

Lend Lease (Millers Point) Pty  
Limited

**Public Domain (Stage 1A)  
Planning Application**

Climate Change and Sea Level Rise  
Report

Final | 18 December 2013

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# Contents

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	Page
<b>1 Introduction</b>	<b>1</b>
1.1 Background	1
1.2 Overview of Proposed Development	1
1.3 Site Location	1
1.4 Scope of Works	3
1.5 Background to Climate Change and Sea Level Rise	3
<b>2 Guidelines and Standards for Sea Level Rise</b>	<b>4</b>
2.1 Planning Guidelines	4
<b>3 Existing Coastal Inundation</b>	<b>7</b>
3.1 Existing Levels	7
3.2 Astronomical Tide	7
3.3 Storm Surge	8
3.4 Waves	8
3.5 Wave Setup	9
3.6 Wave Run up	9
3.7 Wave Overtopping	9
3.8 Existing Sea Level Data	10
<b>4 Climate Change Projections</b>	<b>11</b>
4.1 Increase in Mean Sea Level	11
4.2 Increase in Storm Surge Events	13
4.3 Compounding Impacts of Extreme Rainfall Events	13
4.4 Summary of Sea Level Rise Benchmarks	13
4.5 Projections considered in this assessment	14
<b>5 Potential Impacts of Inundation</b>	<b>15</b>
5.1 Public domain features	15
5.2 Water and Sewerage Infrastructure Impacts	15
5.3 Energy Infrastructure Impacts	16
5.4 Access Point Impacts	16
<b>6 Adaptation Measures</b>	<b>17</b>
<b>7 Risk Assessment</b>	<b>18</b>
7.1 Methodology	18

<b>8</b>	<b>Discussion and Recommendations</b>	<b>21</b>
<b>9</b>	<b>Conclusion</b>	<b>23</b>

# 1 Introduction

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## 1.1 Background

This report supports a State Significant Development Application (SSDA) (SSD6303) submitted to the Minister for Planning and Infrastructure pursuant to Part 4 of the *Environmental Planning and Assessment Act 1979* (EP&A Act). The SSDA seeks approval for public domain works within Stage 1A at Barangaroo South as described in the Overview of Proposed Development section of this report.

## 1.2 Overview of Proposed Development

The Public Domain SSDA seeks approval for the all public domain works within ‘Stage 1A’ of the Barangaroo South Site. These works include typical public domain features such as street paving, street furniture, lighting and planting.

Additional items such as shade/weather protection structures, water features and bicycle facilities are also included in the design of the public domain. Various services and infrastructure such as power and water are incorporated into the proposed works where relevant.

## 1.3 Site Location

Barangaroo is located on the north western edge of the Sydney Central Business District, bounded by Sydney Harbour to the west and north, the historic precinct of Millers Point (for the northern half), The Rocks and the Sydney Harbour Bridge approach to the east; and bounded to the south by a range of new development dominated by large CBD commercial tenants.

The Barangaroo site has been divided into three distinct redevelopment areas (from north to south) – the Headland Park, Barangaroo Central and Barangaroo South.

The Public Domain SSDA Site area is located within Stage 1A of Barangaroo South as shown in Figure 1. The SSDA Site extends over land generally known and identified in the approved Concept Plan as Blocks 1, 2, 3, and X and the area of the foreshore between Block X and Darling Harbour

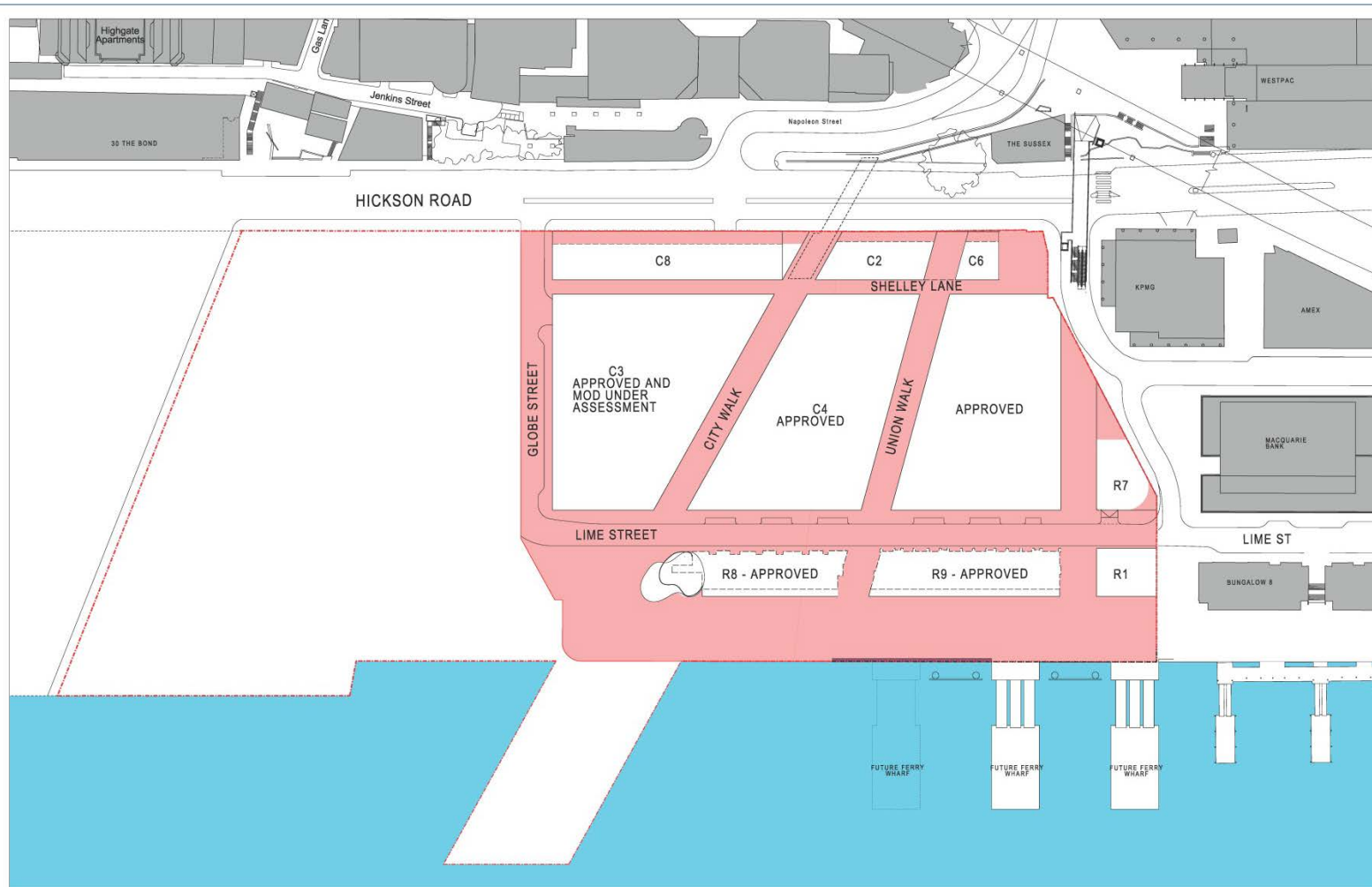


Figure 1 Public Domain Application Site Plan

## 1.4 Scope of Works

The scope of work for this climate change and sea level rise report 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<sup>1</sup>.

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.

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<sup>1</sup> 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

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### 2.1 Planning Guidelines

#### 2.1.1 NSW Sea Level Rise Policy Statement

The NSW State Government released its Sea Level Rise Policy Statement<sup>2</sup> 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 specified 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 was 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.

On 8 September 2012 the NSW government abandoned the 2009 NSW Sea Level Rise Policy Statement and associated planning benchmarks. Local councils in NSW were subsequently encouraged to adopt local sea level rise projections to provide greater flexibility to local conditions across NSW.

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

The NSW Coastal Planning Guideline: Adapting to Sea Level Rise<sup>3</sup> applies to all coastal areas of NSW, including Sydney Harbour, without the requirement to adhere to the repealed NSW Sea Level Rise Policy Statement benchmarks.

The NSW Coastal Planning Guideline: Adapting to Sea Level Rise details the application of sea level rise benchmarks to coastal and flood hazard assessments and in land-use planning. The Guidelines were released in August 2010.

The Planning Guideline provides the following information for development applications in coastal risk areas:

- 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;

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<sup>2</sup> NSW Government, Sea Level Rise Policy Statement, November 2009

<<http://www.environment.nsw.gov.au/climateChange/sealevel.htm>>

<sup>3</sup>[http://www.planning.nsw.gov.au/Portals/0/PlansForAction/pdf/SeaLevelRise\\_Policy\\_web%5B1%5D.pdf](http://www.planning.nsw.gov.au/Portals/0/PlansForAction/pdf/SeaLevelRise_Policy_web%5B1%5D.pdf)

- 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.

### **2.1.3 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.

### **2.1.4 City of Sydney Flood Risk Management Plans**

The City of Sydney has not produced a local council sea level rise policy since the abolishment of the NSW Sea Level Rise policy in 2012. However, the City of Sydney recently released a Draft Interim Floodplain Management Policy (16 July 2013) as an overarching guide to develop local Floodplain Risk Management Plans for each drainage catchment within the local government area. Floodplain Risk Management Plans will consider the existing flood environment, including the potential impact of sea level rise, and recommend specific measures to manage the impact of flooding. The Sydney CBD and Darling Harbour catchment has yet to commence a floodplain risk management study for this catchment. The draft policy is currently on exhibition for public comment and should be finalised in 2014.

### **2.1.5 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 (AR3) (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 AR3 (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 accident 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.

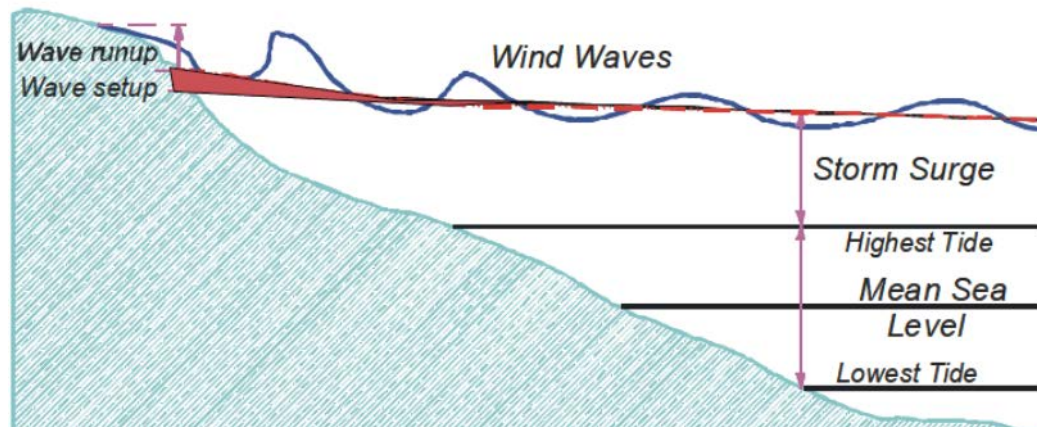


Figure 2 Contribution of Physical Processes to Water Levels<sup>4</sup>

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 3.5m 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.

<sup>4</sup> 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

Table 2 2009 Tidal Levels<sup>5</sup>

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

### 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<sup>6</sup>. 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. 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 six kilometres 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 6km seawards of Barangaroo.

### 3.4 Waves

Waves impacting the Barangaroo site 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.

The site is relatively well sheltered from wind-generated wave disturbance, with extreme events (up to 100 year Average Recurrence Interval (ARI)) limited to a significant wave height of approximately 0.5m with peak period of 3s.

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  $1.8 \times H_s$  (i.e.  $H_{max} \sim 0.9m$ ). The crest level of these extreme waves is slightly more than half the wave height above the still water level.

Vessel wash waves will also impact the site. An assessment of the contribution of vessel waves based on guidance suggests that vessel-generated waves are likely to

<sup>5</sup> Arup, Barangaroo –South Competition: Canal Hydraulic Study, 2009

<sup>6</sup> 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

be smaller than the extreme wind waves estimated 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.

### 3.5 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 ( $<0.1\text{m}$ ) and can reasonably be ignored in practice against the inherent uncertainties with estimating the other components.

### 3.6 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 landwards.

### 3.7 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.

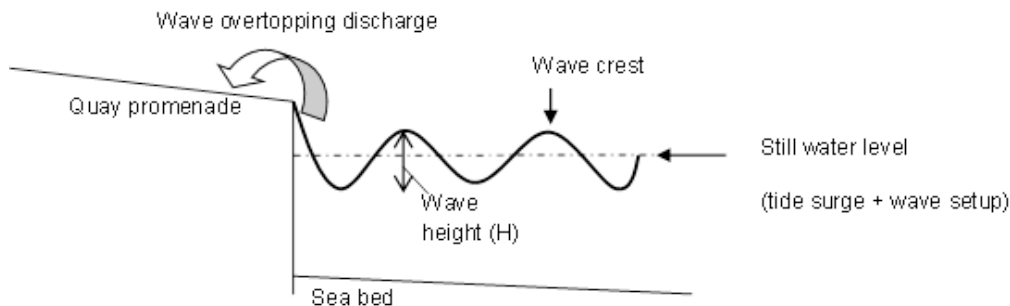


Figure 3 Schematic showing wave overtopping of quay seawall crest

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).

A quantitative estimate of wave overtopping potential for the project has not been undertaken as part of this study. However, given the relatively small wave climate and the fact that the development has a significant buffer zone between the water's edge and buildings, any wave overtopping is expected to be able to be managed with appropriate surface drainage measures.

### 3.8 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. 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<sup>7</sup>

ARI <sup>1</sup>	Maximum Level (m AHD <sup>2</sup> )
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.

<sup>7</sup> 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

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### 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, 2007). The 2013 fifth assessment report (AR5) has been partially completed.

The first report<sup>8</sup> in the collection of three Working Group reports and a Synthesis Report forming the IPCC 5<sup>th</sup> Assessment Report (AR5) was released on the 26 September 2013 and considers new evidence of climate change based on the most recent international scientific and technical assessments. One of the main findings highlighted in the AR5 is that it is now *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. This evidence for human influence has grown since AR4.

The IPCC AR5 Summary Report for Policymakers states that each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 and it is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. According to the AR5, global mean sea level has risen by 0.19 m over the period 1901–2010, based on tide gauge records and additionally on satellite data since 1993.

The IPCC AR5 has adopted new terminology for climate model scenarios which are based on Representative Concentration Pathways (RCPs). RCP's are four greenhouse gas concentration scenarios (RCP2.6, RCP4.5, RCP6, and RCP8.5 meaning +2.6, +4.5, +6.0, and +8.5 watts per square meter ( $W/m^2$ ), respectively) which have been named after a possible range of radiative forcing values in the year 2100.

Climate models suggest that global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6.

Confidence in projections of global mean sea level rise has increased since the AR4. AR5 states that global mean sea level will continue to rise during the 21<sup>st</sup> century under all RCP scenarios (refer to Figure 4).

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<sup>8</sup> Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the IPCC 5th Assessment Report – Summary for Policymakers

AR5 projects that the global mean sea level rise by 2100 relative to 2005 levels will likely be in the ranges described in Table 4.

Table 4 AR5 Global Climate Change Projection of Sea Level Rise

Scenario	Corresponding Sea Level Rise (m)
RCP2.6	0.26 - 0.55
RCP4.5	0.32 - 0.63
RCP6.0	0.33 - 0.63
RCP8.5	0.45 - 0.82

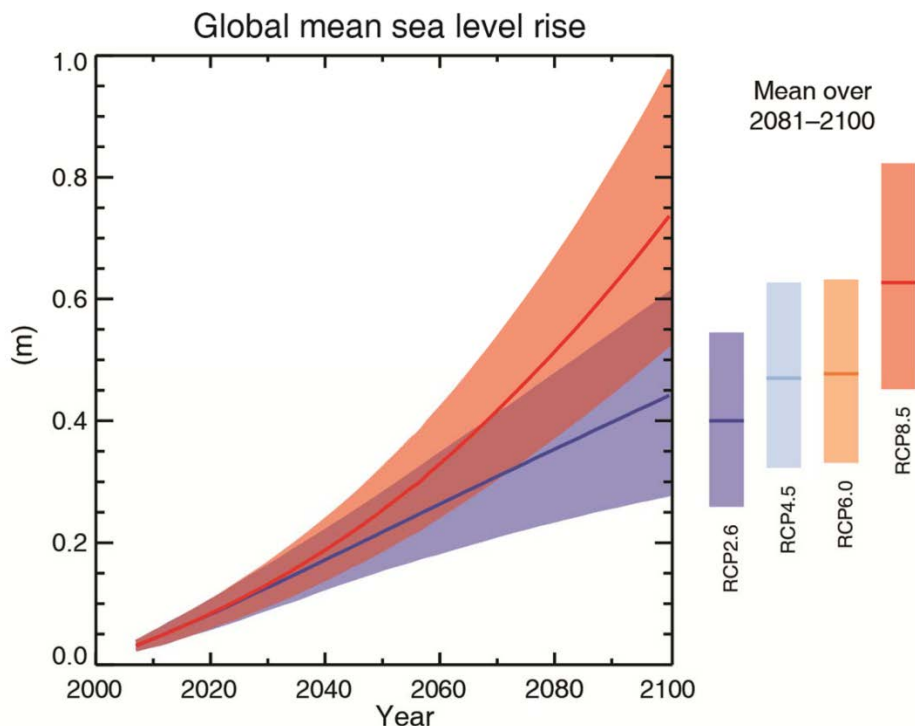


Figure 4 IPCC AR5 Global mean sea level rise modelled projections under RCP scenarios.

Source- IPCC AR5- Approved Summary for Policymakers

These ranges are derived from climate projections in combination with process-based models and literature assessment of glacier and ice sheet contributions. In the RCP projections, thermal expansion accounts for 30 to 55% of global mean sea level rise, and glaciers for 15 to 35%. The increase in surface melting of the Greenland ice sheet will exceed the projected increase in snowfall on the Antarctic ice sheet, leading to an overall increase in future sea level.

The current AR5 projections, including the dynamic response of the Greenland and Antarctic ice sheets (which were excluded in AR4), are slightly higher than previously published AR4 scenarios. Confidence in projections of global mean sea level rise has increased since the AR4 because of the improved physical understanding of the components of sea level, the improved agreement of process-based models with observations, and the inclusion of ice-sheet dynamical changes.

## 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<sup>9</sup>. 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<sup>10</sup>. Extreme rainfall has the potential to compound the impacts (but not necessarily likelihood) of coastal inundation if combined.

## 4.4 Summary of Sea Level Rise Benchmarks

A summary of sea level rise policy benchmarks and projections relevant to the Barangaroo South Stage 1A Public Domain Development Application have been provided in the following table:

Sea Level Rise Benchmarks	Sea level rise by 2100
Abandoned NSW Sea Level Rise Policy Statement	0.9 m
Sydney Harbour Foreshores and Waterways Area Development Control Plan 2005 (requirement for sea wall height)	1.675 m AHD
AS4997-2005 Guidelines for the Design of Maritime Structures	0.4 m
Design Still Water Levels for Sydney Harbour: Annual Recurrence Interval (ARI) of 1/100	1.435 m AHD
IPCC AR5 Upper Limit RCP8.5 projections	0.45 - 0.82 m
Upper bound of Sea Level Rise projected by statistical methods <sup>11</sup>	1.4 m
Suggested upper bound of global mean sea level rise only if all variables are quickly accelerated to extremely high limits <sup>12</sup>	2 m

<sup>9</sup> 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.

<sup>10</sup> <http://www.climatechange.gov.au/climate-change/impacts/national-impacts/nsw-impacts.aspx>

<sup>11</sup> Church, J. White, N. Hunter, J. Lambeck, K. (2008), *Briefing: a post-IPCC AR4 update on sea-level rise*, Antarctic Climate and Ecosystems Cooperative Research Centre

## 4.5 Projections considered in this assessment

For the purposes of this assessment, the following values for mean sea level rise as a result of climate change have been chosen as incremental projection levels to be considered for the design of Barangaroo South- Stage 1A Public Domain (presented in Table 5).

Table 5 Projections of Mean Sea Level Rise

Projection		2050	2100
A	NSW Planning Benchmark- abandoned	0.4m	0.9m
B	IPCC AR5 Upper Limit RCP8.5 Projections	0.32m	0.82m
C <sup>12</sup>	Upper bound of Sea Level Rise projected by statistical methods	-	1.4m
D <sup>12</sup>	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 5) by 2100 is presented in Table 6.

Table 6 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
1 in 100 year Extreme Sea Level Event <sup>1</sup>	1.435	2.335	2.835	3.435
Sydney Harbour Foreshores and Waterways DCP <sup>2</sup>	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 abandoned 0.9m increase as per the NSW Sea Level Rise Policy

## 5 Potential Impacts of Inundation

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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 incorporated into the public domain within Stage 1A including:

- typical public domain features such as street paving, street furniture, lighting and planting and additional items such as shade/weather protection structures, water features and bicycle facilities; and
- various services and infrastructure such as power and water.

### 5.1 Public domain features

#### 5.1.1 Extreme Events

Extreme storm surge events in conjunction with mean sea level rise may cause inundation leading to extensive damage of public domain features including street paving, furniture and lighting, particularly along the Waterfront Promenade. Extreme storm surge events may cause strong winds which could lead to extensive damage of shade/weather protection structures as well as plantings. This may pose safety concerns if structures become unstable. If public domain lighting is nonoperational, this may cause safety and security risks.

Sudden inundation could also pose a serious hazard to human safety and impede access across the site.

#### 5.1.2 Long Term Impacts

Increased frequency of inundation may over time cause the degradation of materials of public domain features. This accelerated degradation of materials has the potential to reduce the life expectancy of public domain features, also increasing maintenance costs.

### 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 public domain pathways, restricting access or exit throughout the Barangaroo Site.

## 6 Adaptation Measures

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It is proposed that the Barangaroo South development will adopt necessary measures to protect against coastal inundation under projections of sea level rise during the lifetime of the development. These measures will provide protection for the whole site incorporating the public domain and associated infrastructure.

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.

A sea wall is proposed to be incorporated into the development as part of the Barangaroo South Public Domain (Stage 1A) works. The minimum sea wall crest level that would be adopted is 2.5mAHD representing the current DCP requirement with the graduated increase in site level to 3.4mAHD to incorporate the additional 0.9m adopted from the repealed NSW Sea Level Rise Policy Statement and the NSW Coastal Planning Guideline: Adapting to Sea Level Rise.

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.

Water Sensitive Urban Design (WSUD) design has been incorporated into the Public Domain and the associated onsite stormwater infrastructure would be appropriately designed to be able to quickly alleviate flood water after an event commences. 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.

However, there is some risk that the 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<sup>12</sup>.

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 public domain within Stage 1A 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 public domain within Stage 1A.

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 7 and Table 8.

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 9 below.

Table 7 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 8 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 9 Risk Rating Matrix

Likelihood	Consequence				
	1	2	3	4	5
	Insignificant	Minor	Moderate	Major	Catastrophic
<b>A Almost Certain</b>	L	M	H	E	E
<b>B Likely</b>	L	M	M	H	E
<b>C Moderate</b>	L	L	M	H	H
<b>D Unlikely</b>	L	L	M	M	H
<b>E Very Unlikely</b>	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 10 below.

Table 10 Potential Risks Summary

Infrastructure	Potential Impact	Likelihood	Consequence	Risk Rating
Public Domain features	Inundation of public walkways and plantings.	D	2	L
	Accelerated degradation of materials and structures from repeat inundation events	D	3	L
	Failure of public domain structures (ie shade structures collapse) as a result of storm surge events	D	2	L
	Failure of lighting in public domain causing a safety and security issue.	D	3	M
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 pedestrian access and/or exit from public walkways and restricted site access points, especially at access points closer to the harbour.	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 0.26 m and 2 m by 2100<sup>12</sup>. 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.

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 is proposed to be addressed in the development the Barangaroo South–Public Domain (Stage 1A) 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 2.5 m AHD and graduating incrementally to 3.4m in site level. This minimum 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);
- equivalent 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 has been designed to protect against long term impacts of coastal inundation as well as to mitigate against extreme wave overtopping events. Proposed Water Sensitive Urban Design (WSUD) design elements have been incorporated into the Public Domain and the associated onsite stormwater infrastructure would be appropriately designed to be able to quickly alleviate flood water after an event commences. Overland flow paths will also be identified to manage the stormwater flows should discharge points 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 have been utilised:

- selection of materials to prevent accelerated degradation of infrastructure and public domain structures such as shading;
- 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

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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 proposed Barangaroo South public domain within Stage 1A.

The purpose of the assessment is to inform and accompany the Development Application for public domain within Stage 1A of the Barangaroo South site.

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 public domain within Stage 1A of the Barangaroo South site will not result in any significant additional impacts beyond those reasonably understood.