Datasets Guidance 2: *Sea-level rise and you*

Future climate change and sea-level rise

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1. Summary of information presented

Sea-level Rise and You provides graphs and tables on future climate change and sea-level rise for:
- every coastal local council in Australia
- up to four greenhouse gas concentration scenarios (the Representative Concentration Pathways, or RCPs)
- the present-day through to 2100.

For *future sea-level rise and its effects*, *Sea-level Rise and You* provides information on:
- mean sea-level rise
- allowances
- inundation, defined here as the temporary or permanent flooding of a portion of land within the coastal zone.

For further information on these datasets, see Sections 2 and 3 and Church et al. (2016).

For *future climate change*, *Sea-level Rise and You* provides graphs of temperature and rainfall extremes for two greenhouse gas scenarios, very high concentrations (RCP8.5) and low concentrations (RCP4.5).

Note that all RCP scenarios show an increase in atmospheric greenhouse gas concentrations up to 2100 when compared to the present day – whereas the increase for RCP8.5 is very high, the increase for RCP2.6 (a strong mitigation scenario) is very low.

The graphs are as follows.
- *Hot days*: Mean annual number of days with maximum temperature greater than 30°C
- *Warm nights*: Mean annual number of nights with minimum temperature greater than 25°C
- *Heatwaves*: Average of longest run of days in each year with maximum temperature greater than 30°C
- *Very wet days*: Mean annual number of days when rainfall exceeds the historic 99.9[th] percentile
- *Dry conditions*: Mean annual (May to April) number of months when total rainfall is less than the historic 10th percentile

The data from which these are calculated come from a number of climate models, and the graphs show the maximum and minimum model values at each time step, as well as the model mean. For further information on these datasets, see Section 4.

All datasets were produced for CoastAdapt by CSIRO, except for the inundation mapping, which was produced by the Cooperative Research Centre for Spatial Information.

When you first enter *Sea-level Rise and You*, you will be asked to enter your council or postcode of interest, as shown in Figure 1. Below the search box are four tabs, for Sea-level rise, Inundation maps, Temperature and Rainfall. The initial setting is for Sea-level rise (which includes the allowance information) – click on the dataset you want.

Figure 1: What you see first when you enter *Sea-level Rise and You*. You can enter a council name or postcode in the top search box and then select one of the four tabs below to see information for that council area.

In this document, Section 2 describes the sea-level rise and allowance information: what the data are, how they are presented, and how they can be used. Section 3 is devoted to the inundation mapping, and Section 4 to the climate extremes information.

2.   Sea-level rises and allowances

2.1   What are the datasets?

The first (and default) on the *Sea-level Rise and You* page (shown in Figure 1) is the sea-level rise tab. It provides information on:

- **Sea-level rise**: graphs and tables of mean sea-level rise for different time points out to 2100, and for the four RCP greenhouse gas concentration scenarios, together with the likely confidence range (66% confidence limits).
- **Allowances**: graphs and tables for the allowances for different time points out to 2100, and for the four RCP greenhouse gas concentration scenarios. The allowance is the height that coastal defences would need to be raised in order to provide the same level of protection as they do today. For further information on allowances, see Appendix 1.

For these datasets, the baseline or historic period is 1986-2005.

The first dataset tells you about the average sea-level rise to be expected at your location. The second tells you about how to plan such that the risk from the impact of the expected change in extreme sea levels (likely to be experienced during a storm) does not increase (see Appendix 1).

The information takes into account both thermal and dynamic influences on sea level, including changes in ocean currents. It does not take into account changes in wave height. The information is for the open coast. For closed bays or estuaries, additional changes may be possible. It also does not account for local land movements such as subsidence.

There is a technical Guidance Report (Church et al. 2016) to accompany these data, and this provides full details on the data and methods used to produce the graphs and tables. The information here is only a very brief overview. To know more, please read the Guidance Report.

The sea-level rise information in *Sea-level Rise and You* is based on model projections that extend only to 2100. Sea-level rise will continue beyond 2100 and, unless we make efforts to reduce greenhouse gas emissions, the rate of rise may increase into the 22nd century.

It is important to remember that surprises can occur, and there is a low but not zero probability (and with high consequences) that sea-level rise will exceed the estimates provided here. For example, if the Greenland and West Antarctic ice sheets melt more rapidly than the current science suggests, then sea-level rise during the 21st century will exceed the values shown here (see Climate change surprises). It is difficult to provide an estimate, but it is possible that sea-level rise might be several tenths of a metre above the projections given here.

2.2 How is the information presented?

For each coastal council, we provide a graph and two tables. These are simply two different ways to display the data, and you may find one more useful than the other. For each council, the underlying data are the same in the tables and the graph.

The graphs (see example in Figure 2) show mean sea-level rise for the four greenhouse gas scenarios (the four RCPs). Using the key (which sits above the graph), you can click on and off the four scenarios, to control the amount of information shown.
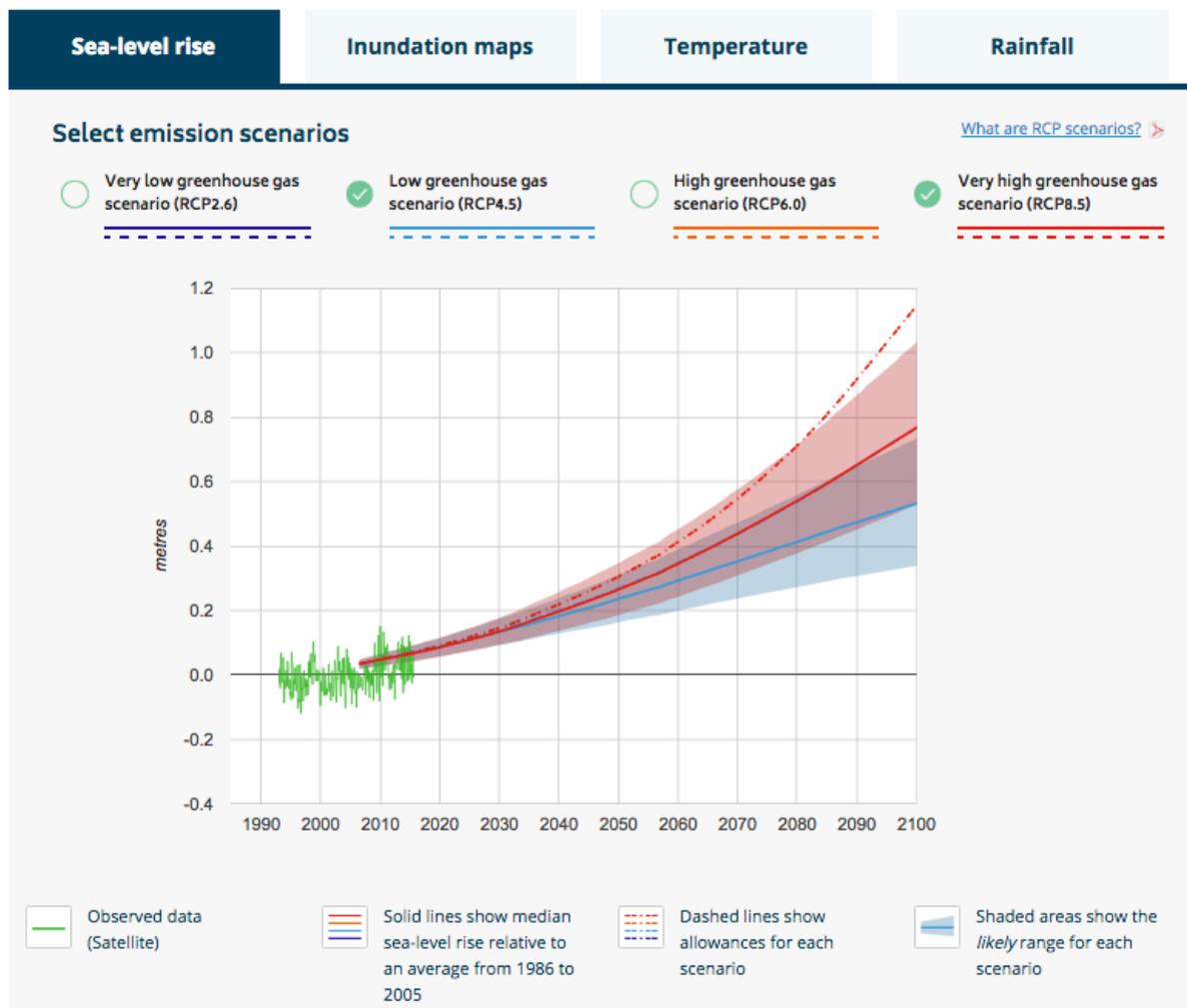

Figure 2: Sea-level rise and allowance graphs in *Sea-level Rise and You*. Here, the user has selected Gold Coast as the council of interest, and very high (RCP8.5) and low (RCP4.5) greenhouse gas concentration scenarios.

Full information on the RCPs is given in the Infographic: What are the RCPs? and in Section 3 of Understanding climate scenarios. The main features of the graph are:

- Mean sea level is a multi-model average calculated from a number of climate models (see Understanding climate scenarios). The averages for each year are then averaged across time (21-year averages) to remove inter-annual variability and produce a smoothed curve.
- By 2100, RCP8.5 (shown by the red lines) has the highest atmospheric greenhouse gas concentrations, RCP2.6 has the lowest (and is shown by the dark purple lines). The two intermediate RCPs are RCP6.0 (orange) and RCP4.5 (pale blue). Note that all RCP scenarios show an increase in atmospheric greenhouse gas concentrations over the present day up to 2100 – whereas the increase for RCP8.5 is very large, the increase for RCP2.6 (a strong mitigation scenario) is quite small.
- The solid line shows median sea-level rise from the present day through to 2100. The shaded areas show the extent of the likely range (i.e. with 66% certainty we expect sea level to lie between these limits).
- The dashed line shows the allowance values. Again, these are multi-model averages smoothed by calculating a 21-year mean. Confidence intervals are not provided. For further information on allowances, see Appendix 1.
- The green lines show observations from satellite. They provide an indication of the extent of present-day inter-annual variability, and demonstrate that in some locations sea levels are rising. An expanded version of the satellite data, with a 5-year running mean (black line), can be obtained by clicking on the icon lower down the page (to the right of the sea-level rise graph).

Each council has two tables (see Figure 3). The first is for sea-level rise and the second for the allowances. For each, the table shows data for four time points: 2030, 2050, 2070 and 2090 (remembering these are actually 21-year averages rather than single year values) and for the four RCPs. Thus, the 2050 value is the multi-model average for 2040-60, and the 2090 value is for 2080-2100. For mean sea-level rise, we also provide the rate of rise (in mm per year) at 2100, giving an indication of how successful emissions reduction has been at limiting sea-level rise (the difference between the RCP8.5 and RCP2.6 values) and setting the scene for how risk will progress in the 22nd century.

Sea-level rise:
(relative to an average calculated between 1986 and 2005)

Date (unit)	Very low (RCP2.6)	Low (RCP4.5)	High RCP6.0)	Very high (RCP8.5)
	Greenhouse gas scenario (RCP)			
2030 (m)	0.13 (0.09-0.18)	0.14 (0.09-0.18)	0.13 (0.09-0.17)	0.14 (0.09-0.18)
2050 (m)	0.22 (0.15-0.29)	0.24 (0.17-0.31)	0.23 (0.15-0.30)	0.27 (0.19-0.35)
2070 (m)	0.31 (0.20-0.42)	0.36 (0.24-0.48)	0.34 (0.23-0.46)	0.44 (0.31-0.58)
2090 (m)	0.39 (0.23-0.55)	0.48 (0.31-0.65)	0.49 (0.32-0.66)	0.66 (0.46-0.88)
Rate of change at 2100 (mm/yr)	4.2 (1.7-6.6)	5.9 (3.2-8.7)	7.5 (4.7-10.5)	11.5 (7.6-16.1)
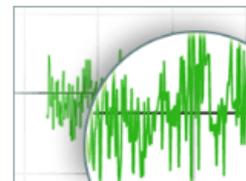
See observed satellite data only >

Allowances:
(relative to an average calculated between 1986 and 2005)

Date (unit)	Very low (RCP2.6)	Low (RCP4.5)	High RCP6.0)	Very high (RCP8.5)
	Greenhouse gas scenario (RCP)			
2030 (m)	0.14	0.15	0.14	0.15
2050 (m)	0.25	0.27	0.26	0.31
2070 (m)	0.39	0.44	0.42	0.55
2090 (m)	0.54	0.66	0.66	0.93

Figure 3: Tables on sea-level rise and allowances in *Sea-level Rise and You* (again for the Gold Coast). The icon to the right takes you to an expanded graph of the satellite information.

2.3   Key documents and acknowledgements

3. Inundation mapping

3.1   What are the datasets?

The second tab on the *Sea-level Rise and You* page (shown in Figure 1) takes you to inundation maps. For each coastal local council in Australia, we provide inundation mapping for two future time points – 2050 and 2100 – and for two different greenhouse gas concentration scenarios (see What are the RCPs?), as follows:

- For 2050, inundation mapping for RCP8.5 (at 2050, there is very little difference in sea-level rise between the four RCP scenarios).
- For 2100, inundation mapping for RCP8.5 (very high concentrations of greenhouse gases scenario) and RCP4.5 (low concentrations of greenhouse gases scenario).

Inundation is modelled using high-resolution digital elevation data and a simple 'bathtub' or 'bucket fill' approach. Sea-level rise information is taken from the CoastAdapt sea-level rise dataset (see Section 2). The result is an approximation only: the model does not take account of existing sea walls or barriers, erosion etc. The notional map resolution is 1:50,000.

The inundation modelling imposes sea-level rise onto the Highest Astronomical Tide (HAT). Thus it does not take account of storm surge or wave height (see the Guidance Report (Church et al., 2016, and Coast and Climate Dynamics for more information). The HAT technically only occurs once every 18 years but in practice water levels can often exceed HAT values because of the influence of wind and waves. According to the OzCoasts website (http://www.ozcoasts.gov.au/climate/sd_fqa.jsp), combining sea-level rise information together with the HAT produces an estimate of "an event that can be expected to occur at least once a year, but possibly more frequently".

The inundation modelling presented here is national, with information for every coastal council in Australia. The underlying LiDAR data has a resolution of 1 m in the horizontal and 0.2 m in the vertical. Individual organisations (e.g. councils and state governments) have undertaken more detailed LiDAR mapping than is used here to produce inundation mapping of greater accuracy (see, for example, the CoastAdapt state-specific information for Victoria).

The inundation modelling is based on sea-level rise information for each coastal council, taken from the *Sea-level Rise and You* sea-level rise dataset. Because it is national, it does not map, for example, state-specific benchmarks for sea-level rise (e.g. for Queensland, 0.2 m by 2050, and 0.8 m by 2100). These benchmarks are provided in Table 1 of Jurisdictional differences.

For more information on bathtub modelling, see the inundation modelling infographic and Appendix 2.

3.2   How is the information presented?

Once you have inserted the council name or postcode in the search box, and clicked on the 'Inundation Maps' tab, you will see a screen similar to that in Figure 4. Each inundation map is presented twice: the top row shows inundation on a satellite base map; the bottom row shows inundation on a topographic/street map. We use two base maps because, although using the

satellite base map is more visually appealing, sometimes locations are masked by shading. The topographic base maps show underlying features such as roads, present-day coastline and built-up areas more clearly.
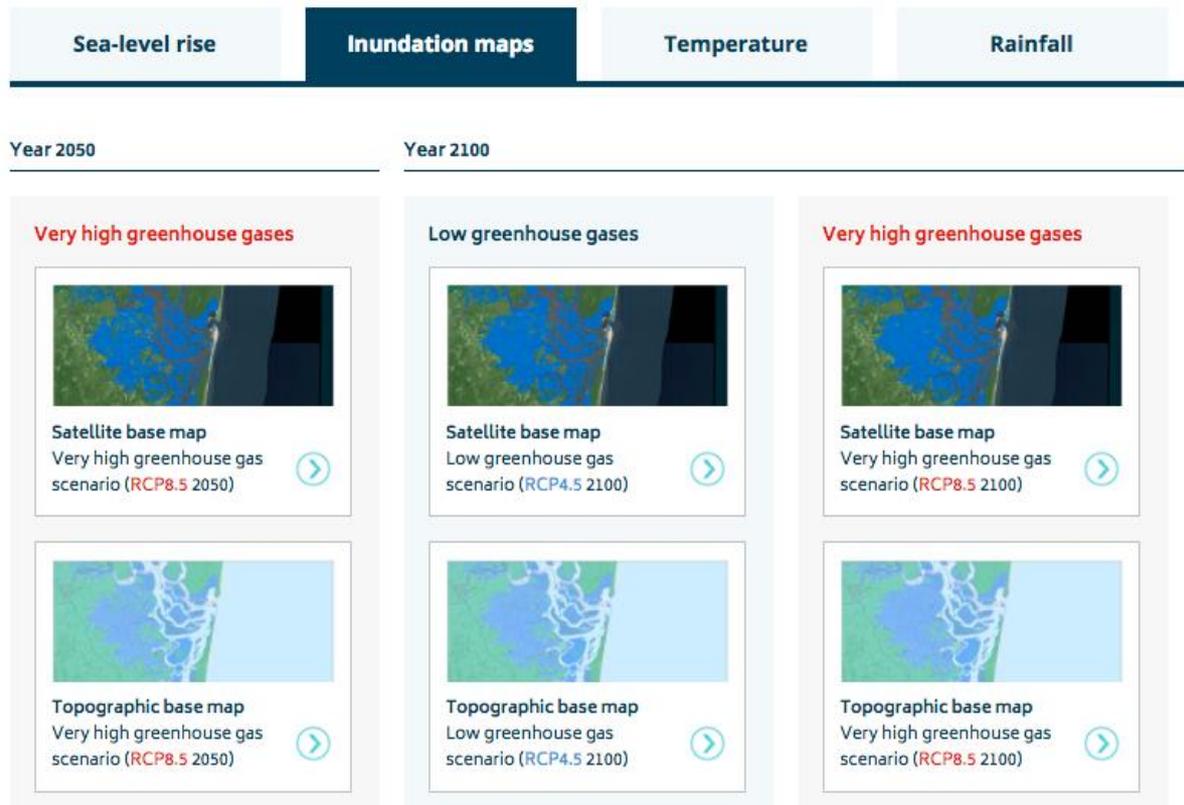

Figure 4: Links to inundation maps in *Sea level Rise and You*.

Each row in Figure 4 shows three clickable thumbnails. In order, from left to right, these are Year 2050 RCP8.5, Year 2100 RCP4.5, and Year2100 RCP8.5. Clicking on one of the six thumbnails takes you through to an inundation map. The map is in pdf format, making it easy for you to download and print. Each map has a key containing important information, as shown in Figure 5.
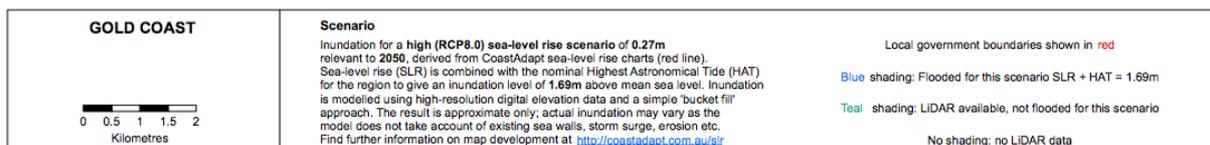

Figure 5: The key for a Gold Coast inundation map. Note that the description of the Scenario tells you the sea-level rise for that council used to initiate the bathtub modelling. Sea-level rise is taken from the *Sea-level Rise and You* datasets.

3.3   How can the information be used?

The following steps are suggested to make use of bathtub inundation modelling in coastal management and adaptation.

1. Use the inundation maps for your council to identify whether any assets or resources of importance are at risk of inundation under a low (RCP4.5) or very high (RCP8.5) greenhouse gas scenario. This information can contribute to a first- or second-pass risk assessment.
2. The Coastal Risk Australia (CRA) inundation tool (http://www.coastalrisk.com.au) can be accessed to explore in more detail the extent of potential inundation for a wider range of sea-level rise scenarios. The CRA is an interactive map tool that uses Google Earth Engine technology and allows users to access inundation maps from high, medium and low sea-level rise scenarios and to investigate coastal inundation using local input data.
3. Bathtub modelling is particularly useful at a regional scale to identify the areas of relatively greater risk of inundation, and to inform prioritisation of adaptation actions in a local or regional strategy.
4. If the bathtub models in *Sea-level Rise and You* or the CRA tool show significant potential inundation in an area of proposed development or investment, it may be advisable to get expert advice on the nature of the inundation risk. More detailed hydrodynamic modelling using local data will likely be required for large developments or for critical infrastructure.

3.4   Acknowledgements

We thank the Cooperative Research Centre for Spatial Information (CRCSI) for the provision of the inundation mapping. The sea-level rise data used to initiate the mapping is taken from the *Sea-level Rise and You* sea-level rise dataset (see Church et al. 2016).

4.   Temperature and rainfall datasets

4.1   What are the datasets

The third and fourth tabs on the *Sea-level Rise and You* page (shown in Figure 1) take you to the temperature and rainfall extremes graphs for each coastal council. The datasets are for extremes only. There are many sources of information on mean climate change, but the adaptation community has a focus on changes in extreme events, which can challenge the resilience of communities and ecosystems. In *Sea-level Rise and You*, we have placed an emphasis on displaying trends in extreme events at council level. A good source of more information on how the Australian climate may evolve over time (both mean and extremes) is the [Climate Change in Australia](#) website.

The datasets are:
- *Hot days*, defined as the mean annual number of days with maximum temperature greater than 30°C
- *Warm nights*, defined as the mean annual number of days with minimum temperature greater than 25°C
- *Heatwaves*, defined as the average of longest run of days in each year with maximum temperature greater than 30°C
- *Very wet days*, defined as the mean annual number of days when rainfall exceeds the historic 99.9th percentile. The 99.9th percentile is calculated from all wet days in the full length of record in the Australian Water Availability Project ([AWAP](#)) database, approximately 110 years.
- *Dry conditions*, defined as the mean annual (May to April) number of months when total rainfall is less than the historic 10th percentile. The 10th percentile is calculated from all months in the full length of record in the AWAP database, approximately 110 years.

These five indicators of extreme weather are calculated from data taken from eight climate models. A more detailed specification is provided in Box 1. There is a [technical report](#) (Clarke et al. 2017) to accompany the temperature and rainfall extremes graphs, and this provides full details on the data and methods used to produce the graphs. The information here is only a very brief overview. To know more, please read the technical report.

Box 1: Specification of temperature and rainfall indicators in *Sea-level Rise and You*

Climate models (selected based on representativeness, data availability, skill and independence):

- ACCESS1-0
- CanESM2M
- CESM1-CAM5
- CNRM-CM5
- GFDL-ESM2M
- HadGEM2-CC
- MIROC5
- NorESM1-M

Time periods in the graphs:

The historic time-period (green dot) is 1981 – 2010. Data for the historic period are from the Australian Water Availability Project (AWAP), see http://www.csiro.au/awap/

The future time-periods are as follows:
- Values (mean, maximum and minimum) for the year 2030 are the means calculated from 2016-2045 data
- Values for the year 2050 are the means calculated from 2036-2065 data
- Values for the year 2070 are the means calculated from 2056-2085 data
- Values for the year 2090 are the means calculated from 2075-2104 data.

Change factors are calculated from the model data and applied to the historic time period.

Greenhouse gas scenarios:

- RCP4.5
- RCP8.5

4.2   How is the information presented?

Figure 6 shows typical temperature extremes graphs from *Sea-level Rise and You*. The key features of these plots are as follows.

- The green dot shows observed conditions, based on 1981-2010 data.
- The bars show future (modelled) conditions for four time slices up to 2090. Red dots are for the very high greenhouse gas scenario (RCP8.5), blue for the low (RCP4.5) scenario. The dot is the mean across the eight climate models, the upper end of the bar is the maximum value from the eight models and the lower end of the bar the minimum.

Hovering your mouse over the points in the graph provides more information. The rainfall extremes graphs present information following the same conventions.
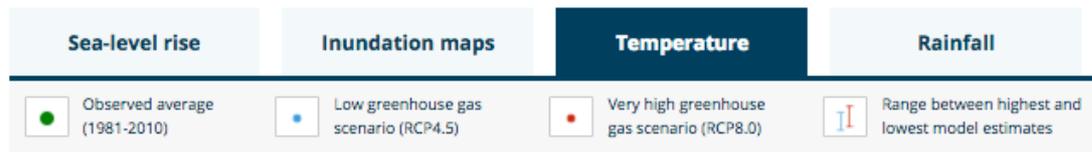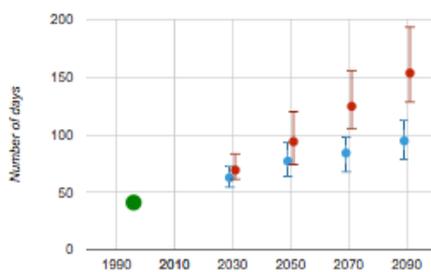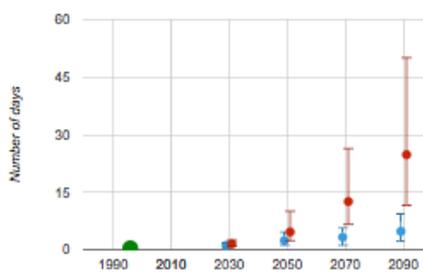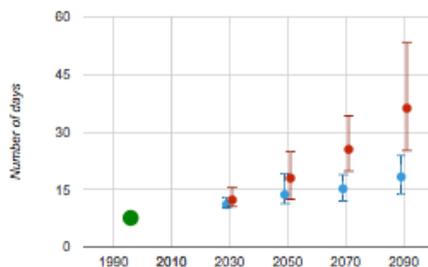

Figure 6: Typical temperature extremes plot from *Sea-level Rise and You*.

4.3   Acknowledgements

Appendix 1: What are allowances and how can they be used?

(Modified from the Guidance Report, Church et al. 2016)

Allowances represent the vertical distance that an asset needs to be raised under rising sea levels so that the present likelihood of flooding does not increase. Allowances are calculated using sea-level rise projections (estimates of future conditions).

For coastal engineering, planning and adaptation, the likelihoods of extreme sea levels, expressed in terms of return periods (i.e. the average time interval between events that exceed a particular height) or exceedance probabilities (the probability that an event exceeding a particular magnitude will occur in any given year), is of considerable importance in informing the design of built infrastructure and coastal protection. Figure A.1 illustrates the relationship between extreme sea-level variability and return periods for two different coastal locations under present-day conditions.

- Location A has large variability in extreme sea levels due to the large variation in the tidal cycle and a tendency for large storm surges to occur.
- Location B has little variation in tidal cycle and a tendency for smaller surges when storms occur, and hence lower variability overall.

In terms of the return periods for storm tides (the combination of storm surge and astronomical tide) Location A (on the left in Figure A.1) is characterised by a steeper return period curve than Location B, as shown in the bottom panels of Figure A.1. The statistical relationships that are represented in these return period curves describe the probability that an exceedance event will occur in a given year. Location A demonstrates a smaller change in the probability that an exceedance event will occur in any year than Location B, for the same rise in sea level (Church et al., 2016).

For the protection of built assets, it is customary to consider the heights associated with particular return periods (e.g. the height of the 1-in-50 or the 1-in-100 year flood event). These planning heights are shown in Figure A.1 (top panel) for the present-day. For the same sea-level rise, these planning heights will be breached far more frequently at Location B than at Location A, due to the nature of sea-level variability (Figure A.1 middle panel). This is reflected in the larger change in the exceedance probabilities already noted at Location B (Figure A.1 lower panel).

In general, when the uncertainty regarding sea-level rise projections is small, as is the case for 2030 (closer to present-day), the allowances are close to the median of the sea-level rise range. However as the uncertainty becomes larger, as is the case for 2090, the allowances also increase and tend to lie between the median and 95th percentile of the modelled sea-level rise range.
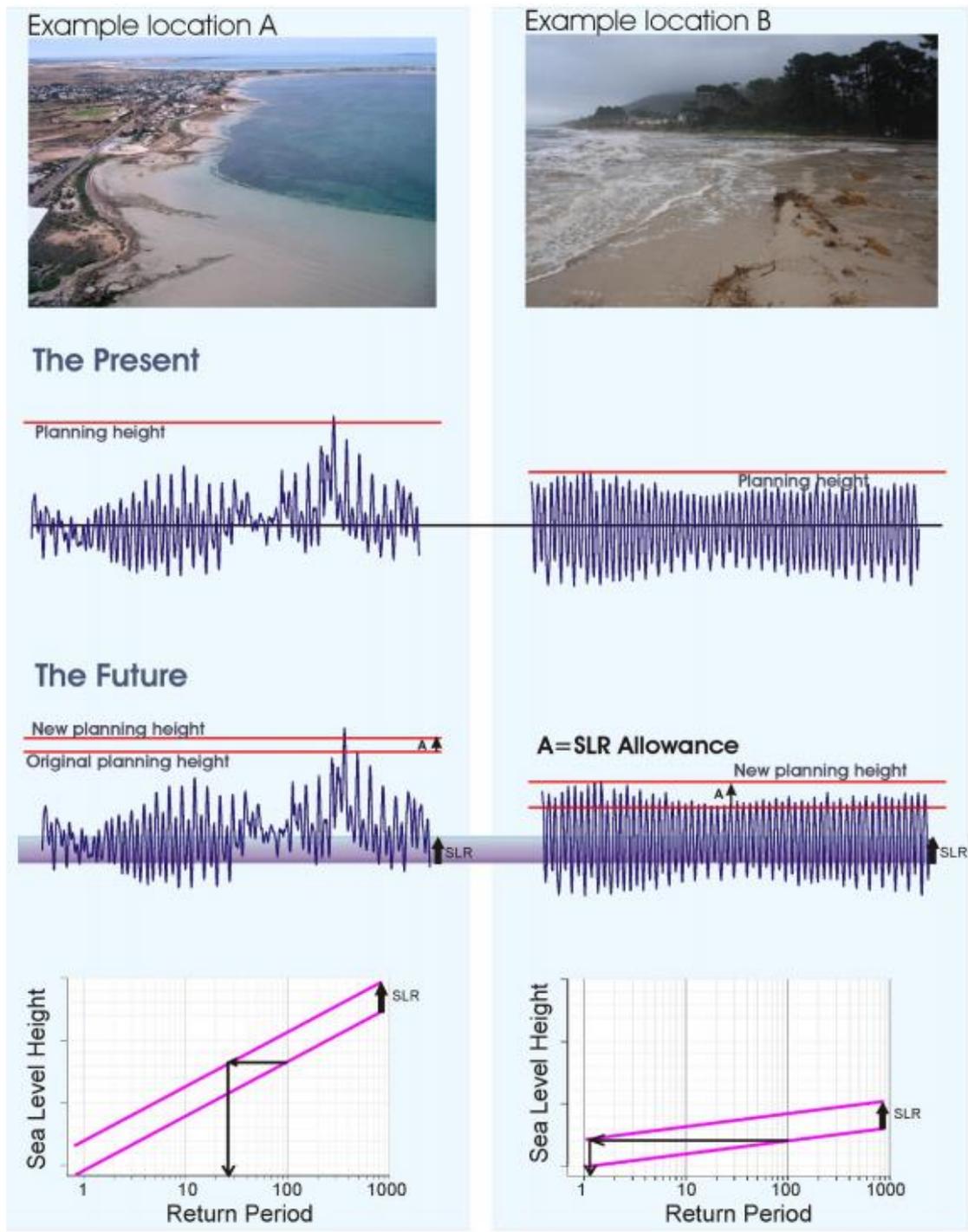
Figure A.1: Two different coastal locations with different extreme sea-level variability. The causes of extreme sea levels vary from place to place and determine present planning heights. Under sea-level rise, the increase in threshold exceedance varies from place to place. (Photo A courtesy of Nick Harvey; Photo B courtesy of Penny Whetton).

Appendix 2: Bathtub inundation modelling

A.2.1　What is bathtub inundation modelling?

Bathtub (or bucket-fill) modelling is a commonly used method to identify areas at risk from inundation. As in a bathtub, such models simply raise water levels and overlay the resulting surface on existing topography.

Bathtub models are elevation-based, so that areas adjacent to the sea and below a given elevation, generally present day mean sea level plus a future sea-level rise scenario, are divided from higher areas using a deterministic line. The lower area is expressed as a zone of inundation and often shaded in light blue.

The most important requirement for bathtub modelling is elevation data in the form of a digital elevation model (DEM). The quality of the DEM, which is a function of the spatial resolution and the vertical accuracy of the data source, has a great influence on the accuracy of the inundation mapping. Airborne light detection and ranging (LiDAR) has become a widely used technique to generate high-resolution and accurate DEMs. LiDAR-derived DEMs have typical horizontal spatial resolutions of 1 m and a global vertical accuracy better than 0.2 m, making them suitable to depict local-scale features.

Because sea levels at a given time will vary by location due to tides, bathtub models generally reference coastal land elevations to tidal data such as mean sea level or mean high water. Bathtub models that take this tidal variation into account will generate more accurate zones of inundation on the land surface.

One issue to be aware of when considering bathtub model outputs is that isolated low-lying areas not connected to the sea can sometimes be identified as at risk of inundation. Some bathtub models correct for this by applying a filter to exclude hydrologically isolated areas at a distance from the sea from being shown as at risk under sea-level rise scenarios.

The Coastal Risk Australia inundation tool uses high-resolution LiDAR data and a simple bathtub model linked to Highest Astronomical Tide data to enable users to explore the potential inundation from sea-level rise scenarios or other high water level events (http://www.coastalrisk.com.au).

A.2.2　Benefits of bathtub modelling

Bathtub modelling is widely used to identify areas at risk of sea level rise because:

- It is a simple and easily implementable method, which enables inundation risk information from several sea-level rise scenarios to be readily obtained and considered in first- or second-pass risk assessments.
- It is appropriate for large or regional-scale risk mapping and, for many areas that lack detailed local data, it is the only feasible approach to identify inundation risk.

- It can be readily linked to existing tools such as GIS or local topographic models, to identify inundation risks to infrastructure or other assets within the area covered by the modelling. The relative simplicity of the models also allows for their use by a wide group of end-users or stakeholders.

However it is important to note that the outputs of bathtub models cannot be considered as a substitute for more detailed studies that are needed to inform significant investment or development decisions.

A.2.3   Limitations of bathtub modelling approaches

Bathtub modelling has a number of limitations, such as that it assumes a calm ocean surface. Results from bathtub models should be considered as approximate only. In particular, bathtub modelling does not do any of the following.

- Include any change to tidal flows in waterways, such as estuaries, that will result from different coastal configurations in some locations.
- Take account of existing sea walls and other protective structures, including some flood mitigation structures. At present there is not a national database of such structures in Australia.
- Consider the influence of wind and waves, and such models therefore provide limited guidance about flood risk from an extreme event, such as a storm surge.
- Take account of the effects of coincident catchment flooding from extreme rainfall events.

Some studies have assessed bathtub models against more detailed hydrodynamic inundation models to determine if the simple models systematically over- or under-estimate the areas of likely inundation extent. The range of different landforms and processes around the coast means that there is not a straightforward answer. Potential inundation around some estuaries may be over-stated by simple bathtub models, but the variation in estuaries from those that show tidal amplification to others which display attenuation compared with ocean tidal levels, means that a uniform trend cannot be assumed. On the open coast, dynamic wind and wave processes suggest that bathtub models could under-estimate the potential for inundation from extreme events.

References

Church, J.A., K.L. McInnes, D. Monselesan, and J. O'Grady, 2016: Sea-Level Rise and Allowances for Coastal Councils around Australia – Guidance Material. CSIRO Report, 64 pp. Accessed 1 February 2017. [Available online at http://coastadapt.com.au/factsheets/sea-level-rise-and-allowances-coastal-councils-around-australia-csiro-guidance-material].

Clarke, J., C. Heady, and T. Erwin, 2017: Temperature and Rainfall Extremes data for CoastAdapt: Methods used to develop projections of temperature and rainfall extremes for use on the NCCARF CoastAdapt website. CSIRO Report, 20 pp. Accessed 23 February 2017. [Available online at https://coastadapt.com.au/factsheets/temperature-and-rainfall-extremes-data-csiro-methods-report].

CSIRO Disclaimer

Appendix 1, the Guidance Report (Church et al. 2016) and the data described in Sections 2 and 4 were provided by CSIRO.

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