AMP Capital / Mirvac

71 - 79 Macquarie Street, Sydney

Climate Change and Sea Level Rise Assessment

REV/02

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Arup
Arup Pty Ltd ABN 18 000 966 165

Arup
Level 10
201 Kent Street
Sydney
NSW 2000
Australia
www.arup.com

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Contents

Executive Summary

It is projected that climate change induced sea level rise will result in an increase in global mean sea level of between 0.26m and 2.0m by 2100. The wide range of projections represents the current uncertainty in projecting the trend in global emissions and the climatic response over such a long time frame. The NSW Government has adopted a planning benchmark of 0.9m mean sea level rise by 2100. Such a sea level rise would result in a 1 in 100 year of storm surge event of approximately 2.335 mAHD not including any allowance for wave effects.

The existing Sydney Harbour Foreshores and Waterways Area Development Control Plan 2005 specifies a requirement for minimum top of sea wall height of 1.675mAHD. Applying a 0.9m allowance for sea level rise to 2100 would require that any new seawalls would be required to be constructed to 2.575mAHD.

Given the height of the existing Circular Quay precinct seawall of between 2.29mAHD (adjacent to Wharf No 2) and 2.45mAHD, the site is likely to be adequately protected (subject to its structural integrity) from inundation until the latter half of the century or unless sea level rise occurs greater than the NSW Government's benchmark

Notwithstanding, consideration of the likely physical impacts of a sea level rise of 0.9m by 2100 suggests that the development is exposed to at least some potential adverse consequences including an increase in wave overtopping potential of the seawall, and impacts on groundwater pressures and buried services. When considering higher sea level rise scenarios (1.4m and 2.0m), the risk of impact on the development would be greater. In particular, the inundation of the ground floor and basement during high tide-surge events could be possible under these scenarios.

The most effective measure to adapt to water inundation impacts on the proposed development would be to raise the existing harbour seawall to an appropriate level. Implementing this measure is beyond the direct control of AMP / Mirvac as the seawall is owned by the Sydney Harbour Foreshore Authority.

However, there are adaptation measures that the applicant does have control over which are recommended to be considered as early as possible in the development planning process:

- Make a specific allowance for sea level rise during the engineering design for the development, particularly in the design of the basement and buried services.
- Locate critical infrastructure (e.g. power generators, data storage) at elevated locations above the 100 year ARI tide-surge level with sea level rise allowance.
- Provide for safe exit routes above storm flood height levels.
- Incorporate appropriate surface drainage along the public domain promenade to allow overtopped wave discharge and runup during storms to be readily removed.

- For structures susceptible to flood inundation or wave splash, select materials with high durability properties to minimise long-term degradation.

A high-level risk assessment summarised in a risk matrix has been undertaken, which effectively concludes that the risk for adverse consequences occurring to the proposed development from the physical impacts of climate change is generally low. These risks would be further reduced if adaptation measures as described above are implemented.

1 Introduction

1.1 Background

This report outlines a climate change and sea level rise assessment undertaken for the proposed redevelopment of 71-79 Macquarie Street, Sydney, known as the Amatil Building. The assessment is required as part of a Concept Plan application for a mixed use development to be assessed under Part 3A of the NSW Environment Planning and Assessment Act 1979.

The assessment is required to respond to the DGR Reference #18 for:

> *"An assessment of the risks associated with sea level rise on the modifications as set out in the NSW Coastal Planning Guideline: Adapting to Sea Level Rise."*

This report specifically responds to this requirement.

1.2 Site Location

The existing Amatil Building is located within the eastern precinct of Circular Quay, Sydney, and is bounded by the Quay Grand and Rail Corp NSW buildings to the north and south respectively, and Macquarie Street to the east. A locality plan is provided in Figure 1 below.

Immediately to the west of the site are the Circular Quay Street East public road, and the Circular Quay pedestrian promenade which runs along the perimeter of Sydney Cove. Sydney Cove is an inlet along the southern shore of Port Jackson (Sydney Harbour), which is used regularly for the berthing of ferries, cruise ships, and other recreational and commercial vessels.

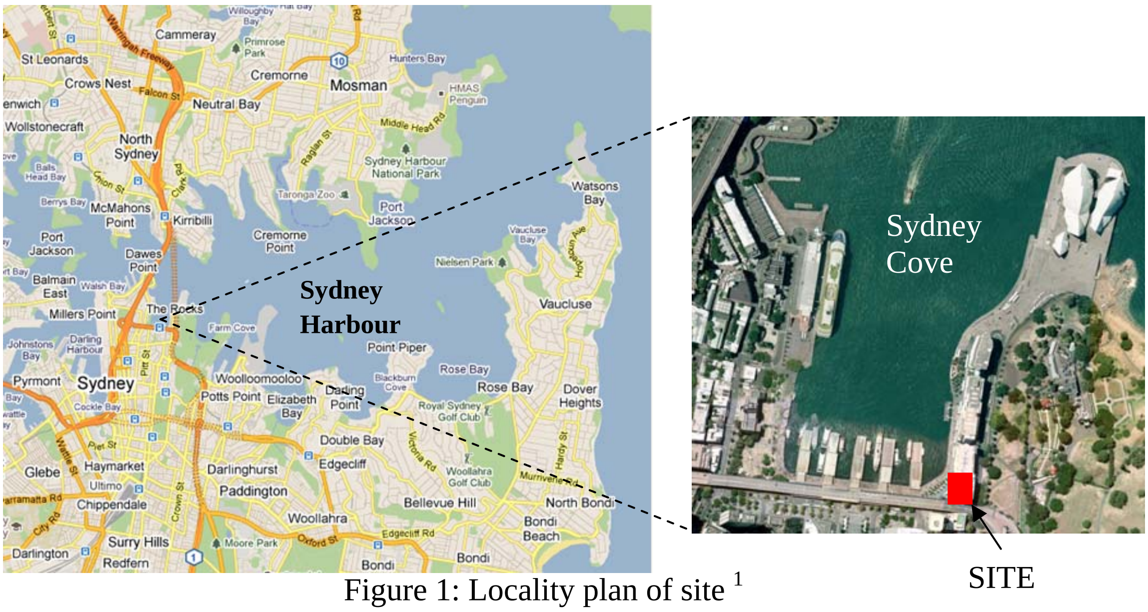

Figure 1: Locality plan of site [1]

[1] Extracts from Google Maps, Google (2011)

1.3 Background to Climate Change and Sea Level Rise

Extreme sea levels currently occur in Sydney Harbour as a result of the compounding effects of tides, storm surge, wave setup and wave run-up, all of which increase the extent of inundation above mean sea level.

Over the life of the proposed Amatil Building redevelopment, local mean sea level rise is projected to occur as a result of global warming inducing:

- thermal expansion of the oceans; and
- the melting of the Greenland and Antarctic ice sheets.

In addition, storm modelling of weather patterns along the NSW coast indicates the potential for increases in the frequency of extreme weather events that contribute to extreme winds and, subsequently, storm surge[2].

As a result of increased mean sea level and increased storm surge, the frequency of inundation on the NSW coast is likely to increase. Compounding this, extreme rainfall events are also projected to increase in frequency in Sydney. Where such events coincide with storm surge, inundation impacts are likely to be increased.

1.4 Scope of Study

This report presents a summary of the future risk to the project as a result of climate change projections of sea level rise.

The report provides:

- a summary of the legislative context for consideration of sea level rise;
- an understanding of the different components of existing sea level and extreme storm surge events;
- an understanding of the various projections of climate change and associated uncertainties;
- a risk assessment of the potential impacts to the project as a result of sea level rise under climate change projections;
- a range of potential adaptation measures.

1.5 Assumptions and Limitations

This study is based on a review of publicly available and client-provided data and does not involve any hydraulic modelling, detailed wave hindcasting modelling, climate modelling or primary data collection. The conclusions and recommendations are therefore subject to the assumptions and limitations of the referenced models and data.

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[2] Hennessy, K., Page, C., McInnes, K., Jones, R., Bathols, J., Collins,D., and Jones, D. 2004. Climate Change in New South Wales. Past Climate Variability and Projected Changes in Average Climate, Part 2 Projected Changes in Climate Extremes, CSIRO and the Australian Bureau of Meteorology

Further, planning for sea level rise and other climate change impacts is subject to inherent uncertainty. The climate change projections referred to in this report, as prepared by the International Panel on Climate Change (IPCC) and adopted by various levels of Australian governments, are scenario based. As such, projections are reported in terms of ranges without any assessment of probability. Therefore the consideration of climate change in determining the future probability of extreme events is limited to the consideration of such ranges.

The results of this study should not be considered as recommendations of design levels for the site but rather provide an assessment of the potential risks based on the preliminary design information.

3 Project Description

3.1 General

The proposed project involves the demolition of the existing Amatil Building located at the southern end of East Circular Quay and redevelopment of the site with a new building accommodating:

- serviced apartments;
- long-term residential accommodation;
- lobby and ground level retailing; and
- basement car parking.

The new building will include a westerly extension of the building footprint to allow completion of the existing colonnade and massing to align with that of the adjoining Quay Grand building to the north. The proposal also includes significant public domain upgrade works and access improvements over Council owned and Crown land, and a new pedestrian link to Macquarie Street from Circular Quay.

Proposed conceptual design plans and section for the development as provided by Mirvac are provided in **Appendix A**.

3.2 Existing Key Features and Levels

The following levels have been taken from topographical survey drawings prepared by Denny Linker & Co dated 31/01/11 (no. 110324 – 4 sheets).

The harbour foreshore fronting the site is treated with a vertical seawall, which runs along the majority of the circular quay precinct. The crest level of the seawall fronting the site varies between 2.29mAHD (adjacent to Wharf No 2) and 2.45mAHD.

The public reserve promenade gradually slopes upwards from the seawall towards the western side of the proposed building (circular quay east) to an approximate level of 2.80mAHD. The level of the eastern side of the proposed building (Macquarie Street) is considerably higher than the circular quay side at about 12.0-13.0mAHD.

A colonnade runs along the western edge of the Quay Grand building on the northern boundary of the existing Amatil building, with an under surface level of approximately 9.5mAHD.

3.3 Proposed Levels

Levels for surface entry points into the proposed new building from the circular quay east and Macquarie Street side are assumed to remain as existing.

A pedestrian linkage between the Circular Quay East Promenade and Macquarie Street levels is proposed with access stairs and horizontal platforms, however levels have not been provided.

The basement carparking would extend down to -11.00mAHD with a plant and lift pit extending to -14.835mAHD on the west side, and -12.135mAHD on the east side. The proposed extension of the existing Quay Grand colonnade would match the level for the existing northern section.

4 Guidelines and Standards for Sea Level Rise

4.1 Planning Guidelines

4.1.1 NSW Sea Level Rise Policy Statement

The NSW State Government released its Sea Level Rise Policy Statement[3] in November 2009 to prepare for predicted sea level rises caused by climate change and inform both local and state plans for coastal development. The policy specifies that a NSW sea level rise planning benchmark is an increase above 1990 mean sea levels of 0.4m by 2050 and 0.9m by 2100. This can be compared with the recently adopted Victorian benchmark of 0.8m by 2100 and the benchmarks which have been adopted by South Australia since 1991 of 0.3m by 2050 and 1m by 2100. The NSW benchmark is consistent with the upper limit of the Intergovernmental Panel on Climate Change (IPCC) AR4 projections of 0.79 m global average sea level rise by the decade of 2090 to 2099.

4.1.2 NSW Coastal Planning Guideline: Adapting to Sea Level Rise

The NSW Sea Level Rise policy statement is supported by the NSW Coastal Planning Guideline: Adapting to Sea Level Rise[4] detailing the application of sea level rise benchmarks to coastal and flood hazard assessments and in land-use planning. The Draft document was released in October 2009 and the final Guideline in August 2010.

The Planning Guideline requires that development applications in coastal risk areas provide the following information:

Information outlining the type of proposed development including:

- nature, bulk, scale and location of proposed development;
- proposed use and occupation of buildings, and those on adjoining land;
- plans illustrating the position and configuration of the proposed development in relation to coastal risks including (where relevant):
  - position of the existing and proposed buildings;
  - existing ground levels to AHD around the perimeter of the building;
  - existing or proposed floor levels in AHD;
  - foundation type; and
  - topographic levels to an accuracy of 0.1m, and structures to an accuracy of 0.01m, showing relative levels to AHD.

[3] NSW Government, Sea Level Rise Policy Statement, November 2009 <http://www.environment.nsw.gov.au/climateChange/sealevel.htm>
[4] http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=1Mz7Sun64mw%3d&tabid=177

A report addressing the following issues relating to sea level rise as they relate to the development site, where relevant:

- increase in sea level and increased tidal range;
- coastal flooding;
- cliff and slope stability; groundwater elevation and/or salinisation;
- information that demonstrates whether the development proposal:
    - is consistent with the relevant coastline or flood risk management plan;
    - is consistent with any relevant DCP that relates to coastal or flood issues;
    - meets the coastal protection and flood risk management requirements of the LEP; and
    - incorporates appropriate management responses and adaptation strategies.

4.1.3 Sydney Harbour Foreshores and Waterways Area Development Control Plan 2005

The Sydney Harbour Foreshores and Waterways Area Development Control Plan 2005 applies to the Foreshores and Waterways Area as identified in the Sydney Harbour Regional Environment Plan which includes the project site. The DCP provides 'Design Guidelines for Water-Based and Land/Water Interface Developments' including design requirements for seawalls.

The DCP specifies a requirement for minimum top of sea wall height of 1.675m AHD. The maximum height for reclamations is also 1.675m AHD. The DCP has not been updated to reflect the NSW Sea Level Rise Planning Benchmark. Any update of the DCP would presumably be required to be consistent with the benchmarks.

4.2 Design Guidelines

4.2.1 AS4997:2005 Guidelines for the Design of Maritime Structures

The Australian Standard for the Design of Maritime Structures includes a provision for sea level rise based on the medium range estimate for 25, 50 and 100 years as put forward in the IPCC third assessment report (2001) as below.

Table 1: AS4997:2005 Allowance for Sea Level Rise

Design life	Sea level rise (m)
25 years	0.1
50 years	0.2
100 years	0.4

NOTE: Based on the mid-scenario from the International Panel on Climate Change (2001)

These values are now considered outdated given the more recent projections and the specific planning controls now introduced by various state governments. However the standard gives guidance into how the impact of storm surges should be taken into account by specifying the minimum height of a deck of a wharf or jetty in tidal conditions. The standard indicates that this should be determined as the ‘1/100 annual accidence of probability elevated water level, plus a suitable freeboard depending on exposure to waves, wave heights, wind set-up, formation of bars at river entrances and seiche’.

5 Existing Harbour Water Levels

Sydney Harbour is subject to a range of physical processes that contributes to water level fluctuations within the harbour. These most important of these include:

- Astronomical tides: Periodic and predictable water level variations due to the gravitational forces of the moon, sun and other celestial bodies on the earth.
- Storm surge: A variation in water level due to the passage of atmospheric weather systems across the surface of the sea.
- Waves: Short-period oscillating disturbances to the water surface generated by local winds or other mechanisms (e.g. vessel wake). Waves can cause the still water level to locally increase slightly though a phenomenon called wave-setup, as well as cause water to run-up or overtop a site's foreshore.

The various contribution of each of these processes to water levels is shown in Figure 2 below.

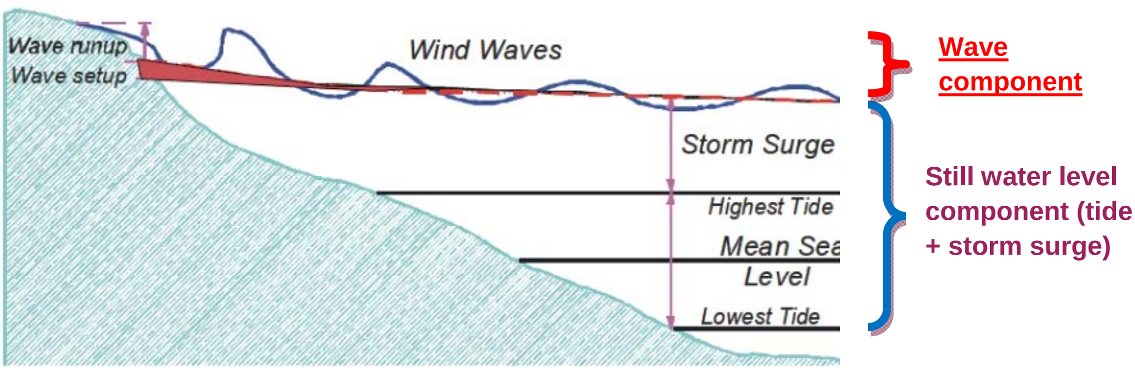

Figure 2: Contribution of Physical Processes to Water Levels [5]

This section discusses the extent of the contributions for each of these components on the water levels in Sydney Harbour.

Partially closed water bodies such as harbours can also induce long period water level oscillations (e.g. from ocean swell, rarely-occurring tsunamis) that are characterised by small amplitudes, but which can be amplified through harbour resonance or seiching. This complex phenomenon has not been considered further in this study.

The contribution from fluvial flows to water level fluctuations can be reasonably assumed to be very small to negligible at Sydney Cove.

[5] Adapted from figure contained in Kathleen L. McInnes, Julian O'Grady and Ian Macadam, The Effect of Climate Change on Extreme Sea Levels in Port Phillip Bay: A Project Undertaken for the Department of Sustainability and Environment, Victoria, CSIRO Marine and Atmospheric Research November 2009

5.1 Astronomical Tide

The astronomical tide component of a given ocean water level is based upon the combined influences of the Sun and the Moon and their position relative to the Earth at any given point in time. The tide is in effect a very long period wave set in motion by the centrifugal force of the rotating earth on the ocean and is governed by the gravitation forces applied by the Moon, Sun and other planets.

The NSW coastal zone experiences semi-diurnal tides, which consist of two high and two low tides daily. The larger or 'spring' tidal range (around 1.2m) occurs during full or new moons when the gravitational pull of the moon and sun are combined. The 2011 tidal levels for Sydney Harbour are presented in Table 2 below.

Table 2 2011 Sydney Harbour Tidal Levels[6]

Tidal Levels	mCD[1]	mAHD[2]
Highest Astronomical Tide	2.10	1.17
Mean High Water Springs	1.60	0.67
Mean High Water Neaps	1.40	0.47
Mean Water Level	1.00	0.07
Mean Low Water Neaps	0.60	-0.33
Mean Low Water Springs	0.40	-0.53
Lowest Astronomical Tide	0.00	-0.93

1. CD = Chart Datum which approximates to LAT and is about 0.93m below AHD.
2. AHD = Australian Height Datum.

5.2 Storm Surge

Storm surges occur as a result of the elevation of the ocean water surface above normal tidal ranges due to the combined effects of 'barometric setup' and 'wind setup'.

Barometric setup occurs where 'low' pressure weather causes a local rise in the ocean water surface (known as the 'inverse barometer effect') and has been measured in the order of 0.2 to 0.4m in NSW coastal waters[7]. Extreme wind speeds not only generate local seas but also tend to pile water up against a shoreline in the direction of the wind. The component of increasing water level attributable to wind action is termed 'wind setup' and is usually of the order of 0.1 to 0.2m[7]. In total, storm surge swells in NSW coastal waters are therefore estimated to be in the order of 0.3 to 0.6m.

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[6] Australian National Tide Tables (2011) for Fort Dennison, which is sufficiently close to the site (approximately 1.5km north-east) to reasonably adopt for the project

[7] NSW Government (1990). Coastline Management Manual, September. 1990 as cited in Watson P.J and D.B Lord (2008). *Fort Denison Sea Level Rise Vulnerability Study*, Coastal Unit, NSW Department of Environment and Climate Change, October 2008

5.3 Extreme Water Levels

It is usually convenient when considering extreme water level events for various Average Recurrence Intervals (ARIs) to combine the components of astronomical tide and storm surge. This combined extreme water level is often referred to as tide surge.

Water levels have been measured continuously at Fort Denison within Sydney Harbour for over 100 years. The data reflects the astronomical tide levels as well as anomalies or variations from the predicted tide resulting from the range of sources discussed above. Similarly, the data inherently incorporates climate change induced sea level over this timeframe.

Extreme value analysis of measured tide gauge data is commonly undertaken to estimate design still water levels. Design still water levels represent the maximum level that can be expected excluding the contribution from wave run-up. Design still water levels produced from Fort Denison data using the Gumbel probability distribution function are shown in Table 3 below.

Table 3: Design Still Water Levels for Sydney Harbour [8]

ARI (years)	Water Level (mAHD)
0.02	0.965
0.05	1.045
0.10	1.095
1	1.235
2	1.275
5	1.315
10	1.345
20	1.375
50	1.415
100	1.435
200	1.455

ARI - Annual Recurrence Interval

AHD - Australian Height Datum

In accordance with AS4997:2005 Guidelines for the Design of Maritime Structures, an extreme still water level for the 100 year ARI (highlighted above) of 1.435mAHD has been considered in this study, noting that an additional allowance for wave run up and harbour seiching is to be made.

[8] Watson P.J and D.B Lord (2008). *Fort Denison Sea Level Rise Vulnerability Study*, Coastal Unit, NSW Department of Environment and Climate Change, October 2008

5.4 Waves

5.4.1 General

The quay foreshore near the site is exposed to wind waves generated within Sydney Harbour and Sydney Cove from a multitude of directions sweeping from W to N in a clockwise direction depending on the prevailing wind direction. The study area is situated sufficiently far enough away from the coastline that it is not expected to receive long-period swell waves.

During a storm with constant wind speed and direction over a fixed fetch (the distance along which the wind is blowing over water to the impact point), waves at a given location will gradually grow until they reach a maximum fetch-limited state of development.

For this study, hindcasting methods have been used to estimate the wave climate at the site based on wind speed, fetch, storm duration, and waterbody depth inputs. Waves impacting the site generated by vessel wash have also been considered.

5.4.2 Extreme Wind Waves

The extreme wind-wave climate has been estimated at the foreshore location closest to the site for various wave generation directions.

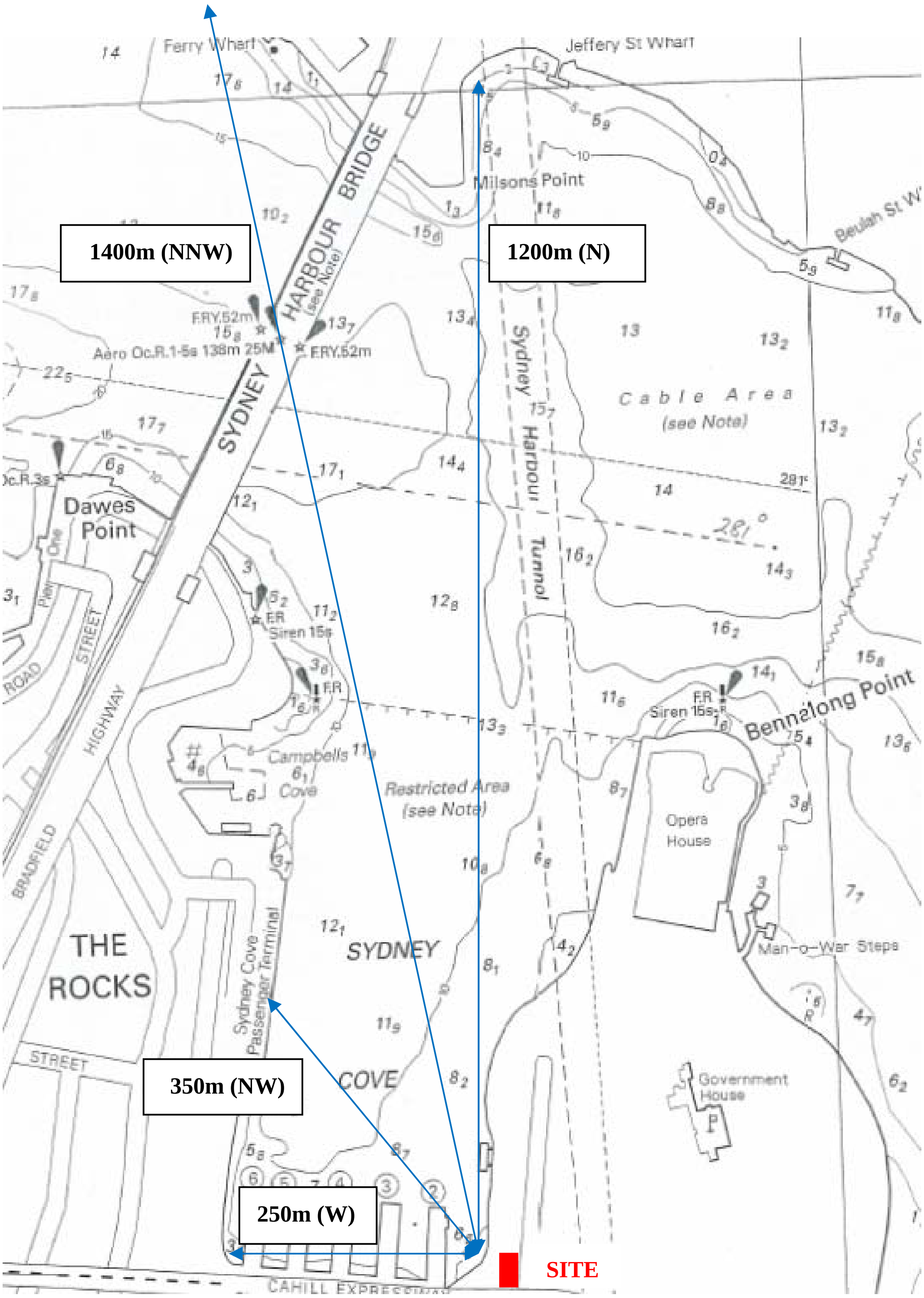

Figure 3: 'Fetches' considered in wave hindcasting exercise for various wave generation directions [9]

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[9] Figure based on extract from AUS Marine Chart 202. Soundings are in meters relative to Chart Datum (CD).

The wind climate at the site has been established for various ARIs based on regional 3-seconds wind speed values recommended in the wind code (Region A2 - Sydney)[10]. These regional wind speeds have been adjusted to transform the values into more-appropriate hourly mean wind speeds, and to account for terrain/height considerations (Terrain Cat 2, <3m height). Table 4 summarises the results.

Table 4 Adopted extreme wind speeds used in wave hindcasting

ARI (years)	Regional 3s gust wind speed (m/s)	Adjusted wind speed (m/s)	Correction for W dir (1.00) (m/s)	Correction for NW dir (0.95) (m/s)	Correction for NNW dir (0.95) (m/s)	Correction for N dir (0.80) (m/s)
5	32.0	21.2	21.2	20.1	20.1	17.0
50	39.0	25.8	25.8	24.5	24.5	20.7
100	41.0	27.2	27.2	25.8	25.8	21.7

The *Young and Verhagen* method[11] for predicting wave growth in inland waters, reservoirs and lakes has been used to estimate the wave climate at the two site locations using the CRESS program tool[12] which assumes fetch limited conditions. This method uses empirical formulae developed from a large set of field measurements to transform the extreme wind speed, fetch and average water depth along the fetch into an extreme significant wave height and period for the various return periods and directions. **Table** 5 summarises the results of the wave hindcasting calculations.

Table 5 Predicted extreme wind-wave climate at site

ARI (years)	W L=250m, d=5m		NW L=350m, d=10m		NNW L=1400m, d=15m		N L=1200m, d=15m	
	H_s (m)[1]	T_p (s)[2]	H_s (m)	T_p (s)	H_s (m)	T_p (s)	H_s (m)	T_p (s)
5	0.17	1.57	0.19	1.68	0.38	2.44	0.29	2.16
50	0.21	1.72	0.23	1.83	0.46	2.67	0.36	2.37
100	0.22	1.76	0.24	1.88	0.48	2.73	0.38	2.42

1. H_s = significant wave height, defined as the average of the highest 1/3 of waves generated during the storm duration
2. T_p = peak wave period, defined as the wave period with the highest frequency in the wave spectrum.

In summary, the worst-case wind-wave height (H_s) generated for a 100 year ARI storm event has been estimated to be around 0.5m from the NNW direction.

It should be noted that these wave heights are defined as the average of the highest one third of waves generated during the storm duration, and therefore larger waves within the storm wave spectrum would periodically impact the site, typically around 1.8 x H_s (i.e. H_{max} ~ 0.9m).

[10] AS/NZS 1170.2:2002 - Structural design actions Part 2: Wind actions
[11] Young, I R (1997). "The growth rate of finite depth wind-generated waves. Coastal Engg, vol 32, no 2-3, pp 181-195
[12] Coastal and River Engineering Support System (CRESS) program – v4.0.5, developed by the Netherlands Ministry of Public Works (Rijkswaterstaat), IHE-Delft and TU-Delft

The crest level of these extreme waves is slightly more than half the wave height above the still water level.

5.4.3 Vessel Wash Waves

Vessel wash waves will also impact the site generated predominantly by ferry boats navigating/berthing nearby. An assessment of the contribution of vessel waves based on guidance suggests that vessel-generated waves are likely to be smaller than the extreme wind waves calculated above, considering vessel speeds are greatly restricted at the subject area. It can be reasonably argued that vessel waves will not act in combination with the extreme wind-generated waves as these vessels would likely not be active in such extreme weather.

5.5 Wave Setup

Wave setup is the local elevation of the still water level within the surf zone due to the transfer of wave-related momentum to the water column during depth-induced wave-breaking. The waves generated in the Sydney Harbour are relatively small in comparison to the water depth and not subject to wave breaking from the sea bed. This means that wave setup in this case would be relatively small in magnitude (<0.1m) and can reasonably be ignored in practice against the inherent uncertainties with estimating the other components.

5.6 Wave Run up

Wave runup is the inland swashing up of water when a wave approaches a beach or sloping foreshore. In this case where the harbour edge treatment is a vertical seawall, wave runup will only occur when the still water level is above the crest of the seawall. If this occurs, waves generated in the harbour have the potential to run up the quay promenade.

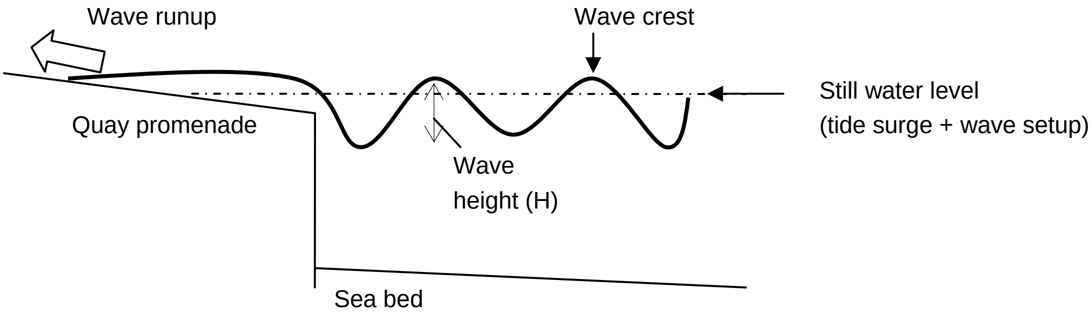

Figure 4: Schematic showing wave runup along quay promenade

The height of run up from waves dissipating energy against a seawall depends on several factors including:

- wave height and period;
- profile of the near shore area; and
- depth of water and wave regularity.

Run-up is usually expressed as a height measured vertically above the still water level, exceeded by a small percentage of waves. A quantitative estimate of wave runup potential for the project has not been undertaken as part of this study.

5.7 Wave Overtopping

Waves reaching the site have the potential to impulsively impact on the seaward face of the quay edge and produce significant volumes of splash. This splash water may then be carried over the edge either under its own momentum or as a consequence of an onshore wind. This phenomenon is often described as wave overtopping.

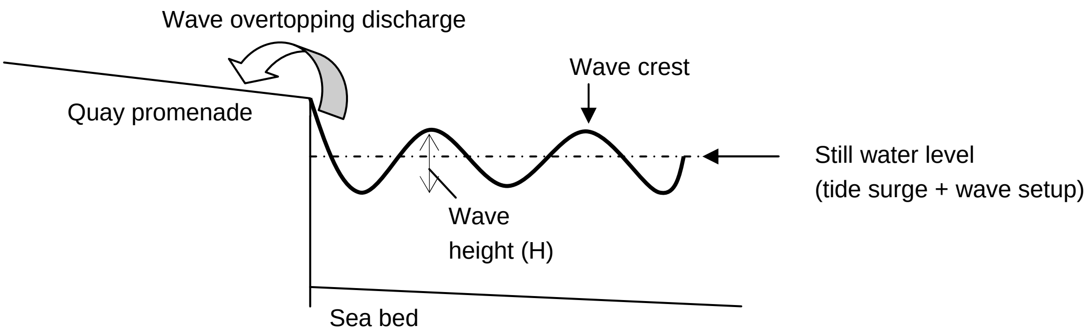

Figure 5: Schematic showing wave overtopping of quay seawall crest

Although this phenomenon is often sporadic, perhaps only happening every few waves within a storm (unlike a gently rising still water level caused by tide surge), it still can potentially contribute to flooding, but also structural damage and safety issues, if not managed appropriately.

The potential for wave overtopping depends on the available design freeboard, the extreme wave characteristics and the type of water's edge treatment (e.g. solid sea wall, or piled suspended edge).

The edge treatment along the circular quay promenade is of a solid vertical wall type, which means that the potential for wave overtopping is relatively high at low freeboards.

A quantitative estimate of wave overtopping potential for the project has not been undertaken as part of this study.

6 Climate Change Projections

6.1 Increase in Mean Sea Level

6.1.1 IPCC Global Projections

In 1988 the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC) to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of anthropogenic climate change. A main activity of the IPCC is to provide in regular intervals an assessment of the state of knowledge on climate change. To date the IPCC has completed four assessment reports (1990, 1995, 2001 and 2007). The fifth assessment report is expected to be finalised in 2014.

The global climate change projections contained in the IPCC assessment reports are based on a combination of six ‘storylines’ of future global greenhouse gas emissions and 23 General Circulation Model (GCM) patterns to simulate climate influences at the global level.

The most recent IPCC Fourth Assessment Report (AR4) provided global climate change projections for mean global sea level rise to the end of the century. These are presented in Table 6 for each of the scenarios.

Table 6: AR4 Global Climate Change Projections[1]

Scenario[1]	**2090-2099 relative to 1980-1999**	
	Temperature Change[2] (°C)	**Corresponding Sea Level Rise[3] (m)**
A1FI	2.4 – 6.4	0.26 – 0.59
A1T	1.4 – 3.8	0.20 – 0.45
A1B	1.1 – 2.9	0.21 – 0.48
A2	1.7 – 4.4	0.23 – 0.51
B1	1.1 – 2.9	0.18 – 0.38
B2	1.4 – 3.8	0.20 – 0.43

[1] Scenarios relate to the set of IPCC storylines drawn from four families:

- A1 - very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies;
- A2 - economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines);
- B1 - rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies;
- B2 - emphasis is on local solutions to economic, social, and environmental sustainability with intermediate levels of economic development, and less rapid and more diverse technological change.

A further 3 groups within the A1 family are defined, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel).[13]

2 The ranges in projections for each of the scenarios represent the range of outputs from each of the GCM patterns used in the modelling.

3 A further 10 to 20cm allowance is to be made for the potential dynamic response of the Greenland and Antarctic ice sheets.

In addition to the values presented in Table 6 above, AR4 also includes an allowance of an additional 10 to 20cm by 2100 for the potential dynamic response of the Greenland and Antarctic ice sheets. Therefore a 0.79 m rise represents the upper limit of the projections. However it should be noted that AR4 further states: 'Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood to provide a best estimator of an upper bound for sea-level rise.'

It should also be noted that there is likely to be regional variation in global mean sea level rises.

Unlike the IPCC Third Assessment Report (2001) (TAR), AR4 (2007) does not provide a time series of sea-level projections through the 21st century, only maximum and minimum projections. For 2090-2099, the TAR and AR4 projections agree well at the upper limit. An estimate of a time series of the maximum IPCC AR4 projections (including the potential dynamic response of the Greenland and Antarctic ice sheets) based on the TAR time series is shown in Table 7 below.

Table 7: Adjusted projections of sea-level (m) for 95-percentile maxima, derived by adjusting the TAR projections to correspond to the AR4 projections at 2095[14].

Year	**Scenario**					
	A1FI	**A1B**	**A1T**	**A2**	**B1**	**B2**
2010	0.060	0.059	0.059	0.060	0.056	0.058
2020	0.099	0.096	0.100	0.097	0.092	0.097
2030	0.146	0.143	0.149	0.139	0.132	0.142
2040	0.204	0.200	0.208	0.190	0.178	0.192
2050	0.278	0.266	0.272	0.251	0.227	0.247
2060	0.368	0.337	0.342	0.320	0.279	0.307
2070	0.471	0.413	0.413	0.401	0.333	0.369
2080	0.584	0.493	0.482	0.490	0.388	0.435
2090	0.701	0.571	0.548	0.588	0.444	0.504
2100	0.819	0.649	0.611	0.692	0.496	0.576

[13] Intergovernmental Panel on Climate Change, Special Report on Emissions Scenarios: Summary for Policy Makers, 2000.

[14] Hunter, J.R. (2008), Estimating Sea-Level Extremes Under Conditions of Uncertain Sea-Level Rise. Submitted to Climatic Change as cited by CSIRO Wealth from Oceans National Research Flagship and the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) <http://www.cmar.csiro.au/sealevel/sl_proj_21st.html>

6.1.2 Developments since AR4

There have been some significant developments since AR4 including evidence that global greenhouse-gas emissions are now tracking well above the (high-impact) A1FI scenario, and that the world has not yet adopted any reasonable mitigation pathway. Furthermore, since 1990, both global temperature and global sea level have been tracking the upper limit of the projections, suggesting that the AR4 projections may be underestimates. Recognising the inadequacies of the current understanding of sea-level rise, simple statistical models relating to observed sea levels to observed temperatures have been developed and applied with projected temperature increases to project future sea levels. These have generally resulted in higher sea level projections for 2100, of up to 1.4 m

In particular, the AR4 projections for sea level rise are subject to increasing concern about a more rapid rate of sea-level rise as a result of the instability of the Greenland and the West Antarctic Ice Sheets. In particular, one Australian study reports that:

'While our understanding of the relevant processes is limited, it is important to recognise that the uncertainties are essentially one-sided: the processes can only lead to a higher rate of sea-level rise than current model projections[15].'

A 2008 study into the constraints of glaciological conditions for sea-level rise suggests that increases in excess of 2 m by 2100 are 'physically untenable'. This suggests that a global 2m mean sea level rise represents an upper bound only if 'all variables are quickly accelerated to extremely high limits'[16].

6.2 Increase in Storm Surge Events

Climate change modelling has suggested that storm winds may become more intense and more frequent on the NSW coastline resulting in higher storm surge during storm events[17]. However, it is unlikely that the full impact of any increased frequency and severity of storm surges will be seen in Sydney Cove with the majority of the ocean wave energy dissipated at Middle Head. There is however some chance that local sea winds will increase in frequency as a result of local wind events. This has not been quantified and in any case is likely to represent a relatively small contribution to increased sea levels when compared to mean sea level rise.

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[15] Church, J.A. White, N.J., Hunter, J.R., Lambeck, K., A post-ICC AR4 update on sea-level rise, 2008, p 3

[16] Pfeffer, W.T., Harper, J.T., O'Neel, S., Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise, 2008
Science Vol. 321. no. 5894, pp. 1340 – 1343, 5 September 2008

[17] McInnes, K., Abbs, D., O'Farrell, S., Macadam, I., O'Grady, J., Ranasinghe, R., Projected Changes in Climatological Forcing for Coastal Erosion in NSW , CSIRO Marine and Atmospheric Research and NSW Department of Environment and Climate Change, August 2007.

6.3 Compounding Impacts of Extreme Rainfall Events

While extreme rainfall events have not been considered in any detail in this assessment, it should be noted that the frequency and intensity of extreme rainfall events is anticipated to increase in NSW under climate change projections[18]. Extreme rainfall has the potential to compound the impacts (but not necessarily likelihood) of coastal inundation if combined.

6.4 Projections considered in this assessment

For the purposes of this assessment, values for mean sea level rise as a result of climate change to be considered are presented in Table 8 below.

Table 8: Projections of Mean Sea Level Rise

Projection		**2050**	**2100**
A	NSW Planning Benchmark	0.4m	0.9m
B	IPCC AR4 Upper Limit A1FI Projections (adjusted time series)	0.28m	0.82m
C	Upper bound of Sea Level Rise projected by statistical methods	-	1.4m
D	Suggested upper bound of global mean sea level rise only if all variables are quickly accelerated to extremely high limits	-	2.0m

The resulting impact on current sea levels at the site for A, C and D projection scenarios in Table 8 by 2100 is presented in Table 9.

Table 9: Projections of Mean Sea Level Rise to 2100

Extreme Water Level	**m AHD**				
	Current Level	**Assumed 1990 Level**[3]	**+0.9m SLR**	**+1.4m SLR**	**+2m SLR**
Mean High Water Springs	0.67	0.607	1.507	2.007	2.607
Highest Astronomical Tide	1.17	1.107	2.007	2.507	3.107
1 in 100 year Extreme Sea Level Event[1]	1.435	Assumed as per current	2.335	2.835	3.435
Sydney Harbour Foreshores and Waterways DCP Min Seawall Crest Level[2]	1.675	-	2.575	-	-

1 Estimated on basis that increased frequency of storm surge events will not affect extreme event magnitudes

2 Assuming that the DCP minimum seawall crest requirement adopts the 0.9m increase as per the NSW Sea Level Rise Policy

3 Adjusted for an observed sea level rise of around 3mm/yr between 1990 and 2011 (i.e. 0.063m).

[18] http://www.climatechange.gov.au/climate-change/impacts/national-impacts/nsw-impacts.aspx

7 Potential Impacts of Sea Level Rise

7.1 General

This section discusses the likely physical impacts from future sea level rise on the proposed development considering the various sea level rise scenarios discussed in Section 6, and the potential adverse consequences to the development.

7.2 Physical Impacts

Physical impacts can be categorised as either:

- Extreme event (short term) impacts occurring where there is an infrequent, storm surge or tidal anomaly event; and
- Long term impacts from the gradual increase in sea level rise and frequent (less extreme) inundation events.

A high-level assessment has been made on the likely physical impacts that each sea level rise scenario considered for this study would have on the critical features of the proposed development, in the absence of any mitigation/adaptation measures adopted.

This assessment is summarised in Table 10 below.

Table 10: High Level Assessment of Physical SLR Impacts on Proposed Development (assuming no mitigation/adaptation measures adopted)

Sea Level Rise Scenario at 2100	Quay Promenade	Building	Water and Sewerage Infrastructure	Emergency Access Points
0.9m SLR (NSW Government Benchmark)	Increase in wave overtopping of seawall at extreme tide-surge + wave climate event. More frequent incidences of wave overtopping of seawall at high tides + extreme wave climate.	Increase in groundwater levels on basement walls.	Existing infrastructure may not be able to meet intended design service requirements.	Increase wave overtopping potential may restrict access along public domain area
1.4m SLR (upper statistical bound)	As with 0.9m SLR, but wave overtopping more frequent and higher in magnitude. Wave run-up of promenade at extreme tide-surge events with only moderate wave climate.	Increase in groundwater levels on basement walls. Inundation of ground floor and basements for 100 year ARI[1] tide-surge event or greater.	Existing infrastructure may not be able to meet intended design service requirements.	Water inundation restricting access to/from western side of building (circular quay east) and western end of pedestrian street linkage for 100 year tide-surge ARI[1] event or greater.
2.0 m SLR (upper physical bound)	As with 1.4m SLR, but more frequent (daily) inundation of harbour water above sea wall crest leading to wave run-up and potential for wave overtopping at most tide levels.	Increase in groundwater levels on basement walls. Frequent inundation of ground floor and basements (many times per year).	Existing infrastructure may not be able to meet intended design service requirements.	Frequent water inundation restricting access to/from western side of building (circular quay east) and western end of pedestrian street linkage (many times per year).

1 ARI = Average Return Interval

7.3 Potential Consequences

Potential consequences with respect to various features of the proposed development as a result of physical impacts on the site from sea level rise as described in Table 10 are outlined below.

7.3.1 Quay Promenade

7.3.1.1 Extreme Events

Extreme tide surge events combined with mean sea level rise would exacerbate wave overtopping of the seawall and wave runup with the potential to damage structures and landscaping within the promenade, and be a hazard to pedestrians. This will be more of an issue for the promenade area closest to the foreshore, however the public domain area of the proposed development is also potentially exposed to these impacts.

7.3.1.2 Long Term

Increased frequency of overtopping and wave run-up over time may exacerbate deterioration of the promenade pavement surface, and other structures and landscaping.

7.3.2 Building

7.3.2.1 Extreme Events

Mean sea level rise in conjunction with extreme storm surge events may cause inundation of the ground floor and basements leading to extensive interior damage and possible structural failure where not mitigated. Sudden inundation of the building could also pose a serious hazard to human safety.

7.3.2.2 Long Term

Rising water levels in the harbour would mean that groundwater levels would also increase. This would lead to an increased groundwater loading on, and potential for seepage through, the building basements.

Increased frequency of inundation may over time cause the degradation of materials, structures and foundations of buildings and facilities to accelerate. This accelerated degradation of materials has the potential to reduce the life expectancy of structures and facilities, also increasing maintenance costs and leading to potential structural failure during extreme events towards 2100 if not mitigated.

7.3.3 Water and Sewerage Infrastructure

7.3.3.1 Extreme Events

There is the potential for significant damage, up-pipe flooding and environmental spills and disruption in service from the inability of existing and newly-built water distribution, stormwater and sewerage systems to cope with rising sea level combined with extreme events or multiple events in a season. These impacts would also be compounded where the tide-surge event coincides with a high rainfall event.

7.3.3.2 Long Term

The degradation of materials used in the construction of water supply, sewer and stormwater pipelines may accelerate through impacts caused by increased frequency of inundation events. This accelerated degradation has the potential to reduce the life expectancy of the infrastructure, increase maintenance costs and possibly lead to structural failure.

7.3.4 Emergency Access Points

7.3.4.1 Extreme Events

Mean sea level rise in conjunction with extreme tide surge events have the potential to flood access points, restricting access or exit from the development during an emergency.

8 Risk Assessment

A high-level risk assessment has been carried out to assess the specific risks to the Amatil building development as a result of potential sea level rise to the year 2100.

8.1 Methodology

The methodology adopted a qualitative risk assessment procedure to evaluate the risks associated with impacts as a result of climate change induced sea level rise on the Amatil building development.

Risk is defined as the combination of consequences and likelihood. For each worst-case scenario, the consequences and likelihood of occurrence were determined in accordance with Table 11 and Table 12. The risk rating was then determined in accordance with Table 13.

Table 11 Qualitative Description of Consequence

Level	Descriptor	Consequence	Social	Financial
1	Insignificant	No change	No adverse human health effects or complaints.	Insignificant financial loss
2	Minor	Localised service disruption. No permanent damage. Some minor restoration work required. Lifespan reduced by 10-20%	Short-term disruption to employees, residents or businesses. Slight adverse human health effects or general amenity issues. Negative reports in local media.	Additional operational costs. Minor Financial loss
3	Moderate	Widespread damage and loss of service. Damage recoverable by maintenance and minor repair. Partial loss of local infrastructure. Lifespan reduced by 20-50%.	Frequent disruptions to employees, residents or businesses. Adverse human health effects. Negative reports in state media.	Moderate financial loss
4	Major	Extensive damage requiring extensive repair. Lifespan reduced by >50%.	Permanent physical injuries and fatalities may occur from an individual event. Negative reports in national media. Public debate about performance.	Major financial loss

Level	Descriptor	Consequence	Social	Financial
5	Catastrophic	Permanent damage and/or loss of service Retreat and translocation of development.	Severe adverse human health effects – leading to multiple events of total disability or fatalities. Emergency response. Negative reports in international media.	Significantly high financial loss

Table 12 Qualitative Description of Likelihood

Level	Descriptor	Description
A	Almost Certain	The event is expected to occur in most circumstances
B	Likely	The event will probably occur in most circumstances
C	Moderate	The event should occur at some time
D	Unlikely	The event could occur at some time
E	Very Unlikely	The event may occur only in exceptional circumstances

Table 13 Risk Rating Matrix

Likelihood	Consequence				
	1	2	3	4	5
	Insignificant	Minor	Moderate	Major	Catastrophic
A Almost Certain	L	M	H	E	E
B Likely	L	M	M	H	E
C Moderate	L	L	M	H	H
D Unlikely	L	L	M	M	H
E Very Unlikely	L	L	L	M	M

E - Extreme risk, requiring immediate action.

H - High risk issue requiring detailed research and planning at senior management level.

M - Moderate risk issue requiring change to design standards and maintenance of assets.

L - Low risk issue requiring action through routine maintenance of assets.

8.2 Results

A summary of the potential risks for various development features over its lifetime (assumed until 2100) for the NSW Government benchmark of 0.9m and without any adaptation measures adopted are identified in Table 14 below.

Table 14 Risk Rating Matrix

Infrastructure	Potential Impact	Likelihood	Consequence	Risk Rating
Quay Promenade	Immediate damage to promenade structures and landscaping	C	2	L
	Risk of injury to promenade pedestrian from wave overtopping	E	4	M
	Accelerated degradation of materials and structures from frequent inundation events	D	2	L
Building	Inundation of ground floor and basements during storm surge events	E	4	M
	Accelerated degradation of materials and structures from frequent inundation events	E	3	L
Water and sewerage infrastructure	Failure of drainage infrastructure as a result of inundation during tide-surge surge events	D	2	L
	Accelerated degradation of materials from frequent inundation events	E	3	L
Emergency Access Points	Restricted access and/or exit from development	D	2	L

9 Mitigation/Adaptation Measures

The most effective measure to adapt to water inundation impacts on the proposed development from potential future sea level rise would be to raise the existing harbour seawall to an appropriate level. This would need to be undertaken along the perimeter of the Circular Quay precinct to be an effective physical barrier from tide-surge waters originating from Sydney Harbour.

The crest level of the existing seawall which runs along the majority of the circular quay precinct varies between 2.29mAHD (adjacent to Wharf No 2) and 2.45mAHD. The existing seawall is therefore likely to provide adequate protection (subject to its structural stability) until the latter half of the century or unless sea level rise occurs greater than the NSW Government's benchmark.

Adopting the NSW Government's SLR benchmark of 0.9m sea level rise scenario at 2100, the seawall would eventually need to be raised to at least 2.335mAHD to ensure 100 year ARI tide surge levels are contained. An appropriate additional freeboard to allow for uncertainties and wave action should also be considered. This compares to the current Sydney Harbour Foreshores and Waterways DCP minimum seawall crest level requirement of 1.675mAHD, which if raised in line with the 0.9m benchmark sea level rise would be set at 2.575mAHD.

The seawall and immediate seaward promenade area is owned and managed by the Sydney Harbour Foreshore Authority (SHFA), and as such decisions on raising the seawall and its overall consequences is not within the direct control of Mirvac (although the development would be a key stakeholder). However, this development is not alone in the Circular Quay precinct that relies on the seawall as a flood barrier from harbour waters, and so it could be argued that the SHFA has a duty of care to implement measures to protect all critical assets landward of the foreshore from any apparent sea level rise, including raising the seawall crest.

In addition to raising the harbour seawall, other adaptation measures should be considered to protect the development from potential adverse impacts from sea level rise:

- Make a specific allowance for sea level rise during the engineering design for the development, particularly in the design of the basement and buried services.
- Locate critical infrastructure (e.g. power generators, data storage) at elevated locations above the 100 year ARI tide-surge level with sea level rise allowance.
- Provide for safe exit routes above storm flood height levels.
- Incorporate appropriate surface drainage along the public domain promenade to allow overtopped wave discharge and runup during storms to be readily removed.
- For structures susceptible to water inundation or wave splash accounting for future sea level rise, select materials with high durability properties to minimise long-term degradation.
- Consider the incorporation of permanent or removable flood barriers at critical points around the site (e.g. entrance to basement).

10 Conclusion

It is projected that climate change induced sea level rise will result in an increase in global mean sea level of between 0.26m and 2.0m by 2100. The wide range of projections represents the current uncertainty in projecting the trend in global emissions and the climatic response over such a long time frame. The NSW Government has adopted a planning benchmark of 0.9m mean sea level rise by 2100.

Consideration of the likely physical impacts of a sea level rise of 0.9m by 2100 (NSW Government benchmark value) suggests that the development is exposed to at least some potential adverse consequences including an increase in wave overtopping potential of the seawall, and impacts on groundwater pressures and buried services. When considering higher sea level rise scenarios (1.4m and 2.0m), the risk of impact on the development would be greater. In particular, the inundation of the ground floor and basement during high tide-surge events could be possible under these scenarios.

Given the height of the existing seawall, the site is likely to be adequately protected from inundation until the latter half of the century or unless sea level rise occurs greater than the NSW Government's benchmark

Notwithstanding, the most effective measure to adapt to water inundation impacts on the proposed development would be to raise the existing harbour seawall to an appropriate level. Implementing this measure is beyond the direct control of Mirvac as the seawall is owned by the Sydney Harbour Foreshore Authority.

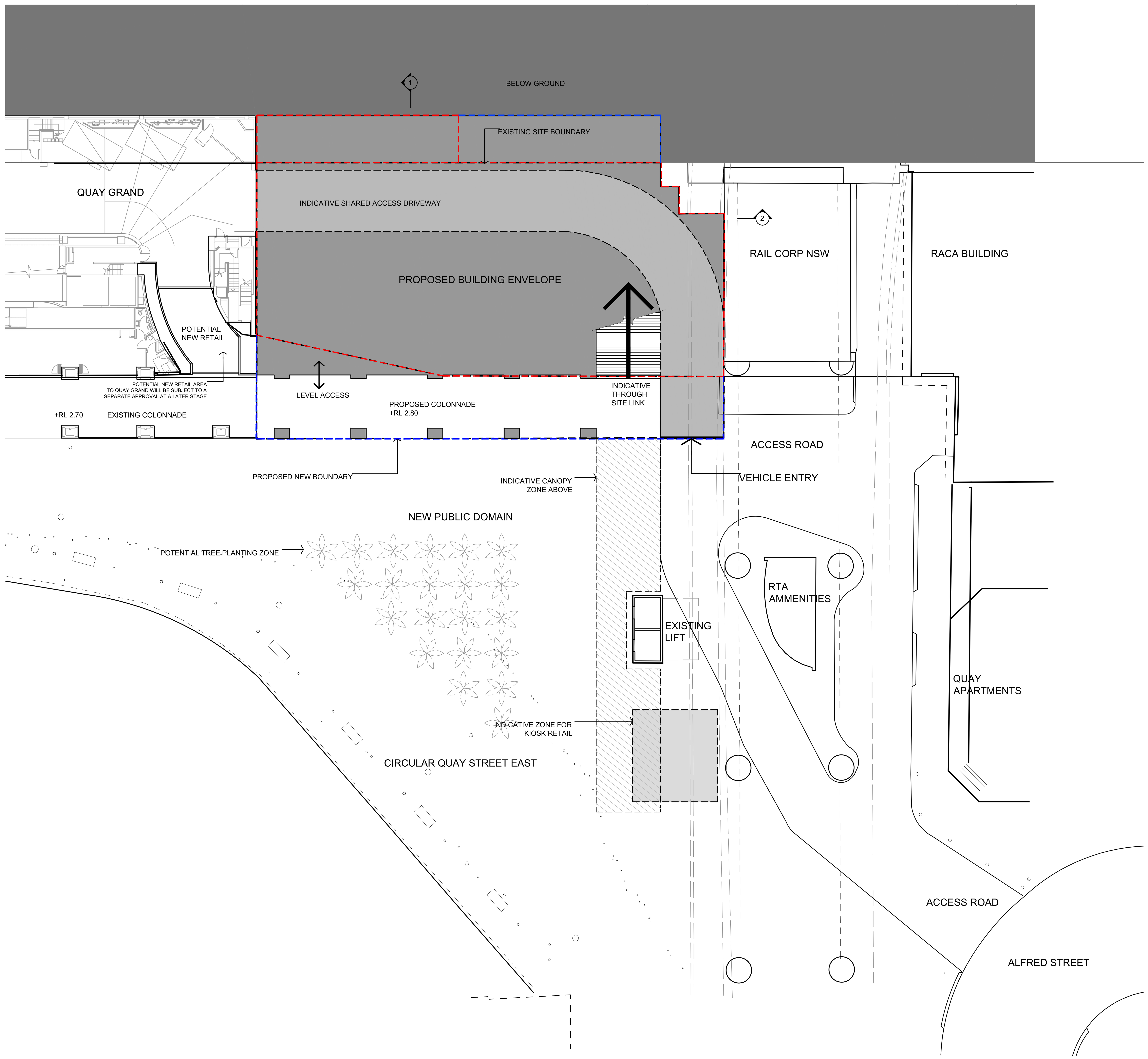
However, there are adaptation measures that the applicant does have control over which are recommended to be considered as early as possible in the development planning process:

- Make a specific allowance for sea level rise during the engineering design for the development, particularly in the design of the basement and buried services.
- Locate critical infrastructure (e.g. power generators, data storage) at elevated locations above the 100 year ARI tide-surge level with sea level rise allowance.
- Provide for safe exit routes above storm flood height levels.
- Incorporate appropriate surface drainage along the public domain promenade to allow overtopped wave discharge and runup during storms to be readily removed.
- For structures susceptible to flood inundation or wave splash, select materials with high durability properties to minimise long-term degradation.
- Consider the incorporation of permanent or removable flood barriers at critical points around the site (e.g. entrance to basement).

A high-level risk assessment summarised in a risk matrix has been undertaken, which effectively concludes that the risk for adverse consequences occurring to the proposed development from the physical impacts of climate change is generally low.

Appendix A

Amatil Building Development - Conceptual Design Plans and Section



Existing Site Boundary

Proposed Site Boundary Extension

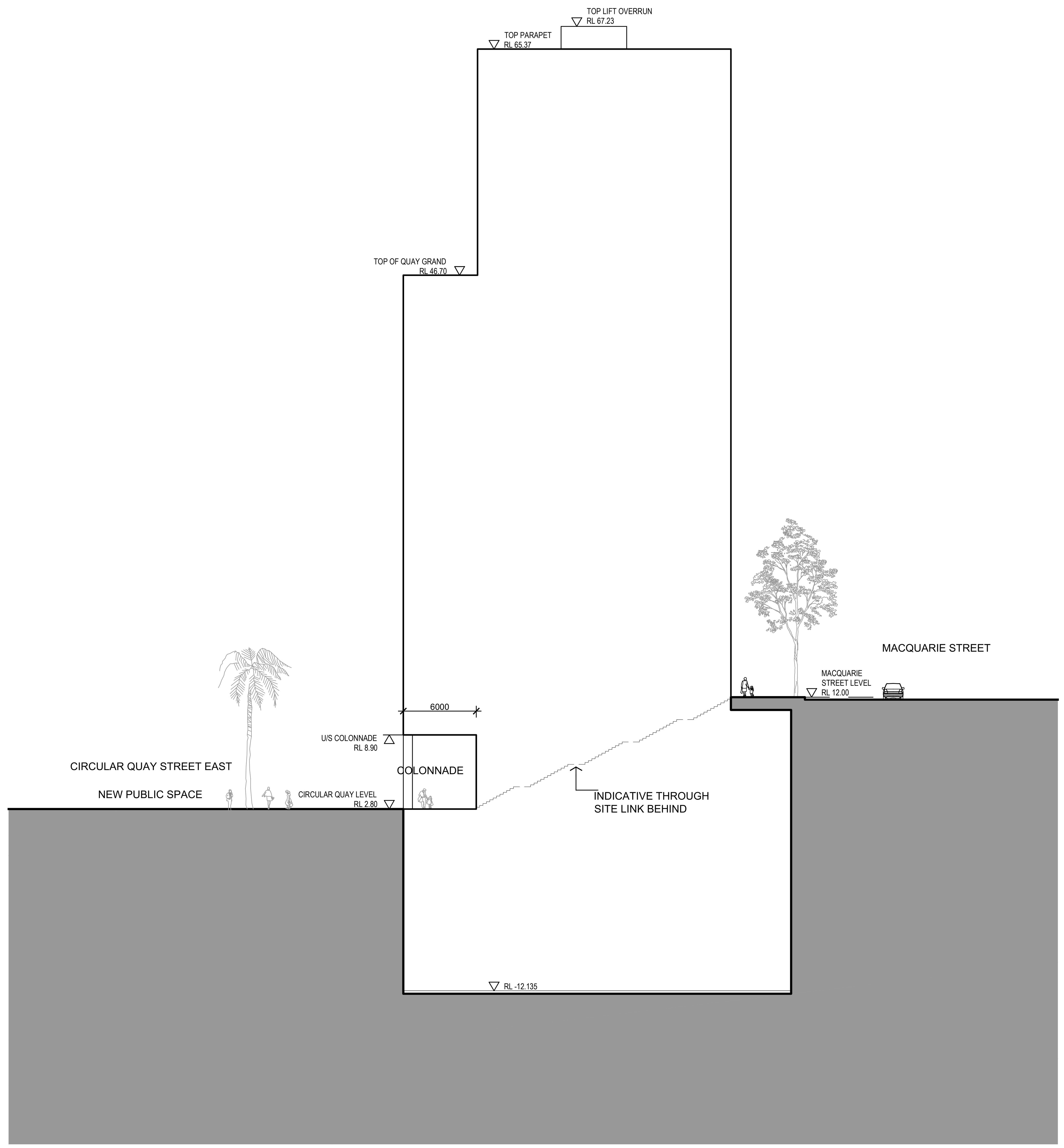
Revision	Date	Scale	Client	Project Name	Drawing
B- Concept Plan	03-11-2011	1:250@A1, 1:500@A3	AMP Capital Investors Mirvac	AX003070 71 Macquarie Street Concept Plan	A101-Proposed Site Plan

HASSELL

Existing Site Boundary
Proposed Site Boundary Extension

HASSELL

Revision	Date	Scale	Client	Project Name	Drawing
B- Concept Plan	03-11-2011	1:125@A1, 1:250@A3	AMP Capital Investors Mirvac	AX003070 71 Macquarie Street Concept Plan	A109- Proposed Massing Plan Basement Levels RL-12.135 RL-2.8



1 Proposed Section 01

Revision	Date	Scale	Client	Project Name	Drawing
B- Concept Plan	03-11-2011	1:250@A1, 1:500@A3	AMP Capital Investors Mirvac	AX003070 71 Macquarie Street Concept Plan	A130- Proposed Section 01

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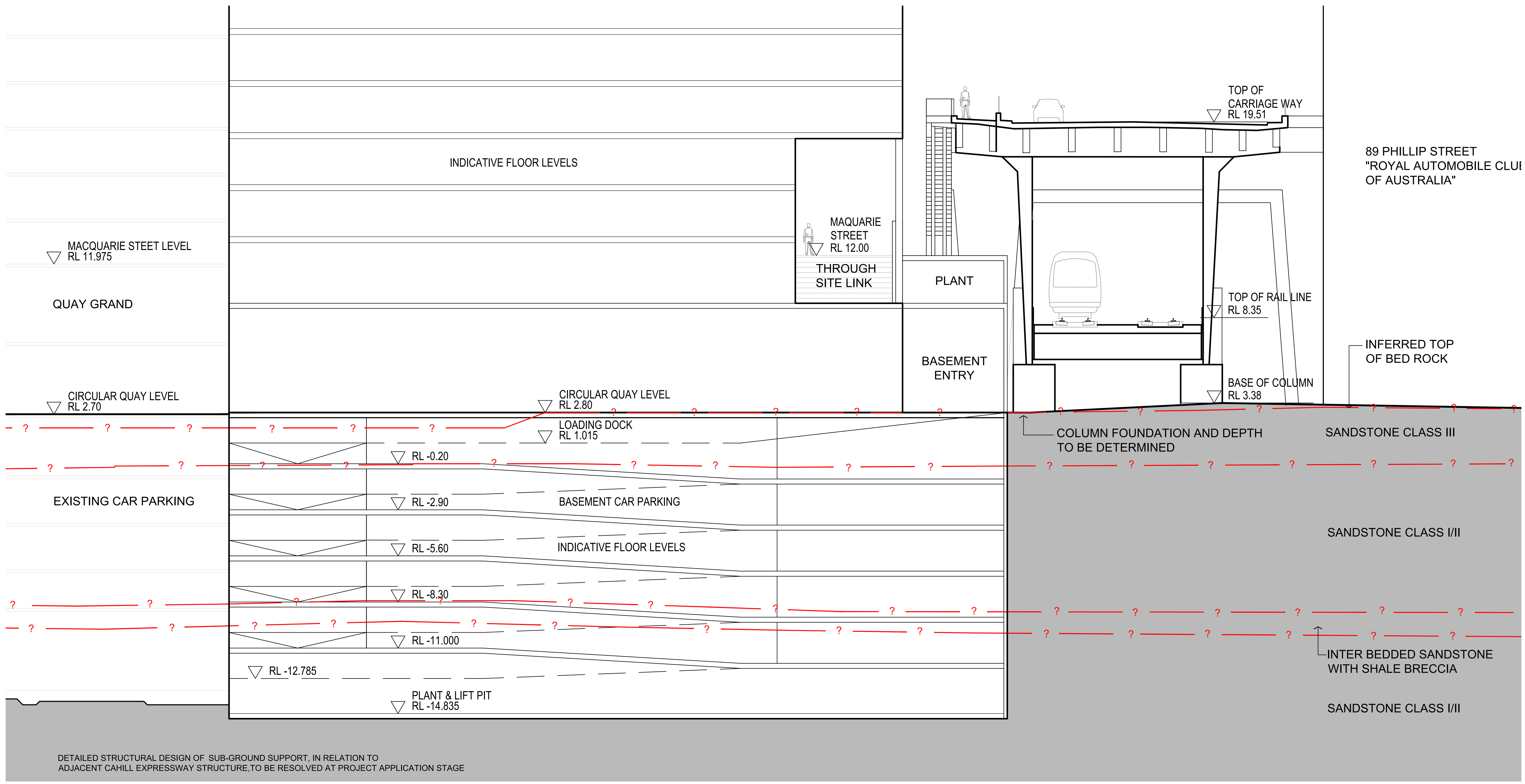

1 Proposed Section 02

— ? — Inferred Ground Conditions (Provided by Coffey Geotechnics)
Assumed location only, subject to site survey

Revision	Date	Scale	Client	Project Name	Drawing
B- Concept Plan	03-11-2011	1:125@A1, 1:250@A3	AMP Capital Investors Mirvac	AX003070 71 Macquarie Street Concept Plan	A131- Proposed Section 02

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