Lend Lease (Millers Point) Pty Limited

Barangaroo South Concept Plan Amendment (MP06_0162 MOD 4)

Climate Change and Sea Level Rise Report

ARUP

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1 Introduction

1.1 Background

On the 20 December 2009, Lend Lease (Millers Point) Pty Limited was appointed as the preferred proponent to develop Barangaroo South: comprising of Blocks 1 to 4 and associated public recreation areas.

The area of land that is subject to the Concept Plan Amendment is indicatively shown in Figure 1, and is herein referred to as “Barangaroo South” or the “Site”. It comprises an open apron which is largely reclaimed over water and is identified in the existing approved Concept Plan as Blocks 1 – 4 and the immediately adjacent public recreation area. Barangaroo South also extends beyond the western edge of the existing apron and includes a north-west oriented intrusion into the existing waters of Darling Harbour (see Figure 1).

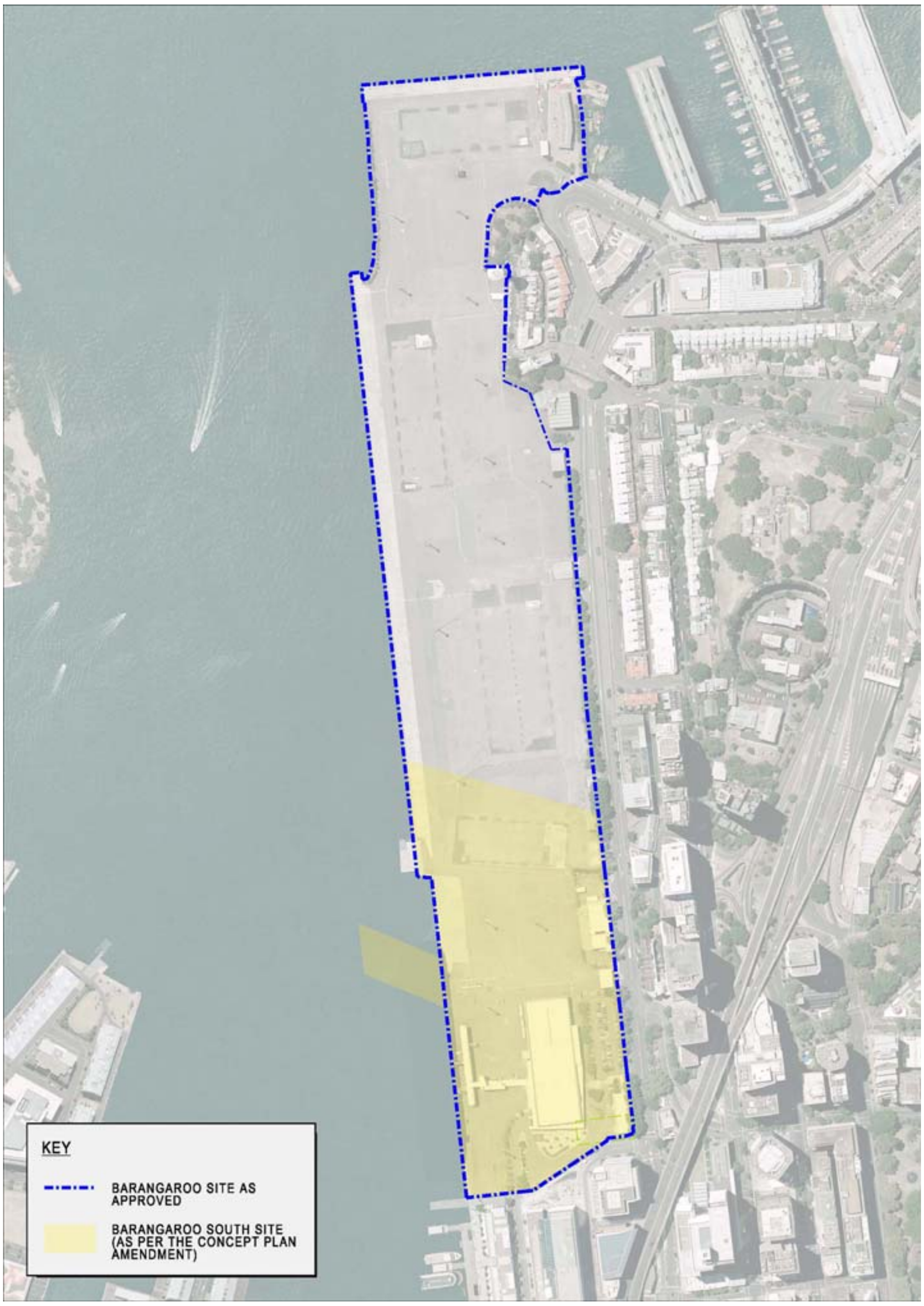

Figure 1: Indicative Site Boundary for Barangaroo South

1.2 Planning History

On 9 February 2007 the Minister approved a Concept Plan for the site and on 12 October 2007 the land was rezoned to facilitate its redevelopment. The Approved Concept Plan allowed for:

- a mixed use development involving a maximum of 388,300m^2 of gross floor area (GFA) contained within 8 blocks on a total site area of 22 hectares;
- approximately 11 hectares of new public open space/public domain, with a range of formal and informal open spaces serving separate recreational functions and including a 1.4km public foreshore promenade;
- maximum building heights and maximum GFA for each development block within the mixed use zone; and
- public domain landscape concept, including parks, streets and pedestrian connections.

A condition of consent also required two enlarged water intrusions into the Barangaroo site, one at the northern end and one at the southern end and the creation of a natural northern headland.

Modification No. 1 was approved in September 2007 which corrected a number of minor typographical errors.

On 25 February 2009 the Minister approved Modification No. 2 to the Concept Plan. The Approved Concept Plan as modified allowed for a mixed use development involving a maximum of 508,300m^2 of gross floor area (GFA) contained within 8 blocks on a total site area of 22 hectares.

On 11 November 2009 the Minister approved Modification No. 3 to the Concept Plan to allow for a modified design for the Headland Park and Northern Cove. The Approved Concept Plan as modified allowed for a mixed use development involving a maximum of 489,500m^2 of gross floor area (GFA) contained within 7 blocks on a total site area of 22 hectares.

The proposed Concept Plan Amendment (MP06_0162 MOD 4) seeks the Minister's consent for:

- additional GFA within Barangaroo South, predominantly related to an increase in residential GFA;
- redistribution of the land use mix;
- an increase in height of a number of the proposed towers within Barangaroo South;
- the establishment of the new pier and landmark building extending into the Harbour; and
- reconfiguration and activation of the public waterfront area through the introduction of uses including retail and residential to the west of Globe Street

1.3 Purpose

This report has been prepared in support of the Concept Plan Amendment (MP06_0162 MOD 4) for Barangaroo. It addresses the Director General Requirement to provide:

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

The following provides a high level review of the risks of climate change in increasing sea levels in Sydney Harbour and the potential inundation impact on the Barangaroo South.

Accordingly this assessment addresses sea level rise as a result of climate change. Other projected climate change impacts have not been specifically considered.

1.4 Scope of Work

The scope of work includes:

- review of existing occurrence of coastal inundation;
- review of climate change projections (for mean sea level rise, storm surge) and provide qualitative assessment of likelihood of inundation;
- identify and provide qualitative assessment of consequences of inundation on the development;
- identify potential adaptation measures; and
- assess risk of each impact with and without adaptation measures using a risk matrix.

1.5 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 Barangaroo development, global 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[1].

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] 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

2 Guidelines and Standards for Sea Level Rise

2.1 Planning Guidelines

2.1.1 NSW Sea Level Rise Policy Statement

The NSW State Government recently released its Sea Level Rise Policy Statement[2] 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 draft 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 IPCC AR4 projections of 0.79 m global average sea level rise by the decade of 2090 to 2099.

2.1.2 NSW Draft Coastal Planning Guideline: Adapting to Sea Level Rise

The NSW Sea Level Rise policy statement is supported by the NSW Draft Coastal Planning Guideline: Adapting to Sea Level Rise[3] detailing the application of sea level rise benchmarks to coastal and flood hazard assessments and in land-use planning. The Draft Guidelines were released in October 2009 and are due to be finalised in mid-2010.

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

- 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 and contours of site;
  - existing or proposed floor levels in AHD and foundation type; and
  - topographic levels to an accuracy of 0.1m, and structures to an accuracy of 0.01m, showing relative levels to AHD;
- a report addressing the following issues relating to sea level rise as they relate to the development site, where relevant:
  - permanent increase in sea level and increased tidal range; and
  - coastal flooding;
- information that demonstrates whether the development proposal:
  - is consistent with the relevant approved coastline or floodplain management plan;
  - is consistent with any relevant DCP that relates to coastal or flood issues;
  - meets the coastal protection requirements of the LEP; and
  - incorporates appropriate management responses and adaptation strategies.

[2] NSW Government, Sea Level Rise Policy Statement, November 2009 <http://www.environment.nsw.gov.au/climateChange/sealevel.htm>

[3] http://www.planning.nsw.gov.au/LinkClick.aspx?fileticket=1Mz7Sun64mw%3d&tabid=177

2.1.3 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 Barangaroo 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 top of sea wall height of 1.675 m 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 Benchmarks. The process for updating the DCP would not likely occur until after the finalisation of the NSW Draft Coastal Planning Guideline: Adapting to Sea Level Rise. Any update of the DCP would be required to be consistent with the final guideline.

2.1.4 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

Allowance for Sea Level Rise (AS4997-2005)	
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 that the minimum height of 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".

3 Existing Coastal Inundation

Sydney Harbour is subject to a range of physical processes including wind, waves, tidal fluctuations and associated currents. Each of these processes contributes to water levels and the extent to which inundation is experienced on rare occasions where wave run up overtops foreshore structures. The various contribution of each of these processes is shown in Figure 2 below.

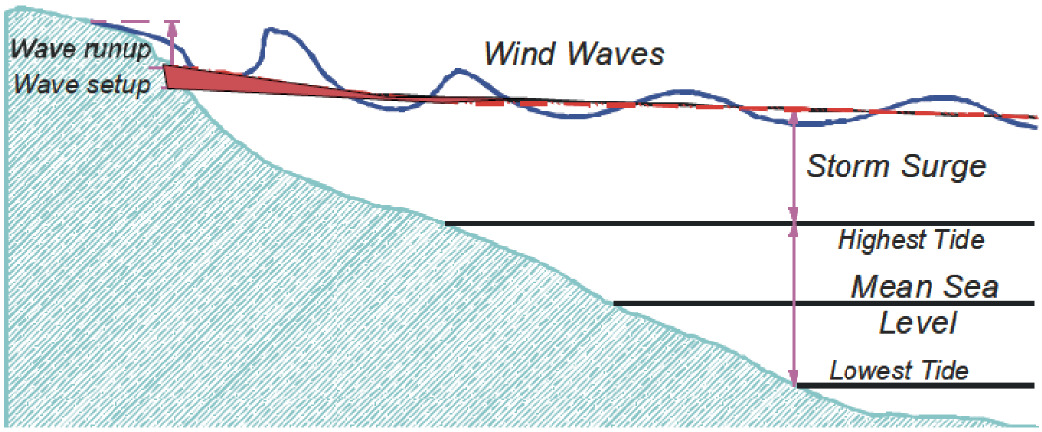

Figure 2 Contribution of Physical Processes to Water Levels[4]

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

3.1 Existing Levels

The existing sea wall at Barangaroo varies from 2.1m to 2.2m AHD with the site rising to 2.06 to 3.5 m AHD at Hickson Road approximately 200m landwards of the seawall.

3.2 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 2m) occurs during full or new moon when the gravitational pull of the moon and sun are combined. The 2009 tidal levels for Sydney Harbour are presented in Table 2 below.

Table 2 2009 Tidal Levels[5]

Tidal Levels	m AHD
Highest astronomical Tide	1.075
Mean high water Springs	0.675
Mean low water Springs	-0.675
Lowest astronomical Tide	-0.935

[4] 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] Arup, Barangaroo –South Competition: Canal Hydraulic Study, 2009

3.3 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[6]. 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 of the order of 0.1 to 0.2m[6]. In total storm surge swells in NSW coastal waters are therefore estimated to be in the order of 0.3 to 0.6m.

Barangaroo is situated approximately 6km from the ocean entrance at South Head. The majority of wave energy directed into the Harbour from the ocean is dissipated on the shorelines around Middle Head. While storm surge swells have been observed to penetrate into the Harbour, they tend to only reach as far as Nielsen Park and Rose Bay some 2km seawards of Barangaroo.

3.4 Wind and Current Related Waves

Waves occurring within the Harbour are generally as a result of local wind driven seas or from recreational and commercial vessels.

Very small, extremely long period waves (including tsunamis) associated with strong currents have also been known to impact upon Sydney Harbour in the past.

3.5 Wave Run up and Wave Set up

Wave setup and wave run up influence the height that waves reach as wave energy is dissipated at the shoreline. On beaches it can elevate the water level by as much as 7m. However, the wind and boat wave climate on Sydney Harbour is comparatively less than that experienced on the open coast from swell.

However, run up from wave energy dissipation against seawalls is still significant.[7] 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.

3.6 Existing Sea Level Data

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.

[6] 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

[7] EurOtop (2007). "Wave Overtopping of Sea Defences and Related Structures: Assessment Manual", Produced by Environmental Agency (UK), Coastal Engineering Research Council (Germany) and Rijkswaterstaat (Netherlands), August, 2007, 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

Similarly, the data inherently incorporates climate change induced sea level over this timeframe.

Extreme value analysis of tide 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	Maximum Level (m AHD)
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

1. ARI - Annual Recurrence Interval
2. AHD - Australian Height Datum

In accordance with AS4997-2005 Guidelines for the Design of Maritime Structures, the relevant design still water level is the 1/100 ARI (highlighted above), 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

4 Climate Change Projections

4.1 Increase in Mean Sea Level

4.1.1 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 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 4 for each of the scenarios.

Table 4 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).[9]

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.

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

In addition to the values presented in Table 4 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), 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 5 below.

Table 5 Adjusted projections of sea-level (m) for 95-percentile maxima, derived by adjusting the TAR projections to correspond to the AR4 projections at 2095[10]

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

4.1.2 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:

[10] 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>

"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[11].

A recent 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"[12].

4.2 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[13]. However, it is unlikely that the full impact of any increased frequency and severity of storm surges is likely to impact Barangaroo 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.

4.3 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[14]. Extreme rainfall has the potential to compound the impacts (but not necessarily likelihood) of coastal inundation if combined.

4.4 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 6 below.

Table 6 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	-	2m

The resulting impact on current sea levels at Barangaroo (for A, C and D projection scenarios in Table 6) by 2100 is presented in Table 8.

[11] Church, J.A. White, N.J., Hunter, J.R., Lambeck, K., A post-ICC AR4 update on sea-level rise, 2008, p 3
[12] Pfeffer, W.T., Harper, J.T., O'Neel, S., Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise Science Vol. 321. no. 5894, pp. 1340 – 1343, 5 September 2008
[13] 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.
[14] http://www.climatechange.gov.au/climate-change/impacts/national-impacts/nsw-impacts.aspx

Table 7 Projections of Mean Sea Level Rise to 2100

Extreme Water Level	m AHD			
	Current Level (No Sea Level Rise)	+0.9m SLR	+1.4m SLR	+2m SLR
Highest Astronomical Tide	1.075	1.975	2.475	3.075
Highest Astronomical Tide +0.3m Surge	1.375	2.275	2.775	3.375
Highest Astronomical Tide +0.6m Surge	1.675	2.575	3.075	3.675
1 in 100 year Extreme Sea Level Event[1]	1.435	2.335	2.835	3.435
Sydney Harbour Foreshores and Waterways DCP[2]	1.675	2.575	3.075	3.675

1 Estimated on basis that increased frequency of storm surge events will not affect the 1 in 100 year event magnitude

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

5 Potential Impacts of Inundation

The potential impacts of inundation can be categorised as either:

- extreme event impacts; or
- long term impacts.

Extreme event inundation impacts occur where there is a one-off storm surge or tidal anomaly event whereas long term impacts refer to the gradual increase in sea level rise and repeat (less extreme) inundation events.

The potential associated impacts below are related to different types of infrastructure which are to be incorporated into the Concept Plan.

5.1 Buildings

5.1.1 Extreme Events

Extreme storm surge events in conjunction with mean sea level rise may cause inundation leading to extensive damage and possible structural failure during extreme events. Sudden inundation could also pose a serious hazard to human safety.

5.1.2 Long Term Impacts

Increased frequency of inundation may over time cause the degradation of materials, structures and foundations of buildings and facilities. 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.

5.2 Water and Sewerage Infrastructure Impacts

5.2.1 Extreme Events

There is the potential for significant damage, environmental spills and disruption in service from the inability of water distribution, stormwater and sewerage systems to cope with extreme events or multiple events in a season.

5.2.2 Long Term Impacts

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 infrastructure, increase maintenance costs and possibly lead to structural failure.

In addition stormwater from the site will discharge to the Harbour via a pipeline located below the top of seawall height. There is therefore potential for the pipeline to be backfilled during a storm surge event. In the worst case scenario, where an extreme rainfall event and extreme storm surge event occur concurrently towards 2100 when mean sea level rise reaches the maximum projected limits, the discharge point may become obstructed such that the stormwater system would fail and stormwater would discharge to the Harbour via overland flow paths.

5.3 Energy Infrastructure Impacts

5.3.1 Extreme Events

Extreme events may cause the flooding of onsite power substations which may lead to an increase in the cost of infrastructure maintenance and an increased frequency and duration of blackouts and service disruption.

5.4 Access Point Impacts

5.4.1 Extreme Events

Extreme storm surge events have the potential to flood access points to buildings restricting access or exit.

6 Adaptation Measures

It is proposed that the development will adopt necessary measures to protect against coastal inundation under projections of sea level rise during the lifetime of the development.

The flood protection measures would be designed to incorporate projections of global mean sea level rise such that the development is to be protected from inundation under the climate change altered storm surge event.

The minimum sea wall crest level that would be adopted is 2.575mAHD representing the current DCP requirement with an additional 0.9m to meet the NSW Draft Coastal Planning Guideline: Adapting to Sea Level Rise.

The stormwater discharge point will be located below the seawall crest level at the highest point possible to allow gravity flow of the site run-off to the Harbour. The pipeline will be designed to be of sufficient capacity to manage partial backfilling from inundation during storm surge events which may occur towards 2100. Overland flow paths will also be identified to manage the stormwater flows should the discharge point become obstructed which may occur towards 2100 during an extreme storm surge event.

As part of the sea wall design, consideration would also be given to mitigating against extreme wave impact events in combination with extreme water levels, which may include additional crest raising, or incorporating wave dissipation modifications e.g. recurves and berms within the wall.

The design landscaped levels across the site would be chosen such that any inundation is restricted from entering the basement (or alternatively raise the basement to ground level). The onsite stormwater infrastructure would be appropriately designed to be able to quickly alleviate flood water after an event commences.

However, there is some risk that mean sea level rise will exceed the NSW Planning Guideline by 2100. Statistical analysis of previous sea level rise suggests 1.4m is possible but that 2m is unlikely to be exceeded.

To address the potential risk, principles of adaptive management would be adopted. That is, the seawall would be designed to allow it to be incrementally increased in height should future research change in Government policy or actual events suggest that sea level rise will be greater than current projections.

In addition to the seawall, there are also additional adaptation measures available to protect onsite buildings and infrastructure including:

- selection of materials including marine grade materials to prevent accelerated degradation;
- use of tidal flaps on stormwater discharge point;
- locating key infrastructure at elevated locations closer to Hickson Road (such as substations); and
- providing for safe exit routes above storm flood height levels.

7 Risk Assessment

A risk assessment has been carried out to assess the residual risks to the Concept Plan as a result of sea level rise.

7.1 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 Barangaroo Concept Plan.

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 8 and Table 9. The consequences and likelihoods have been considered against the proposed adaptation measures in Section 6. The risk rating was then determined in accordance with Table 10 below.

Table 8 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 9 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 10 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.

A summary of the potential risks are identified in Table 11 below

Table 11 Potential Risks Summary

Infrastructure	Potential Impact	Likelihood	Consequence	Risk Rating
Buildings	Inundation of basements and ground level during storm surge events	D	4	M
	Accelerated degradation of materials and structures from repeat inundation events	D	3	L
Water and sewerage infrastructure	Failure of water infrastructure as a result of overland inundation during storm surge events	D	3	L
	Failure of water infrastructure as a result of overland inundation during storm surge events compounded with extreme rainfall event	E	3	L
	Accelerated degradation of materials from repeat overland inundation events	E	2	L
	Failure of stormwater discharge system as a result of submersion of discharge point resulting in flooding where coinciding with extreme rainfall event	D	4	M
	Accelerated degradation of stormwater infrastructure as a result of partial inundation of stormwater discharge point	C	2	L
Energy Infrastructure	Inundation of substation during storm surge events	E	3	L
	Accelerated degradation of materials from repeat inundation events	E	2	L
Access Point Impacts	Restricted access and/or exit from car park	E	2	L

8 Discussion and Recommendations

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 2m 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.

Notwithstanding, the NSW Government has adopted a planning benchmark of 0.9m mean sea level rise by 2100.

There is a risk that such a sea level rise would result in inundation of the Barangaroo site by either direct coastal inundation or by a failure of the stormwater system where the discharge point to the Harbour becomes submerged.

This could be addressed in the proposed development contemplated under the Barangaroo South– Concept Plan Amendment (MP06_0162 MOD 4) by the establishment of a seawall (either at the current existing seawall alignment at Barangaroo South or set back from the existing alignment in the form of a fold, landscape wall or appropriate graded rise in the new proposed ground plane) at a minimum height of 2.575m AHD. This height is:

- greater than the current 1 in 100 year event (1.435 m AHD) for Sydney Harbour plus an additional 0.9m to accommodate mean sea level rise (2.335 m AHD);
- equal to the current Sydney Harbour Foreshores DCP (1.675 m AHD) plus an additional 0.9m (2.575 m AHD); and
- able to be incrementally increased in the future to respond to actual demonstrated sea level changes.

The sea wall (or alternate) could be designed to protect against long term impacts of coastal inundation as well as to mitigate against extreme wave overtopping events. The stormwater discharge point will be located within the existing caisson structure seawall or basement perimeter retention system/groundwater control wall in the case of Southern Cove at the highest point possible to allow gravity flow of the site run-off to the Harbour. The pipeline will be designed to be of sufficient capacity to manage partial backfilling from inundation during storm surge events which may occur towards 2100. Overland flow paths will also be identified to manage the stormwater flows should the discharge point become obstructed which may occur towards 2100 during an extreme storm surge event.

There is a residual risk of inundation impacts on the development as a result of climate change induced sea level rise if the following occurs:

- mean sea level rise in Sydney Harbour is greater than 0.9m; and
- an extreme storm surge event occurs greater than current 1 in 100 year event.

This could also be compounded where the storm surge event coincides with a high rainfall event.

To mitigate against these residual and co incidental risks where appropriate, the following measures can be considered:

- selection of materials to prevent accelerated degradation of infrastructure and buildings;
- locating key infrastructure at elevated locations closer to Hickson Road (such as substations);
- providing for safe exit routes above storm flood height levels; and
- adoption of principles of adaptive management such that the seawall or alternative landscaping elements are designed so its height may be incrementally increased

should future research, change in Government policy or actual events suggest that sea level rise will be greater than current projections.

9 Conclusion

This Climate Change and Sea Level Rise assessment report has been prepared by Arup to provide a high level review of the risks of climate change in increasing sea levels in Sydney Harbour and the potential inundation impact on the Barangaroo Concept Plan.

The purpose of the assessment is to inform and accompany the Concept Plan Amendment (MP06_0162 MOD 4).

The assessment concludes that risks associated with projected sea level rise are manageable, by utilising industry standard and proven design and construction techniques, principally through the adoption of recommended minimum seawall design criteria which include:

- the adoption of recommended minimum seawall design (or subsequent landside wall, public domain levels and the like) heights to address the risk of inundation; and
- designing the seawall (or subsequent landside wall) such that it can be readily and incrementally raised in the future in response to actual sea level rises.

Arup concludes that the development scheme presented in the proposed Concept Plan Amendment (Modification 4) will not result in any significant additional impacts beyond those reasonably understood and expected to have been contemplated in the Approved Concept Plan (as modified).