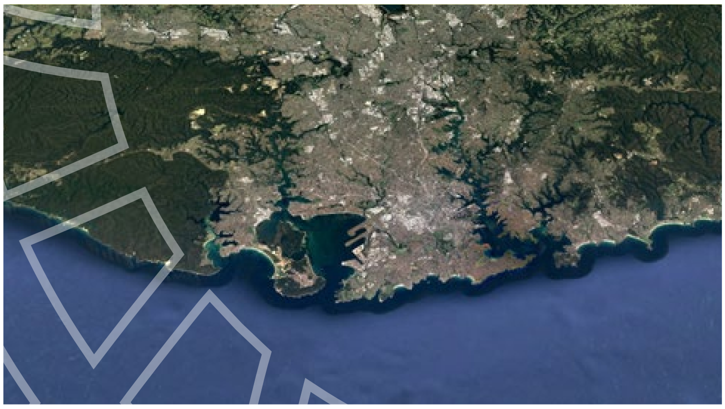
“Where will our knowledge take you?”



Georges River Tidal Inundation Study

November 2018

Document Control Sheet

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Synopsis: This report presents the results of a tidal inundation modelling assessment completed for the Georges River within the Georges River Council LGA.

REVISION/CHECKING HISTORY

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0	5/09/2018	DXW		VPR	
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DISTRIBUTION

Destination	Revision										
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Acronyms

AHD	Australian Height Datum
BOM	Bureau of Meteorology
CCIA	Climate Change in Australia
CO_2	Carbon Dioxide
Council	Georges River Council
CM Act	*Coastal Management Act 2016*
CM SEPP	State Environmental Planning Policy (Coastal Management) 2018
DCP	Development Control Plan
DECCW	[former] Department of Climate Change and Water
DEM	Digital Elevation Model
GIA	Glacial Isostatic Adjustment
HAT	Highest Astronomical Tide
IPCC	Intergovernmental Panel on Climate Change
LEP	Local Environmental Plan
LGA	Local Government Area
LiDAR	Light Detection and Radar (aerial laser survey of topography)
OEH	NSW Department of Planning & Environment Office of Environment & Heritage
NSW LPI	[former] New South Wales Department of Land and Property Information
RCP	Representative Concentration Pathway
SLR	Sea Level Rise

1 Introduction

1.1 Purpose of the Tidal Inundation Assessment

Georges River Council (Council) is currently conducting a Review of LEP and DCP planning controls for foreshore development (the Review) for the foreshore of the Georges River within Council's Local Government Area.

The literature review conducted for the Review identified studies for the Georges River that have determined the event-based inundation levels and risks associated with catchment flooding, elevated ocean water levels and sea level rise (SLR). The Review has determined that storm-based periodic events are adequately defined for preparing planning controls for foreshore development. However, it is apparent that the extent of the future tidal limit with sea level rise (representing a permanent and not storm-based) along the foreshore has not been adequately defined.

This assessment has involved hydraulic modelling to determine the tidal inundation level in the Georges River at present and for future timeframes with consideration of projected future sea level rise.

For this assessment, the TUFLOW hydraulic modelling software has been applied to determine changes in the tidal range along the estuary, which may exacerbate the potential extent of tidal inundation with sea level rise. While simplified 'bath tub' or 'bucket fill' sea level rise inundation maps do exist for the Georges River, these assessments do not account for the increase or decrease in the tidal range with sea level rise that may occur in relation to the geomorphology of an estuary, such as flow constricted reaches. By accounting for these potential changes, the hydraulic modelling of sea level rise related inundation undertaken for this report provides a more rigorous assessment of potential impacts over time.

The methodology and results of the tidal inundation modelling assessment, including resultant extent mapping, is presented in this report.

1.2 Why Sea Level Rise Impacts Need to be Considered

All organisations, including local councils, can freely and readily access information (measurements and projections) about sea level rise. Given the social, financial and environmental risks presented by sea level rise, it is imperative for local councils to understand the likely extent of sea level rise related impacts. It is no longer possible to ignore the risks presented by sea level rise, even at the current measured rate of rise.

Global mean sea level rose about 1.6 mm/year on average during the 20th Century (CSIRO, 2016a). Since 1992, high quality measurements of sea level rise have been made by satellite altimeters. From 1992 to present, Global Mean Sea Level (GMSL) has risen at a rate of around 3.2 ± 0.4 mm/year (CSIRO, 2016b). The rate of sea level rise over the past 20 years is therefore about double that of the previous century. If the rate of sea level rise were to remain at its present level of 3.2 mm/year, sea level can be expected to be nearly 0.3 m higher than today by 2100.

Bureau of Meteorology [BOM] & CSIRO released new regional projections for Australia in 2015, including for the NSW coast. The CSIRO (2015) suggest a 'likely' range for sea level rise of 0.45 to

0.88m by 2090 for the highest emission scenario (along which sea level rise is currently tracking, as noted above). The 'likely' range is based on the rate of sea level rise more than doubling from its present rate of 3.2 mm/year. This is not unreasonable given that the rate of sea level rise has already doubled over the last 20 years.

This report outlines an additional element of potential sea level rise risk for which Council does not have existing detailed analysis, namely the potential extent of permanent inundation. This study will add to the very good information currently held by Council about the periodic or event based risks associated with sea level rise.

NSW legislation also provides a legal imperative, and exemption for liability, for local councils to consider sea level rise, as detailed below.

Coastal Management Act 2016	Section 3 Objects of this act *(f) to mitigate current and future risks from coastal hazards, taking into account the effects of climate change,*
Local Government Act 1993:	Council are exempt from liability for acting in good faith with respect to flooding and coastal hazards, as explained in Section 733 below: S733 Exemption from liability—flood liable land, land subject to risk of bush fire and land in coastal zone: *(1) A council does not incur any liability in respect of:* *(a) any advice furnished in good faith by the council relating to the likelihood of any land being flooded or the nature or extent of any such flooding, or* *(b) anything done or omitted to be done in good faith by the council in so far as it relates to the likelihood of land being flooded or the nature or extent of any such flooding.* *(2) A council does not incur any liability in respect of:* *(a) any advice furnished in good faith by the council relating to the likelihood of any land in the coastal zone being affected by a coastline hazard (as described in the coastal management manual under the Coastal Management Act 2016) or the nature or extent of any such hazard, or* *(b) anything done or omitted to be done in good faith by the council in so far as it relates to the likelihood of land being so affected.* *(3) Without limiting subsections (1), (2) and (2A), those subsections apply to…* *(f5) the provision of information relating to climate change or sea level rise…*

2 Model Development

The Georges River catchment within the Georges River Council LGA boundary was modelled using the TUFLOW hydraulic modelling software to provide a representation of tidal behaviour with sea level rise. A description of the main model parameters is discussed below.

2.1 Channel Cross Sections

The study area was modelled entirely using 1D cross sections to ensure model run times were manageable and to best represent the in-channel topography, where LiDAR data is inadequate in representing the channel characteristics. Cross sections were spaced approximately 0.5 to 1 km apart, as presented in Figure 2-1.

The model cross sections were based on bathymetric (hydrographic) survey data collected from the main reaches of the Georges River by the Office of Environment and Heritage (OEH) between 1976 and 1997.

The channel roughness (Manning's 'n') was varied with channel width and form. Values range from 0.03 in the lower reaches to 0.1 in the upper reaches. These parameters were adjusted iteratively to achieve a model calibration to recorded data at Como Bridge and Picnic Point.

2.2 Boundary Conditions

2.2.1 Tidal Data

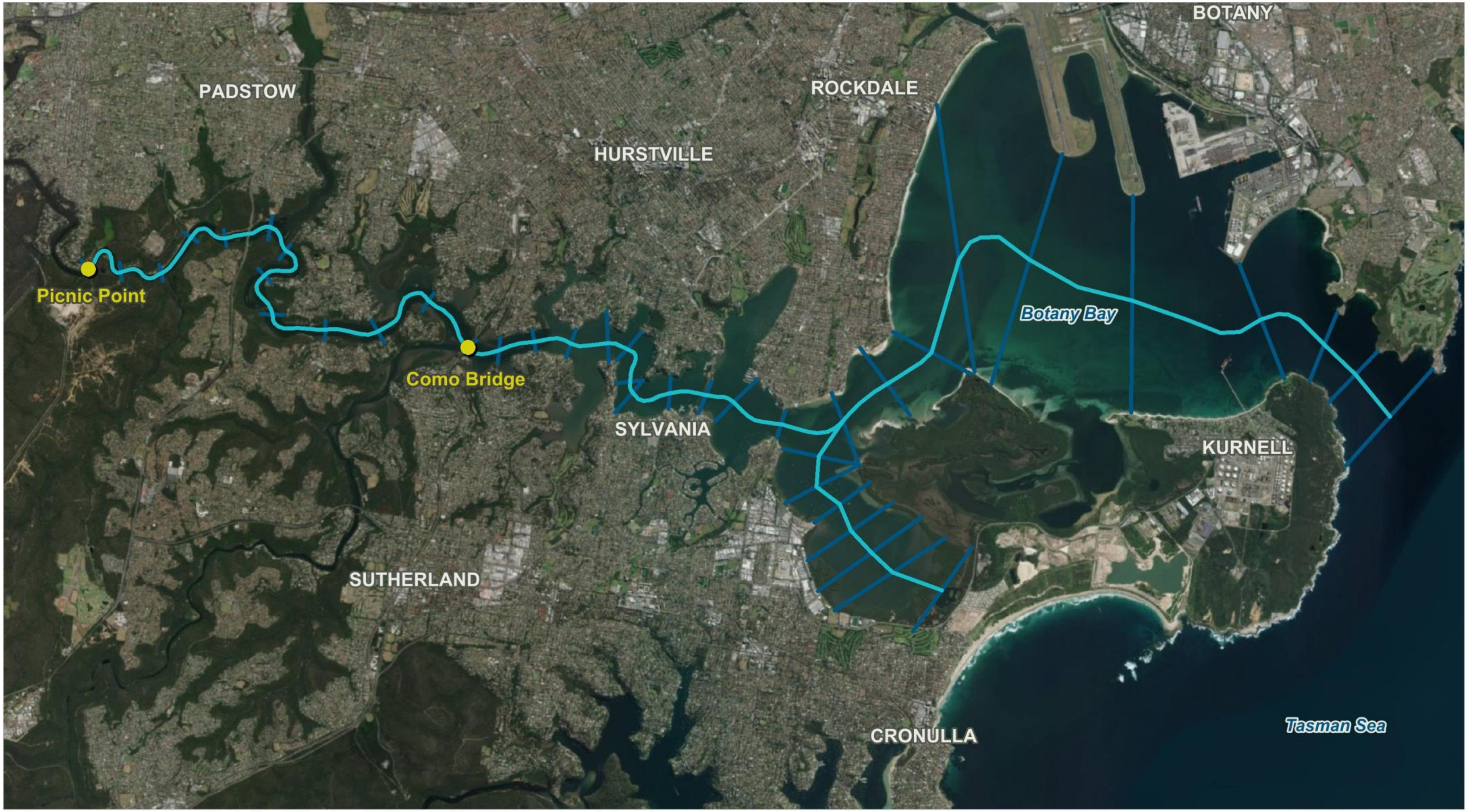
For model calibration, an 11-day period comprising 3/06/2016 to 14/06/2016 was used, due to the large recorded tidal anomaly (peak water level of 1.29 m AHD). The recorded data from the Sydney gauge was used as the downstream boundary to the model at the Tasman Sea.

For the climate change modelling, a representative highest astronomical tide (HAT) boundary was adopted, peaking at around 1.06 m AHD. This boundary was then adjusted in elevation to simulate the range of potential future sea level rise scenarios.

2.2.2 Sea Level Rise

Sea level rise data was obtained from the Climate Change in Australia (CCIA) climate projections outlined in Chapter 8 of the Technical Report (BOM & CSIRO, 2015) for the East Coast South sub-cluster. Four principal emission scenarios, or Representative Concentration Pathways (RCPs) were modelled in the CCIA report to determine sea level rise projections for the Sydney coastline. IPCC give the following descriptions to the RCPs:

- RCP 2.6: Global greenhouse gas emissions peak between 2010 and 2020 and substantially decline thereafter;
- RCP 4.5: Global greenhouse gas emissions peak around 2040 and decline thereafter
- RCP 6.0: Global greenhouse gas emissions peak around 2080 and decline thereafter; and
- RCP 8.5: Global greenhouse gas emissions continue to rise throughout the 21st Century.



LEGEND

- Model reach
- Model cross section
- Gauge location

Title:
TUFLOW Model Configuration

Figure: 2-1

Rev: A

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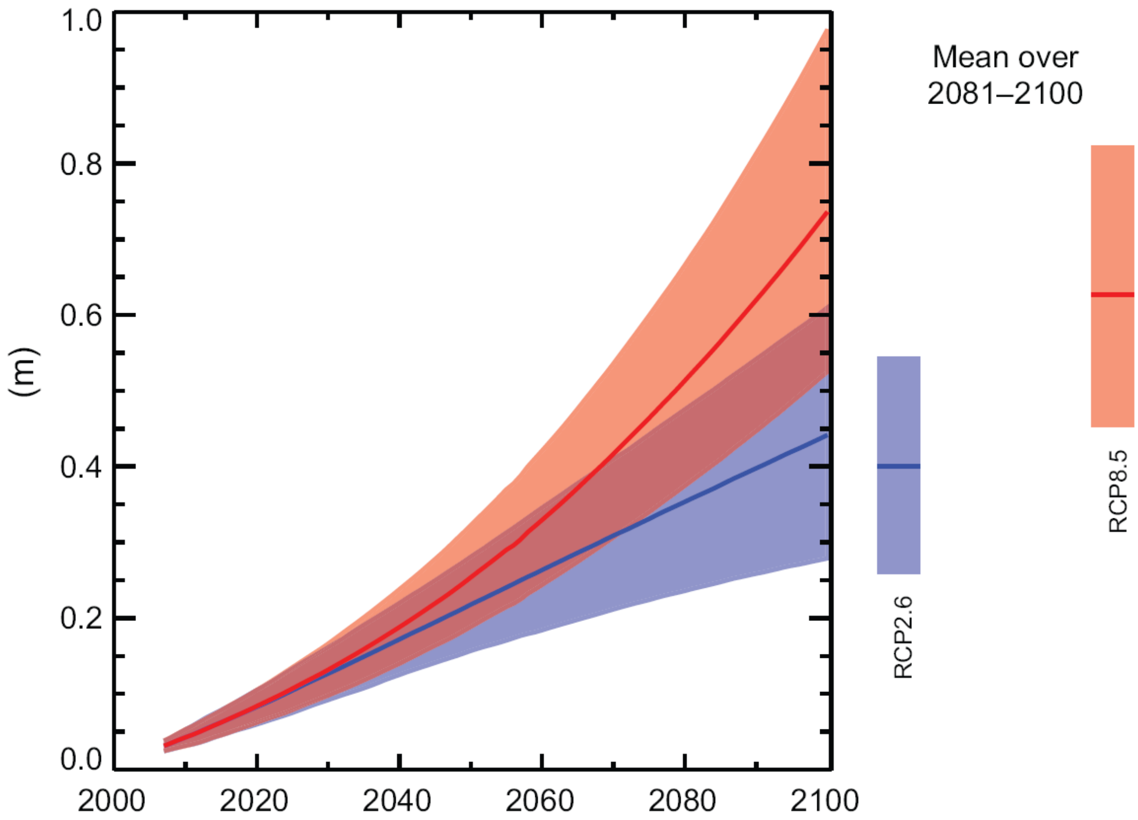

Figure 2-2 Projections of Global Sea Level Rise Relative to 1986-2005 Mean Sea Level: RCP 2.6 and 8.5 (IPCC, 2014)

For the tidal inundation modelling, three RCPs for greenhouse gases were chosen, being the low emission scenario RCP 2.6, a moderate emission scenario RCP 6.0 and the highest emission scenario RCP 8.5.

Four future planning horizons were selected for model simulation, being the present (2018), 2050, 2070, and 2100 horizons. The present-day scenario is required to benchmark the change in tidal inundation extents in future. The timeframes 2050 and 2100 are generally used in coastal hazard assessments in NSW, and so have been adopted for this assessment. The timeframe of 2070 was also assessed because this is approximately 50 years from the present and a 50-year period is typically applied to residential development by local Councils.

Climate projections are designed to present the response of predicted plausible climate change based on the impact of external factors such as concentrations of greenhouse gases. As such, upper limits of change, or 90th percentile, lower limits (10th percentile) and median (50th percentile) projections have been determined through climate modelling and refer to the largest foreseeable change (upper limit), the lowest foreseeable change (lower limit) and the median change (BOM & CSIRO, 2015). For each emission scenario and planning horizon, the lower, median and upper scenarios were simulated, as presented in Table 2-1.

The present and 2100 timeframes do not have specific SLR projections in the CCIA Technical Report. For these two timeframes, SLR projections (low, median and high) for each emission scenario were interpolated from the projections given for the other timeframes.

Modelling of the present-day condition requires inclusion of sea level rise that has occurred to date. The median values from the three emissions scenarios are broadly consistent with average sea level rise rates measured at Fort Denison since 1990 of around 3.1 mm/year (DECCW, 2010; BOM & CSIRO, 2015). When the signal correlated with the Southern Oscillation Index is removed, the relative tide gauge trend for Fort Denison is much lower at 0.8 mm/year considering data from 1966 to 2010. The trend is then adjusted to 1.3 mm/year when corrected for Glacial Isostatic Adjustment (GIA) and atmospheric pressure changes (BOM & CSIRO, 2015).

Table 2-1 Future Sea Level Rise Projections

	2018	2030	2050	2070	2090	2100
	Lower Limit					
RCP 2.6	**0.06**	0.09	0.14	0.19	0.22	**0.25**
RCP 6.0	**0.06**	0.08	0.15	0.23	0.32	**0.34**
RCP 8.5	**0.08**	0.10	0.19	0.31	0.45	**0.44**
	Median					
RCP 2.6	**0.09**	0.13	0.22	0.3	0.38	**0.42**
RCP 6.0	**0.09**	0.13	0.22	0.34	0.48	**0.50**
RCP 8.5	**0.10**	0.14	0.27	0.44	0.66	**0.67**
	Upper Limit					
RCP 2.6	**0.13**	0.18	0.29	0.42	0.54	**0.59**
RCP 6.0	**0.13**	0.17	0.30	0.46	0.65	**0.68**
RCP 8.5	**0.13**	0.19	0.36	0.59	0.88	**0.90**

*Note that values in **bold** indicate they have been estimated based on interpolation of SLR projections presented in Chapter 8 of the Technical Report (Bureau of Meteorology & CSIRO, 2015).*

2.3 Results Processing

Modelled tidal surfaces output from the TUFLOW model were projected onto a Digital Elevation Model (DEM) derived from NSW LPI LiDAR data, with the resultant inundation extents being extracted. The horizontal resolution of the DEM is 5 m, with LiDAR data typically having a vertical accuracy of around 0.1 m.

3 Results

3.1 Introduction

Tidal inundation mapping provides an indication of the land that is likely to remain permanently inundated with sea level rise. That is, unlike storm-driven inundation events where the water will recede following the storm, these maps illustrate the regular high tide water level in the future due to sea level rise effects in the Georges River. The tidal water level applied for this assessment is the HAT, which occurs approximately once per year. Areas that are inundated at least annually are reasonably considered to be permanently inundated, because the inundation occurs too frequently for the land to be used in the same manner as land that is typically dry. Land affected by the HAT is typically considered to be part of the natural waterway.

Inundation mapping has been produced for the RCP 8.5 SLR projections for each future planning horizon. RCP 8.5 represents a future emissions scenario whereby little effort has been made to lower and mitigate emissions (i.e. ‘business as usual’), and consequently where CO_2 concentrations would continue to rapidly rise to 940 ppm by 2100. RCP 8.5 was selected as it represents the likely greatest increase in global mean temperatures (2.6 to 4.8°C), global mean sea levels (0.45 to 0.82 m), emissions and land use change by 2100. As such, it is the most conservative or ‘worst-case’ scenario (CSIRO & BOM, 2015).

3.2 Discussion

Figure A-1 presents the current (2018) tidal inundation extents for the HAT including current best-estimate SLR trends. The SLR trends are based on the RCP 6.0 scenario with the median SLR plotted (see Table 2-1 for SLR projections). As shown, the inundation extent is largely contained within the Georges River channel. Impacted lots remain seaward of Council’s existing foreshore building line.

Figure A-2 to Figure A-4 present the tidal inundation extents for HAT including the RCP 8.5 SLR projections at 2050, 2070, and 2100 respectively. At each timeframe, the lower, upper and median limits for the RCP 8.5 SLR projections have been plotted. The inundation extents gradually broaden with each subsequent planning horizon, culminating at 2100.

Figure A-5 presents the current 2018 tidal inundation extent (as plotted in Figure A-1) against the tidal inundation extents modelled for the RCP 8.5 upper limit SLR projections for 2050, 2070 and 2100. Generally, the tidal inundation extents remain similar to the present across the different planning horizons, with the majority of inundation remaining within the Georges River channel. There are a few notable exceptions to this, however, that will need to be considered in the context of the existing foreshore building line and planning controls.

3.2.1 Comparison with Existing Foreshore Building Line

There are many sections of foreshore where the existing foreshore building line will continue to provide some form of setback to the projected future HAT level with sea level rise by 2100, albeit being reduced to some degree. For example, there are minor areas of foreshore inundated by 2100 at Carlton Crescent (Kogarah Bay), Townson St (Blakehurst), Kyle Bay, and Jewfish Point, although the existing foreshore building line is landward of the future inundation extent, (see Figure A-6 to Figure A-8).

There are other areas where the foreshore building line is compromised by the future HAT inundation extent as shown in most notably:

- Beverley Park Golf Club north of Ramsgate Road;
- Kogarah Bay Creek;
- Carss Park particularly adjacent to the swimming beach;
- Poulton Creek north of Morshead Drive;
- Neverfail Bay; and
- Soily Bottom Point.

Revision of the foreshore building line to allow for future inundation will be a key consideration in all areas where inundation extends beyond the current channel. In addition, the foreshore building line, in map form, is not continuous, and this may present issues when attempting to provide a consistent planning strategy.

3.2.2 Inundation Impacts Across Various Land Zones

The change in land area affected by tidal inundation extents modelled for the RCP 8.5 upper limit SLR projections for 2050, 2070 and 2100 compared with the current 2018 tidal inundation extent (as plotted in Figure A-1) was calculated, as presented in Table 3-1 for each land zoning in the Georges River Council LGA. Zones where the impact of inundation is significant (either in terms of the increase in area inundated and/or the consequence of inundation) are highlighted.

As indicated in the table, not all land zones are affected by inundation. The land zones affected by inundation are: Low Density Residential (R2); Medium Density Residential (R3); National Parks and Nature Reserves (E1); Public Recreation (RE1), Recreational Waterways (W2), and Environment Conservation (E2).

The area of Low Density Residential land inundated almost triples from 3.6 ha at present to 10.1 ha by 2100. As a percentage of the total land area within the Low Density Residential zone, the area experiencing inundation is minor, being 0.1% at present increasing to 0.4% by 2100. The area of Medium Density Residential land is minimal, being 0.2 ha (0.1% of total) at present increasing to 0.4 ha (0.1%) by 2100. While the area of residential land affected by inundation appears small, the potential consequence of a permanent loss of land to inundation is significant.

Infrastructure lands have a minor impact from inundation. At present, the area affected by tidal inundation is 1.7 ha (0.7% of total) increasing to 2.0 ha (0.8% of total) by 2100. Infrastructure uses typically affected by inundation will be stormwater or sewer assets that by their nature need to be located on low lying land. Planning controls for infrastructure uses on foreshore lands affected by inundation will still need to be considered.

Table 3-1 Area Within Each Land Zone Affected by Tidal Inundation Over Time

Georges River Council LGA	Total Area Per Zone (Ha)	2018 (RCP 6.0, median)		2050 (RCP 8.5, upper)			2070 (RCP 8.5, upper)			2100 (RCP 8.5, upper)			
		Tidal Inundation Area (Ha)	% of total	Tidal Inundation Area (Ha)	Increase in Tidal Inundation Area (Ha) from 2018	% increase	Tidal Inundation Area (Ha)	Increase in Tidal Inundation Area (Ha) from 2018	% increase	Tidal Inundation Area (Ha)	% of total	Increase in Tidal Inundation Area (Ha) from 2018	% increase
Commercial Core	5.3												
Deferred Matter	4.9												
Infrastructure	245	1.7	0.7%	1.8	0.2	11.8%	2.0	0.3	18.0%	2.0	0.8%	0.4	23.2%
Light Industrial	115												
Local Centre	51												
Low Density Residential	2539	3.6	0.1%	5.0	1.4	37.6%	7.2	3.6	97.8%	10.1	0.4%	6.5	179%
Medium Density Residential	282	0.2	0.1%	0.2	0.1	26.6%	0.3	0.1	61.7%	0.4	0.1%	0.2	102%
Mixed Use	58.4												
National Parks and Nature Reserves	19.2	8.6	45.1%	9.1	0.4	4.8%	9.3	0.7	7.9%	9.5	49.4%	0.8	9.5%
Neighbourhood Centre	10.2												
Public Recreation	474	22.9	4.8%	33.9	11.0	48.1%	43.5	20.6	89.9%	49.9	10.5%	26.9	118%
Recreational Waterways	591	581	98.2%	581	0.5	0.1%	585	4.0	0.7%	587	99.3%	6.5	1.1%
Private Recreation	1.4												
High Density Residential	13.0												
Environmental Conservation	1.8	0.1	2.7%	0.2	0.1	244%	0.2	0.2	378%	0.3	15.6%	0.2	476%
Enterprise Corridor	2.3												
TOTAL	**4414**	**618**	14.0%	631	**13.7**	2.2%	647	**29.4**	4.8%	**659**	14.9%	**41.6**	6.7%

Public Recreation lands affected by tidal inundation more than doubles from 22.9 ha (4.8% of total) at present to 49.0 ha (10.5% of total) by 2100. A notable proportion of the increased inundation extent occurs in Carss Park. Given the highly urbanised nature of the Georges River LGA, these foreshore public recreation lands are vital areas of leisure, recreation, and foreshore access for the population both within the LGA and greater Sydney. A loss of public recreation lands to inundation should therefore be considered significant.

At present 45.1% (8.6 ha) of National Parks and Nature Reserves land is already naturally inundated. By 2100, the area of inundation increases to 9.5 ha (49.4% of the total), an increase of some 9.5%. Only a very small area (1.8 ha) of the LGA is zoned as Environment Conservation. Within this, however, the area inundated by HAT increases from < 0.1 ha (2.7% of total) to 0.3 ha (15.6% of total) by 2100.

The Recreational Waterways zone obviously covers the water-based area of the Georges River LGA. It is included in the calculations for completeness only, as the zoning is designed for water-based land uses.

3.2.3 Implications for Foreshore Planning Controls

The tidal inundation mapping presents a permanent change in the waterway extent, and so cannot be managed using traditional flood style planning controls. For many event-based hazards such as flooding, development can be designed to withstand the event because the impacts are relatively short term (i.e. the floodwaters recede) and the land use will return to normal. The impacts of tidal inundation mapped above are permanent, and so the existing or future land use may no longer be tenable.

Managing the permanent inundation hazard requires a transitioning process where land that is not currently inundated but will be in future will need to shift from planning controls that allow for land-based development to controls that avoid land-based development. How this transitioning process is handled with respect to the position of, or planning controls associated with, the foreshore building line and different land zones will be a key consideration for this project.

Consideration of the design life of proposed developments will be important, as residential development would typically be designed to last for 50 years or more. For residential development, transitioning to avoidance of development may need to start immediately depending on the projected timing of inundation impacts.

For infrastructure, the design life for assets is typically 100 years. However, infrastructure assets may necessarily need to be placed on low-lying land (e.g. stormwater outlets, or sewer pumping stations). Avoidance is not a realistic option for such infrastructure, and development controls may relate to design criteria instead.

For public recreation lands, recreational facilities will still be appropriate within the inundation area, however at some point, facilities will need to be transitioned landward, particularly in locations such as Carrs Park where the inundation impact is potentially substantial. Recreational facilities typically have a far shorter design life (25 years or less), so seeking to avoid development at present may not be appropriate. This is because the shorter life recreational facilities could be installed, enjoyed and removed well before inundation impacts occur. Transitioning could be coordinated with the replacement of facilities due to wear and tear.

It is assumed that the inundation area currently protected within the national parks and environment conservation lands are wetland habitats. An appropriate management approach is to allow for such habitats to naturally evolve and migrate with the change in water level. In a highly urbanised setting such as the Georges River LGA, allowing for migration of habitats may result in some loss in adjacent habitats, as they are squeezed against the built urban environment. With respect to the foreshore building line and planning controls, National Parks and Nature Reserve zones and Environment Conservation zones presumably provide adequate protection for natural habitats in or near waterways, however this should be confirmed during the Review project.

4 References

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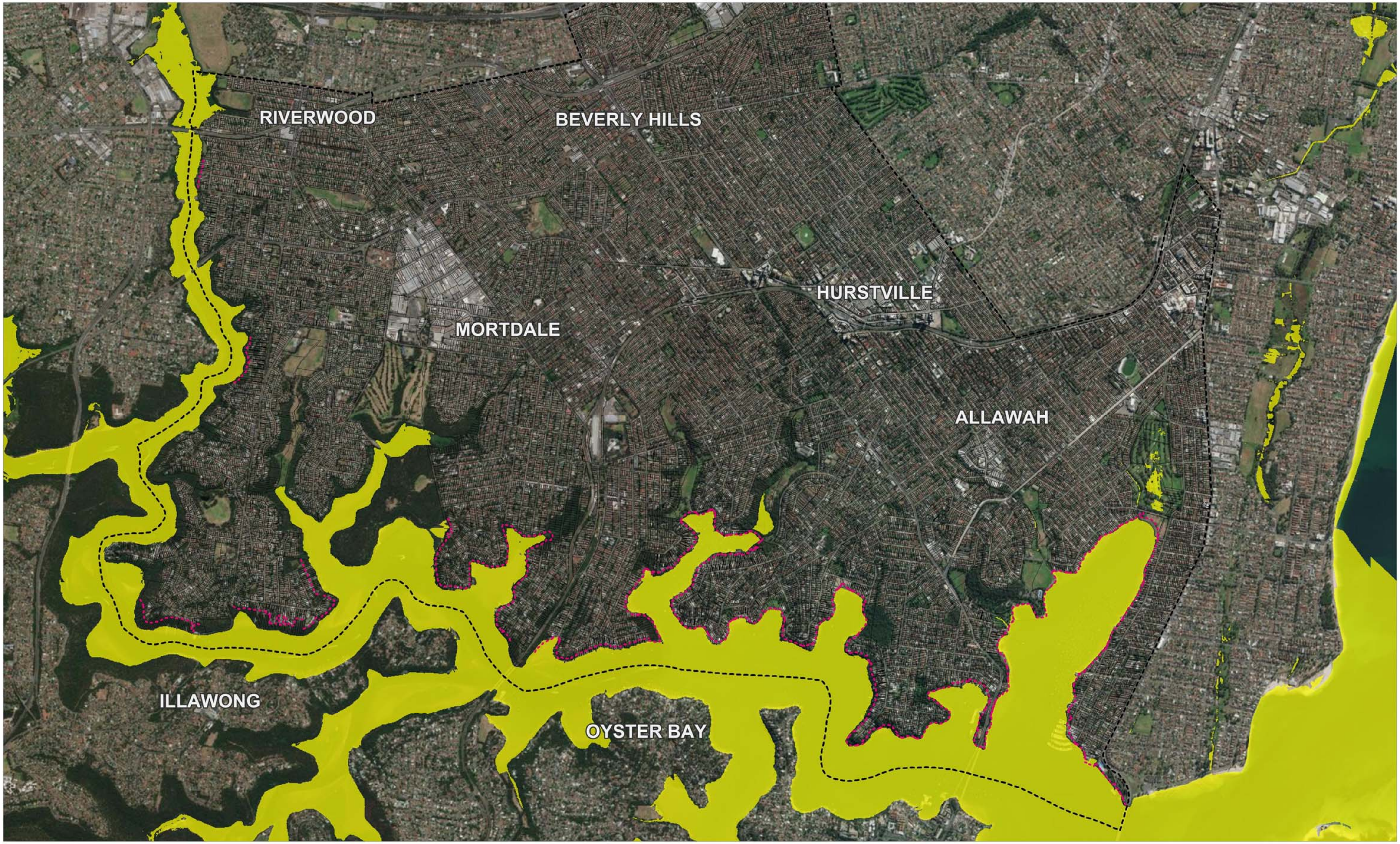
Appendix A Mapping Figures



LEGEND

Tidal Inundation Extent

LGA Boundary

Foreshore Building Line

Title:

Tidal Inundation Extent (2018 SLR & RCP 6.0)

Figure: A-1

Rev: A

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LEGEND

SLR Change Limit

- Lower
- Median
- Upper
- LGA Boundary
- Foreshore Building Line

Title:

Tidal Inundation Extent (2050 SLR & RCP 8.5)

Figure: **A-2**

Rev: **A**

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LEGEND

SLR Change Limit

- Lower
- Median
- Upper
- LGA Boundary
- Foreshore Building Line

Title:

Tidal Inundation Extent (2070 SLR & RCP 8.5)

Figure: **A-3**

Rev: **A**

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LEGEND

SLR Change Limit

- Lower
- Median
- Upper
- LGA Boundary
- Foreshore Building Line

Title:

Tidal Inundation Extent (2100 SLR & RCP 8.5)

Figure: **A-4**

Rev: **A**

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LEGEND

SLR Horizon, RCP & Limit

- 2018 (RCP 6.0, median)
- 2050 (RCP 8.5, upper)
- 2070 (RCP 8.5, upper)
- 2100 (RCP 8.5, upper)
- LGA Boundary
- Foreshore Building Line

Title:
Tidal Inundation Extents

Figure: **A-5**

Rev: **A**

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.5 1km
Approx. Scale

BMT
www.bmt.org

Filepath: K:\N21048_Georges_River_Tidal_Inundation\MI\Workspaces\Figures\SLR_Extents\DRG_005_Extents_RCP8.5_A3.wor

LEGEND

SLR Horizon, RCP & Limit

- 2018 (RCP 6.0, median)
- 2050 (RCP 8.5, upper)
- 2070 (RCP 8.5, upper)
- 2100 (RCP 8.5, upper)
- LGA Boundary
- Foreshore Building Line

Title:

Tidal Inundation Extents - Kogarah Bay

Figure: **A-6**

Rev: **A**

N

0 200 400m

Approx. Scale

BMT

www.bmt.org

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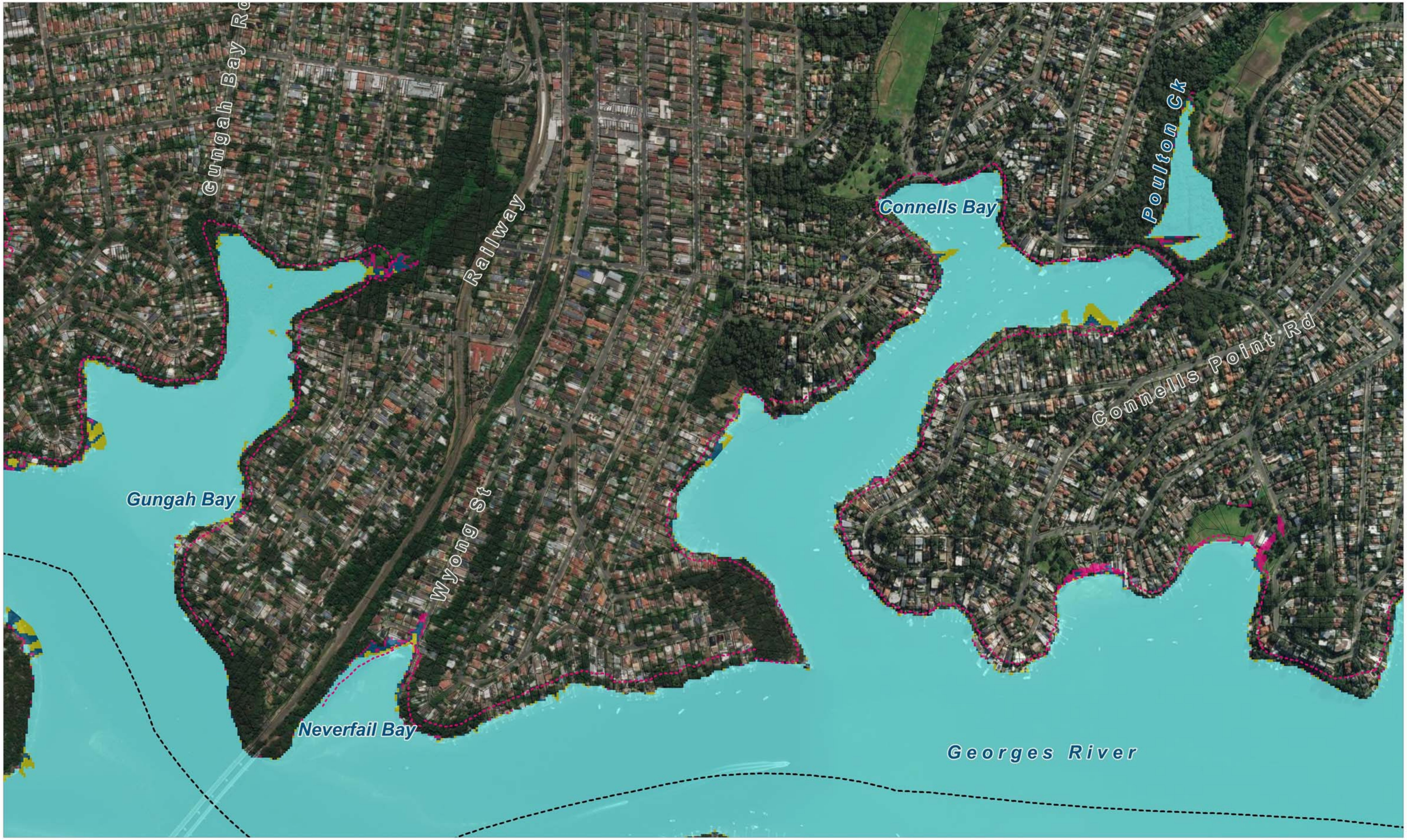

LEGEND

SLR Horizon, RCP & Limit

- 2018 (RCP 6.0, median)
- 2050 (RCP 8.5, upper)
- 2070 (RCP 8.5, upper)
- 2100 (RCP 8.5, upper)
- LGA Boundary
- Foreshore Building Line

Title:

Tidal Inundation Extents - Oatley

Figure: A-7

Rev: A

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N

0 200 400m

Approx. Scale

BMT

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LEGEND

SLR Horizon, RCP & Limit

- 2018 (RCP 6.0, median)
- 2050 (RCP 8.5, upper)
- 2070 (RCP 8.5, upper)
- 2100 (RCP 8.5, upper)
- LGA Boundary
- Foreshore Building Line

Title:

Tidal Inundation Extents - Lugarno

Figure: **A-8**

Rev: **A**

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N

0 200 400m

Approx. Scale

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