Development Application for this site and will be relied on by Pittwater Council as the basis for ensuring that the coastal risk management aspects of the proposed development have been adequately addressed to achieve an acceptable risk management level for the life of the structure, taken as at least 100 years unless otherwise stated and justified in the Report and that reasonable and practical measures have been identified to remove foreseeable risk.

Signature ……………………………………………………………..

Name ……………… Peter Horton ………………………………………..

Chartered Professional Status…… MIEAust CPEng NER ……………

Membership No. …… 452980 ……………………………………………

COASTLINE RISK MANAGEMENT POLICY FOR PITTWATER

FORM NO. 1(a) - Checklist of Requirements for Coastal Risk Management Report for Development Application or Part 5 Assessment

Development Application for Northern Beaches Council
Name of Applicant

Address of site Mona Vale Beach Reserve (amenities building)

The following checklist covers the minimum requirements to be addressed in a Coastal Risk Management Report. This checklist is to accompany the Coastal Risk Management Report and its certification (Form No. 1).

Coastal Risk Management Report Details:

Report Title: Coastal Engineering Advice on Mona Vale Beach Amenities and Lifeguard Facilities Building, Including Consideration of Tolerable Risk

Report Date: 9 September 2020

Author: Horton Coastal Engineering Pty Ltd

Please mark appropriate box

- ☑ Comprehensive site mapping conducted Survey provided and beach profiles analysed (date)
- ☑ Mapping details presented on contoured site plan to a minimum scale of 1:200 (as appropriate) Figure 15 is considered to be adequate
- ☐ Subsurface investigation required
  - ☐ No Justification ……………………………………………….
  - ☑ Yes Date conducted See Section 6 ……………………………………………
- ☑ Impact by and upon coastal processes identified
- ☑ Coastal hazards identified
- ☑ Coastal hazards described and reported
- ☑ Risk assessment conducted in accordance with Council's Policy
- ☐ Adequacy of existing coastal protection measures assessed and certified N/A
- ☑ Opinion has been provided that the design can achieve the risk management criteria in accordance with Council's Policy provided that the specified conditions are achieved.

☑ Design Life Adopted:

☐ 100 years
☑ Other 40 years
specify

☑ Development Controls as described in the Pittwater Coastline Risk Management Policy have been specified

☑ Additional actions to remove risk where reasonable and practical have been identified and included in the Coastal Risk Management Report.

I am aware that Pittwater Council will rely on the Coastal Risk Management Report, to which this checklist applies, as the basis for ensuring that the coastal risk management aspects of the proposal have been adequately addressed to achieve an acceptable risk management level for the life of the structure, taken as at least 100 years unless otherwise specified, and justified in the Report and that reasonable and practical measures have been identified to remove foreseeable risk.

Signature Peter Horton

Name Peter Horton

Chartered Professional Status MIEAust CPEng NER

Membership No. 452980