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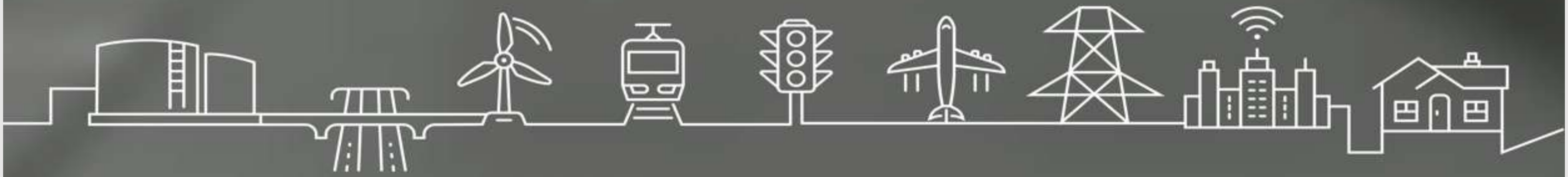


ADAPTING THE EAST

Climate Risk Engine analysis of future heat impacts to Eastern Sydney

A report for Sydney Water – May 2020

ADAPTING THE EAST

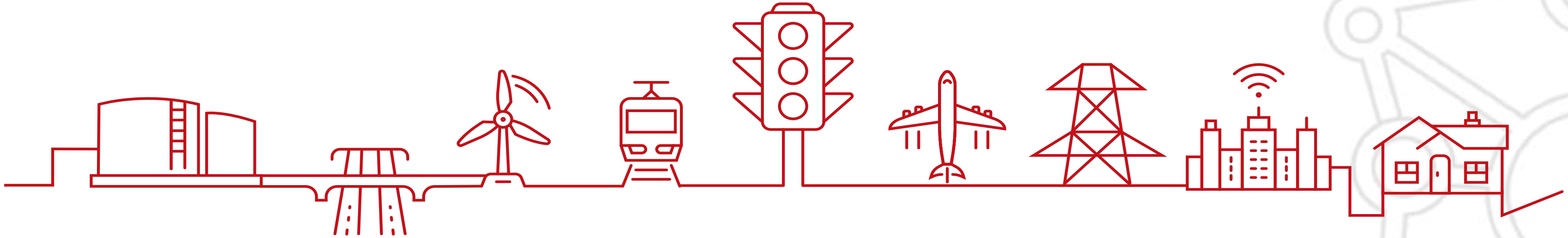
CLIMATE RISK PTY LTD Research Team: Jacquelyn Lamb, Karl Mallon, Michael Bojko

Project Team: Nicola Nelson, Anna Flack, Farhana Rifat, Merran Griffith

DR KARL MALLON
DIRECTOR SCIENCE AND SYSTEMS
SYDNEY
NSW, AUSTRALIA
KARL@CLIMATERISK.COM.AU

JACQUELYN LAMB
CHIEF OPERATIONS OFFICER
SYDNEY
NSW, AUSTRALIA
JACKIE@CLIMATERISK.COM.AU

MICHAEL BOJKO
CLIMATE ANALYST
SYDNEY
MICHAEL@CLIMATERISK.COM.AU



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XDI CROSS DEPENDENCY INITIATIVE

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY key findings

In Eastern Sydney, temperatures are rising. The Adapting the East Report quantifies the current and future heat impacts in Eastern Sydney to people and infrastructure, by analysing 3 case study areas. Adaptation planning significantly reduces Human Heat Stress and infrastructure Heat Failure disruption in the future.

HEAT FAILURE PROBABILTY

The current (2020) Heat Failure Probability already shows an extreme heat failure probability i.e. >30%.

Macquarie Corridor	29.9%-65.0% in 2020, 71.8%-87.5% in 2050.
Airport Precinct	35.6%-88.6% in 2020, 71.8%-94.9% in 2050.
Sydenham Bankstown	41.7%-94.7% in 2020, 78.5%-99.9% in 2050.

HUMAN HEAT STRESS

Human Heat Stress (HHS) events will increase by 42% – 45% by 2050 without adaptation, with approximately 485,000 human heat stress impact events in 2050.

ADAPTATION

2°C adaptations have short-lasting effects, and do not sufficiently reduce HHS events. To have a lasting effect on heat failure and to begin reducing HHS events, **4°C** cooling adaptations are necessary.

7°C adaptation generally result in low heat failure rates across the 3 case study areas, although there are hotspots in Sydenham Bankstown and Airport, and HHS events persist at some locations.

4°C adaptations result in significant health cost savings, but these savings can be roughly doubled if **7°C** adaptations are implemented.

Extreme heat days
>35°C
increasing by
2.34 days by 2039
6.13 days by 2079
NARCliM, ADAPTNSW 2020

Maximum annual temperature
average increase of
0.57°C by 2039
0.98°C by 2079
NARCliM, ADAPTNSW 2020

Human Heat Stress
will increase by
42% – 45%
by 2050
without adaptation

Avoided costs
associated with reducing Human Heat Stress events from a
4°C adaptation
add up to $9.4 million

EXECUTIVE SUMMARY recommendations

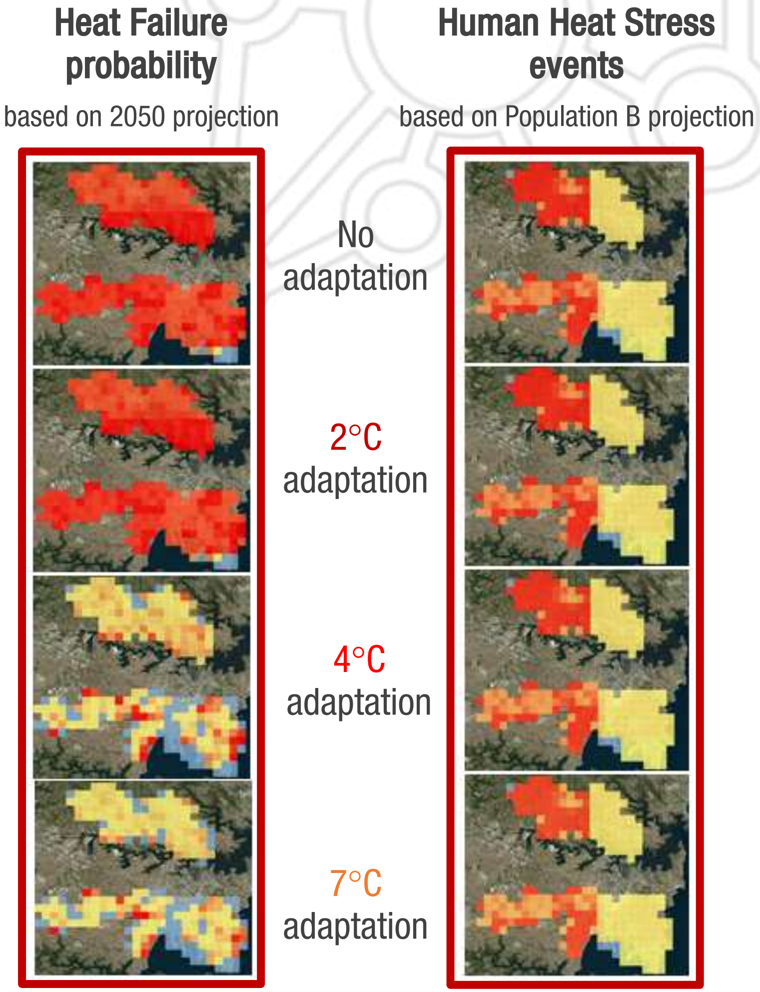
Increasing urban heat is already resulting in adverse impacts on human health and asset performance in Eastern Sydney. These impacts are only going to intensify in the future unless ambient temperatures are reduced significantly through implementation of heat adaptation. It is recommended that Sydney Water consider the following:

1. Any adaptation planning to reduce heat needs to aim to reduce ambient heat by a minimum of 4°C, where possible. Certain localised hotspots will require ambient heat reduction of more than 7°C to reduce heat-related impacts.

2. The selection of effective adaptation measures for localised application will require area-specific consideration based on the existing land-use pattern i.e. to reduce the temperature of Sydney Airport area (existing land use – impermeable paved area), a combination adaptation measure such as Greenery + Cool & Permeable Pavements + Water + Shading Devices, should be considered to achieve at least 4°C temperature reduction. For effective temperature reduction, this will require targeted and detailed land use planning, starting in the early stages of any proposed development.

3. Relevant agencies need to work in collaborate on implementing adaptations. There is an opportunity for Sydney Water to actively support the water requirements for any adaptation measures e.g. water features or irrigated surfaces, which will have an immediate and effective reduction of the heat and heat-related impact in the Eastern Sydney region.

4. Design standards should stipulate that all new Sydney Water assets require a minimum temperature design threshold of 50°C to address the risk of heat failure disruption. Existing Sydney Water assets should be retro-fitted to a minimum of 50°C during standard maintenance cycles.



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EASTERN SYDNEY REGION

BACKGROUND

> " Climate change is making heatwaves worse in terms of their impacts on people, property, communities and the environment. Heatwaves have widespread impacts, ranging from direct impacts on our health to damage to ecosystems, agriculture and infrastructure. "
>
> Climate Council, 2014

Sydney Water is developing a regional-scale integrated water servicing master plan for Eastern Sydney (called Eastern Sydney Regional Master Plan) to reimagine the role of water to support the Greater Sydney Commission's (GSC) vision for a more liveable, productive and sustainable Greater Sydney.

Eastern Sydney is home to 2.7 million people, with population growth occurring much sooner than in Western Sydney. Eastern Sydney's population is projected to increase to 3.4 million by 2041 (GSC projections). Changing climate, with increasing temperature is one of the major issues identified (The Eastern Sydney Regional Master Plan (ESRMP) Issues Paper, Sydney Water, 2019) for this growing region, including some of Sydney's hottest locations within this region such as Sydney and Bankstown Airports.

Sydney Water is taking an active role in recognising urban heat and climate impacts. Sydney Water is also investing to understand the potential role of water to contribute directly to urban cooling by providing recycled water for irrigation of open space/greening, naturalisation and through other collaborative measures with other stakeholders.

BACKGROUND

Adapting the East is one of the many concepts of ESRMP, assessing the climate impact in the context of urban renewal and densification in the Eastern Sydney region. The study is considering climate (specifically heat) impacts on human health, liveability, the environment and infrastructure, and assessing the effectiveness of different adaptation strategies to reduce these impacts. Findings from this concept will directly support and be complementary (both ways) to the benefits of other ESRMP concepts, namely urban greening, waterway health and recycled water schemes. Understanding of key heat/climate impacted areas and the most effective heat adaptation measures will also support climate-sensitive decisions and measures to integrate and implement short, medium and long-term outcomes into the ESRMP pathways process.

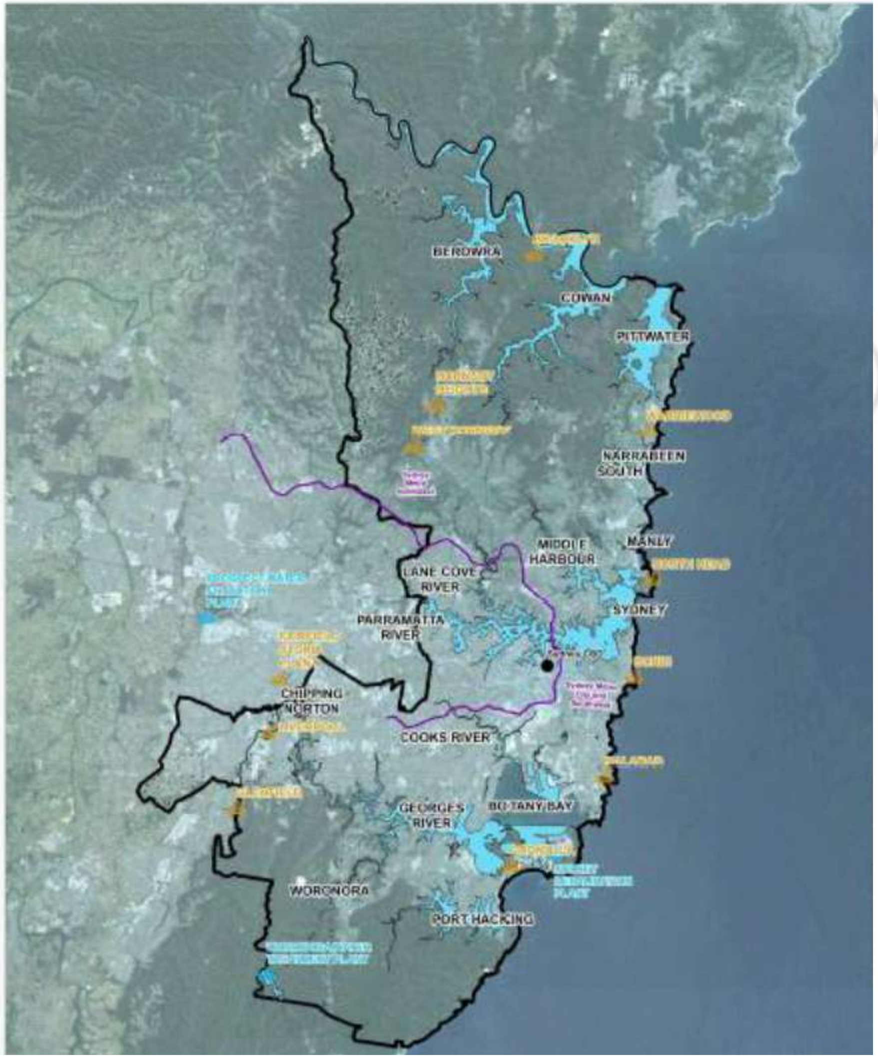


Figure 1 Eastern Sydney Region Outlined in black

Sydney WATER

XDI CROSS DEPENDENCY INITIATIVE

PROJECT SCOPE

- Hazard analysis is limited to Heat (extreme temperature) only.
- Land use planning uses representative assets not ‘real’ assets as they are in the landscape today.
- The area analysed is limited to the 3 case study areas with the Eastern Sydney Region.
- Adaptations are applied using the temperature reductions, not the specific adaptation measure. This enables the decision maker to apply adaptations within the achievable temperature reduction that suit the landscape.
- The Urban Heat Island Mitigation Performance Index (UHI) Tool has been used as the basis of the degree of temperature reduction for each adaptation measure. The Urban Heat Mitigation Performance Index aims to provide local governments with a broad range of urban heat island mitigation options tailored to certain microclimates and urban contexts.
- Cost-Benefit Analysis work is based on an existing urban forest project, and has not been complete for all potential adaptation pathways.

CASE STUDY AREAS

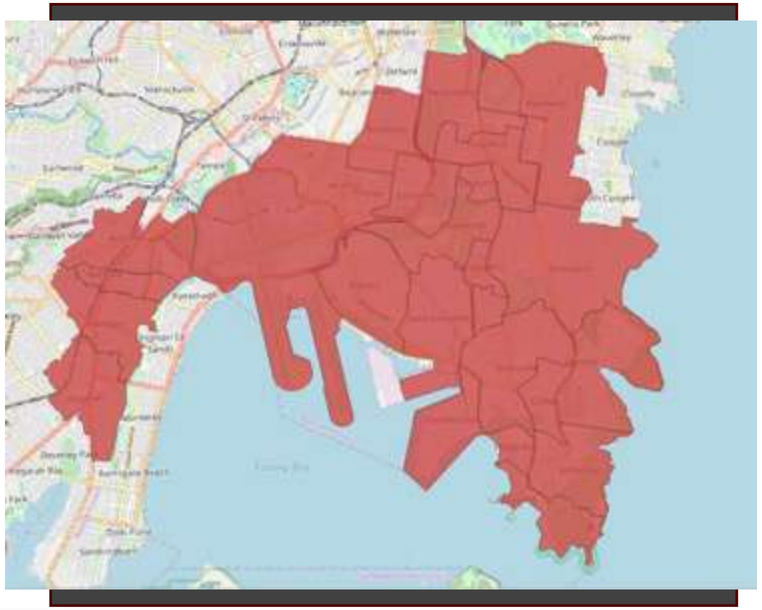
Growth around the Eastern Sydney region is mainly infill development, which presents opportunities for improvements and adaptation measures. Key growth areas around the Eastern Sydney Region are primarily located along the Eastern Economic Corridor, which stretches from Macquarie Park to Sydney Airport and Sydenham to Bankstown urban renewal corridor. Additionally, GSC has identified a few collaboration areas around the Eastern Region. Collaboration areas were identified due to their metropolitan significance and potential to grow into centres of increased productivity and innovation, like Randwick, Kogarah etc.

Urban renewal to accommodate population growth in the economic corridor and collaboration areas will cause densification and increase urban heat island effect, which would have an impact on the liveability in the growth precincts. For 'Adapting the East', three areas of significance were selected based on opportunities and need for improvements to mitigate climate impact – the Airport precinct, Macquarie Corridor and Sydenham to Bankstown Corridor.

CASE STUDY AREAS

Airport Precinct

Includes Randwick and Kogarah as GSC's collaboration areas and Sydney Airport as one of the hottest places in the Sydney region.



Macquarie Corridor

Part of Eastern Economic Corridor, which stretches from Macquarie Park, Chatswood and St Leonards.

Sydenham Bankstown Corridor

An urban renewal corridor identified by NSW Government.

Figure 2 Case Study Area Boundaries, as provided by Sydney Water.

ADAPTING THE EAST
KEY RESULTS – BASELINE

"Heatwaves kill more Australians than any other natural disaster. They have received far less public attention than cyclones, floods or bushfires—they are private, silent deaths which only hit the media when morgues reach capacity or infrastructure fails." PWC, 2011

See the Adapting the East report for more detailed analysis

In Eastern Sydney, temperatures are rising

Extreme heat days

>35°C

increasing by

2.34 days by 2039

6.13 days by 2079

NARCliM, ADAPTNSW 2020

Maximum annual temperature

average increase of

0.57°C by 2039

0.98°C by 2079

NARCliM, ADAPTNSW 2020

Human Heat Stress

will increase by

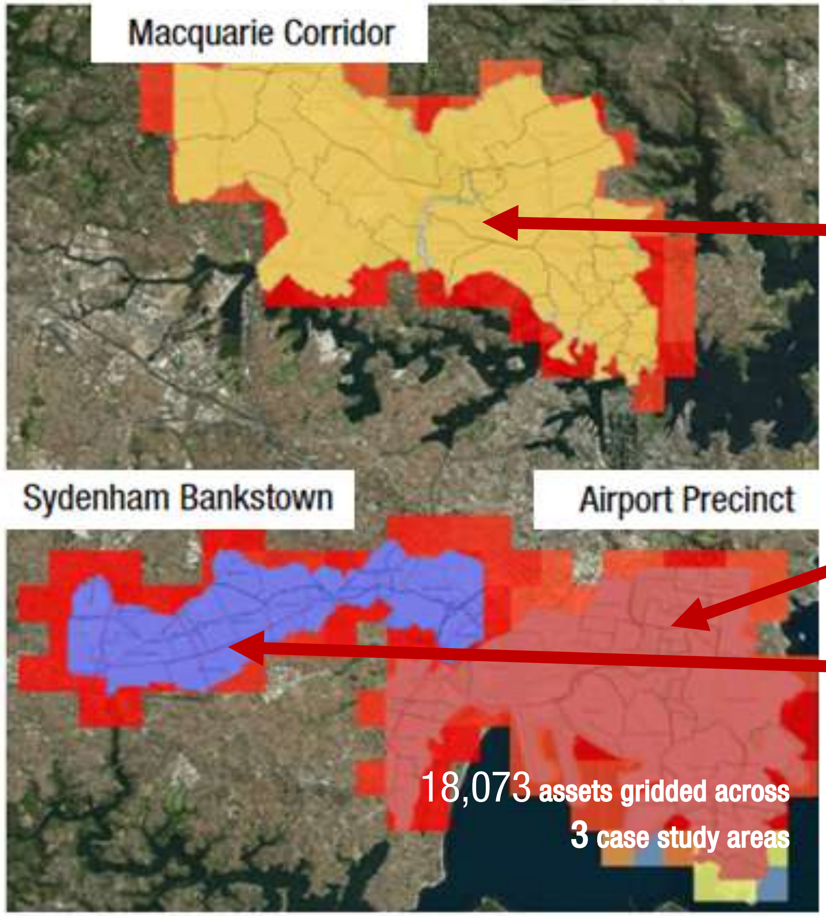
42 – 46%

by 2050

without adaptation

Population is growing

Eastern Sydney's population is expected to reach 3.4 million by 2050.



Probability of asset failure is increasing

Maximum Asset Failure Probability without adaptation.
Assets include residential buildings, parks, schools, industry, etc.

Macquarie Corridor
2020 = 65%
2050 = 88%

Airport Precinct
2020 = 89%
2050 = 95%

Sydenham Bankstown
2020 = 95%
2050 = 99.9%

Sydney WATER

XDI CROSS DEPENDENCY INITIATIVE

ADAPTING THE EAST
KEY RESULTS – ADAPTATION

Modelling shows that **at least 4°C cooling** is needed to reduce Heat Failure probability in 2050, however, there are still hotspots and areas for improvement in Sydenham Bankstown.

There is a **high chance of Human Heat Stress** events even **after 7°C** cooling, especially in the Macquarie Corridor.

See the Adapting the East report for more detailed analysis

Heat mitigation

Adaptation options were selected from the Urban Heat Island Mitigation Performance Index Tool and include:

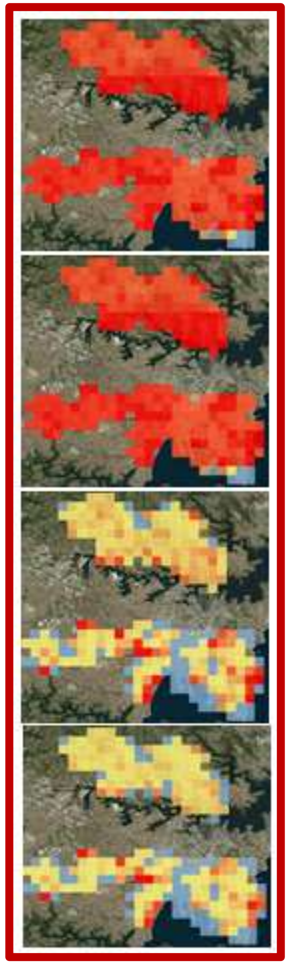
- Cool building materials
- Shading structures
- Evaporative cooling*
- Irrigated vegetation*
- Water in the landscape*

Adaptation options were combined to achieve 2°C, 4°C and 7°C cooling scenarios.

** Adaptation options Sydney Water can directly contribute to*

Heat Failure probability

based on a 2050 projection



No adaptation

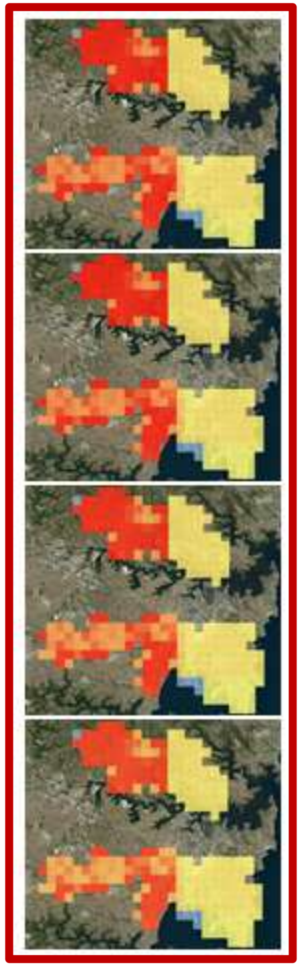
2°C adaptation

4°C adaptation

7°C adaptation

Human Heat Stress events

based on a 2050 population projection



Avoided costs

Based on a 4°C adaptation, avoided costs associated with reducing Human Heat Stress events add up to

$9.4 million

Recommendations:

1. Adaptation planning aims to reduce ambient heat by a minimum of 4°C.
2. Area-specific consideration is required when selecting adaptation measures for localised application.
3. Relevant agencies need to collaborate on implementing adaptations.
4. Design standards minimum temperature design threshold of 50°C.

Sydney WATER

XDI CROSS DEPENDENCY INITIATIVE

CLIMATE PRIMER

CLIMATE PRIMER - RCP

"Human-driven climate change has contributed to the increase in hot days and heatwaves. The increase in greenhouse gases in the atmosphere, is trapping more heat in the lower atmosphere (IPCC 2013), that in turn increases the likelihood of heatwaves and hot days and decreases the likelihood of cold weather."
Climate Council, 2014

RCP is the Representative Concentration Pathway for a atmospheric greenhouse gas concentration (not emissions) trajectory adopted by the IPCC. Four pathways were used for climate modelling and research for the IPCC fifth Assessment Report (AR5) in 2014.

The pathways describe different climate futures, all of which are considered possible, depending on the volume of greenhouse gases (GHG) emitted in the years to come. This uses the highest scenario, RCP 8.5, which best represents the current trajectory GHG emissions and is a standard stress test for physical risk.

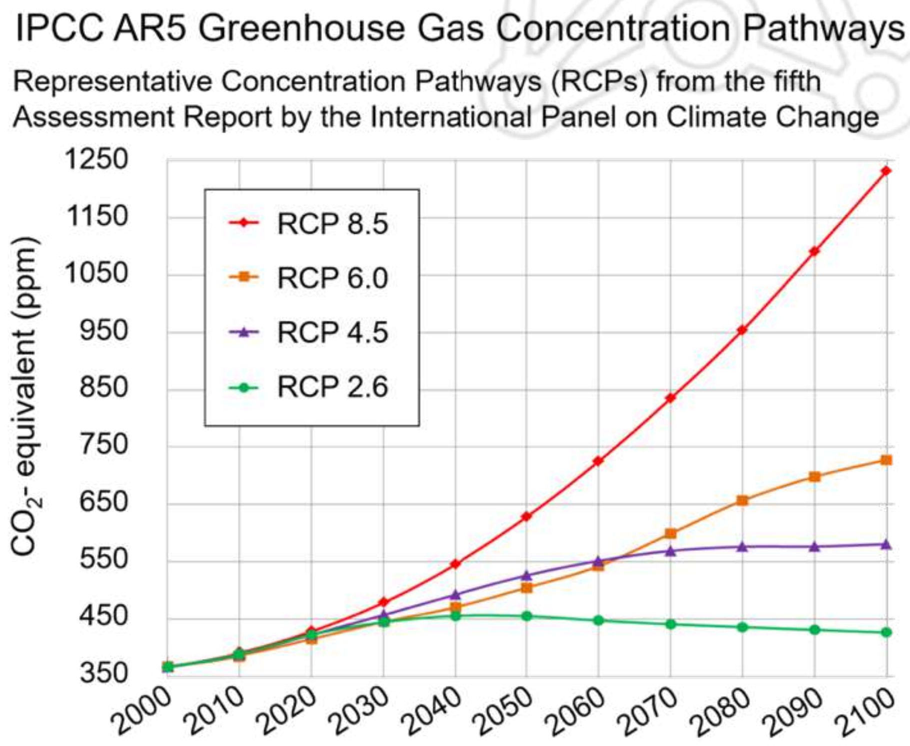


Figure 3 AR5 RCPs, 2017

CLIMATE PRIMER – NARCliM

Climate change projections are presented for the near future (2030) and far future (2070), compared to the baseline climate (1990–2009). The projections are based on simulations from a suite of twelve climate models run to provide detailed future climate information for NSW and the ACT.

For Metropolitan Sydney the NSW Climate projections summary states:

- Change in number of days a year max temp > 35ºC between 2020-2039 is in increase by 2.34 day(s), and for 2060-2079 in increase by 6.13 day(s).

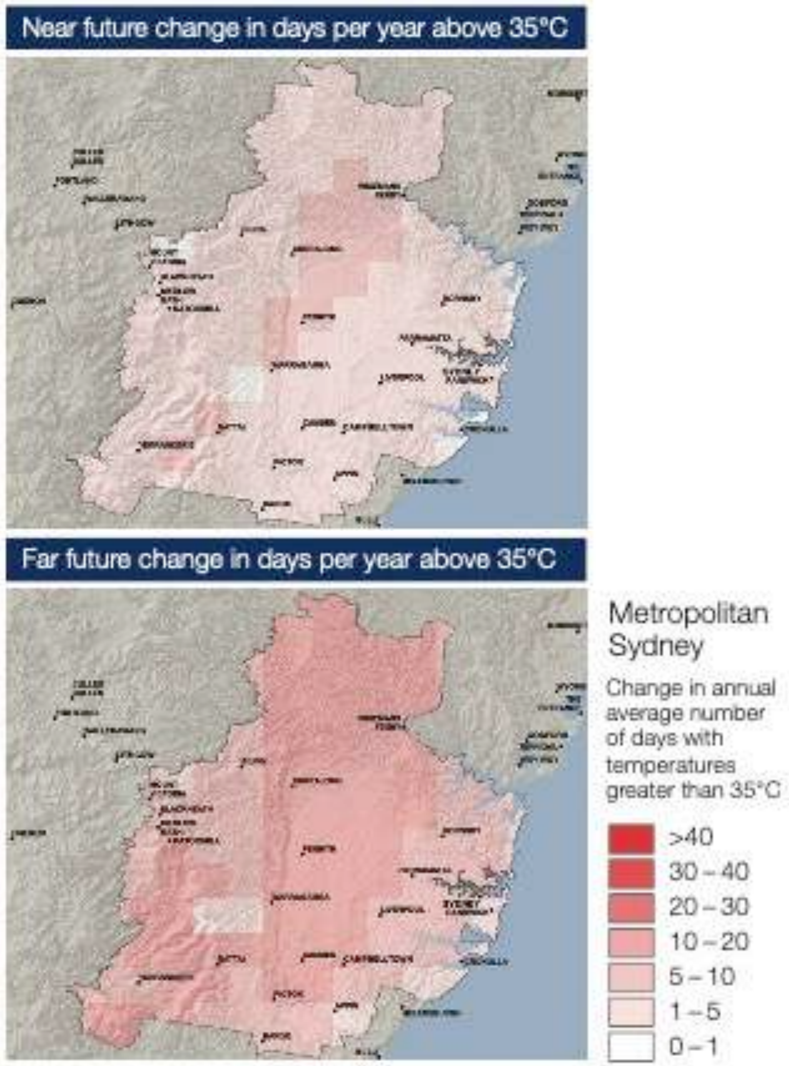


Figure 4 Metropolitan Sydney Climate change snapshot
Source: ADAPTNSW 2014

NARCliM cont.

Time series analysis of NSW and ACT Regional Climate Modelling (NARCliM) data in Eastern Sydney reveals the maximum annual temperature in the base period 1990-2009 was 43.58°C. NARCliM projects a likely 0.57°C average increase in the period 2020-2039, and a 0.98°C average increase in the period 2060 to 2079.

The analysis uses NARCliM:

- RCP: 8.5
- CMIP3 SRES A2
- Global Climate Model (GCM): MIROC 3.2
- Regional Climate Model (RCM): R2

"Despite the considerable focus on mitigating urban overheating in Western Sydney, the City of Sydney's temperature in summer is continually rising and still poses an increased health risk for its inhabitants. Within the City of Sydney LGA, the frequency of extreme heat days (>35°C) is projected to increase to 15 by 2070."

City of Sydney, 2016

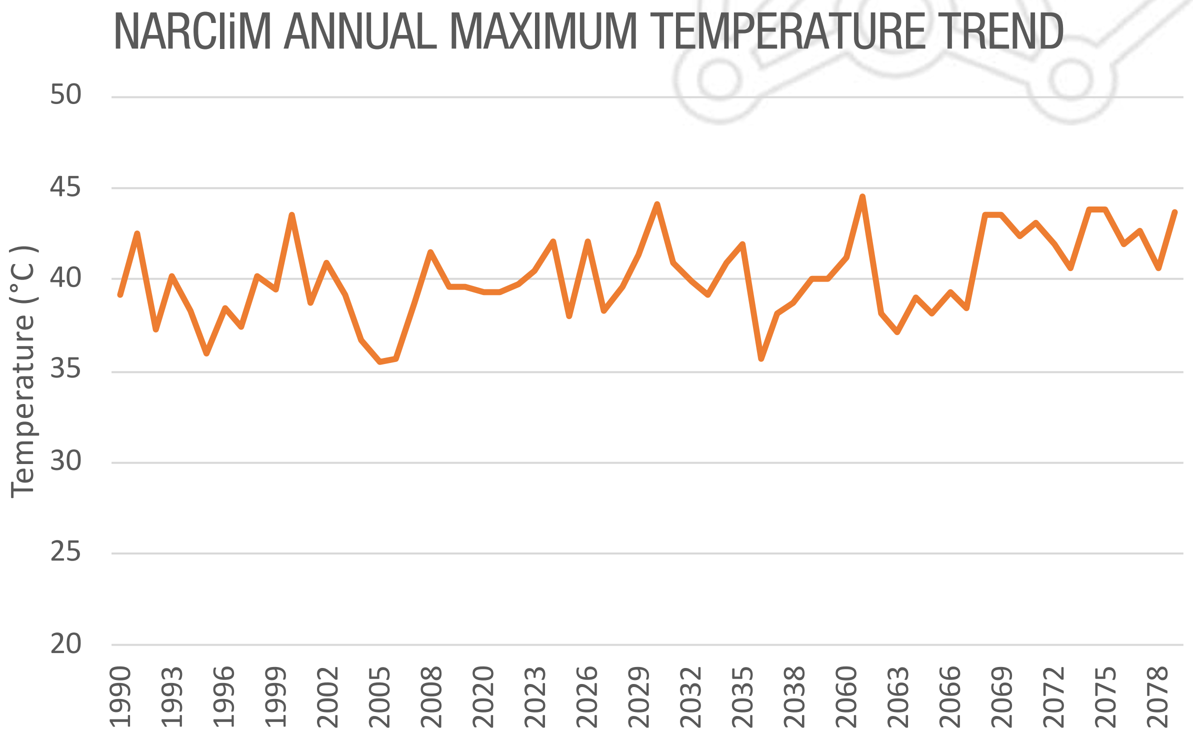


Figure 5 NARCliM annual maximum temperature projection at lon=151.2221-lat=-33.9415

*Actual extremes may be higher, ADAPTNSW 2020

CLIMATE PRIMER - UHI

"Global climate change and the urban heat island (UHI) phenomenon – whereby cities absorb and release more heat than the surrounding countryside – carry growing potential to make urban life at particular times and places an exercise in low-grade misery."
Osmond, P., & Sharifi, E., 2017

The Urban Heat Island (UHI) effect is caused by roads and structures absorbing sunshine and radiating heat. UHI increases ambient temperature in high-density urban areas compared to surrounding suburban or rural areas.

If overlooked in the planning and designing of our cities, UHI can significantly increase the demand for energy, water and healthcare services.

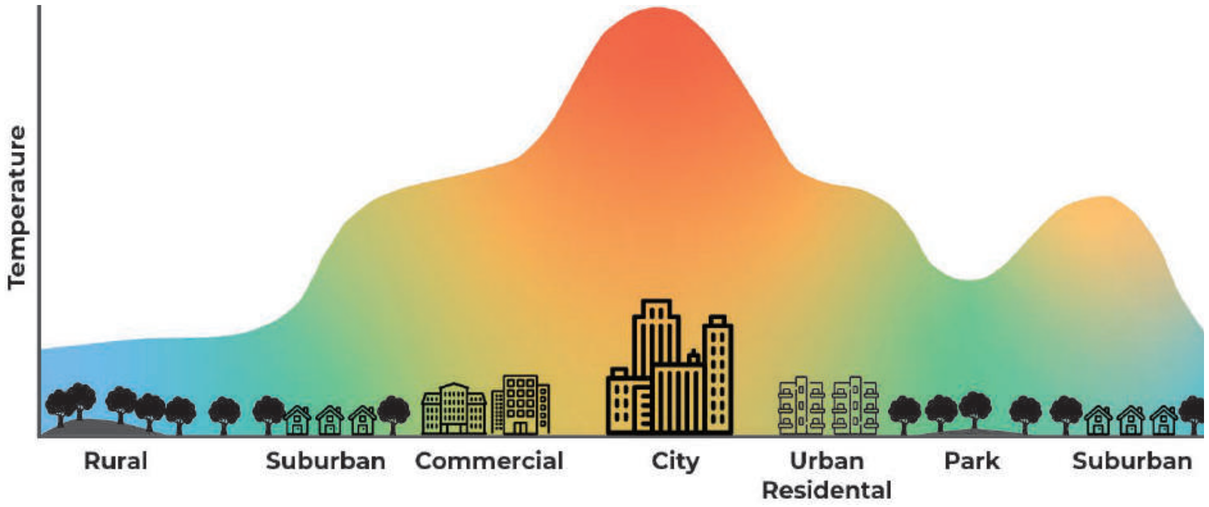


Figure 6 Source: Osmond, P., & Sharifi, E. 2017

CLIMATE PRIMER – To what extent is UHI included in the data?

The Bureau of Meteorology (BoM) stations are embedded in highly urbanised areas. Therefore we assume that UHI (at 10m above ground) is included within the data historical and projected climate data.

No further UHI accommodation should be made e.g. increasing the temperature projections based on city density, lest there would be double counting of UHI.

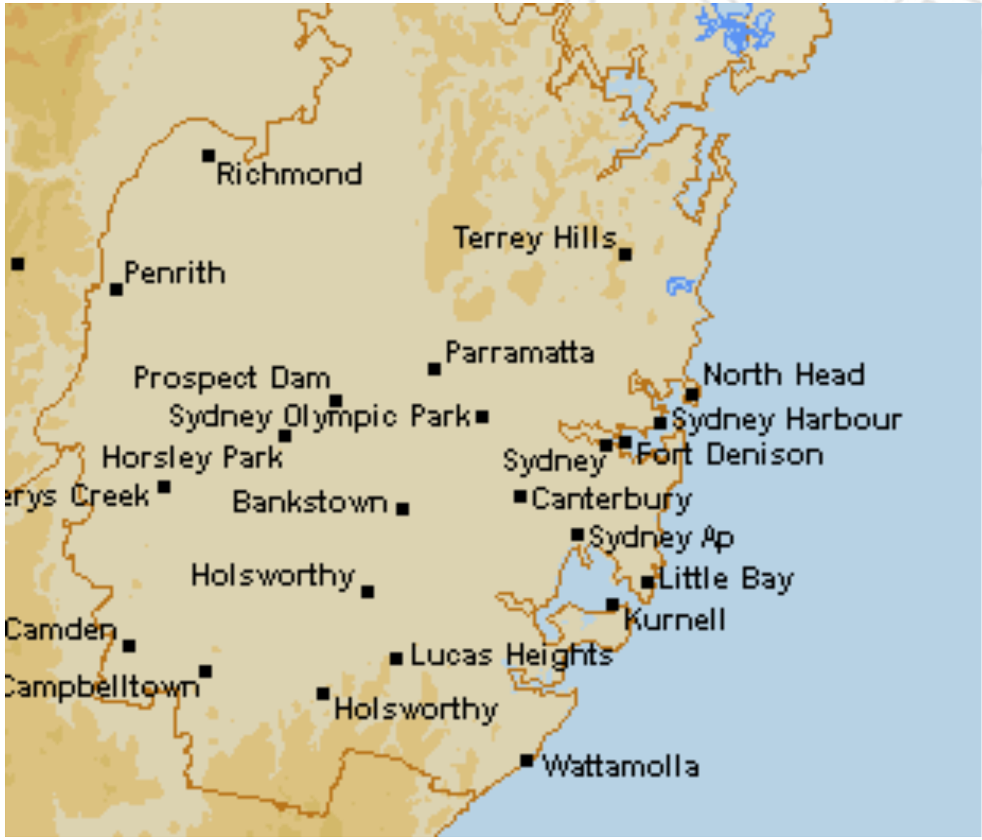


Figure 7 Source: BoM Stations, 2020

CLIMATE PRIMER – HHS

"Heatwaves kill more Australians than any other natural disaster. They have received far less public attention than cyclones, floods or bushfires—they are private, silent deaths which only hit the media when morgues reach capacity or infrastructure fails."
PWC, 2011

Human Heat Stress (HHS) can have a range of impacts from moderate reductions in productivity as people need more breaks or unusual working hours, through to acute health impacts requiring hospitalisation.

The Melbourne 2009 heatwave required railway repair workers to work at night to repair buckled railways (McEvoy et al. 2012). It's estimated that 374 people died of heat stress related illness in the same event (ABS, 2010).

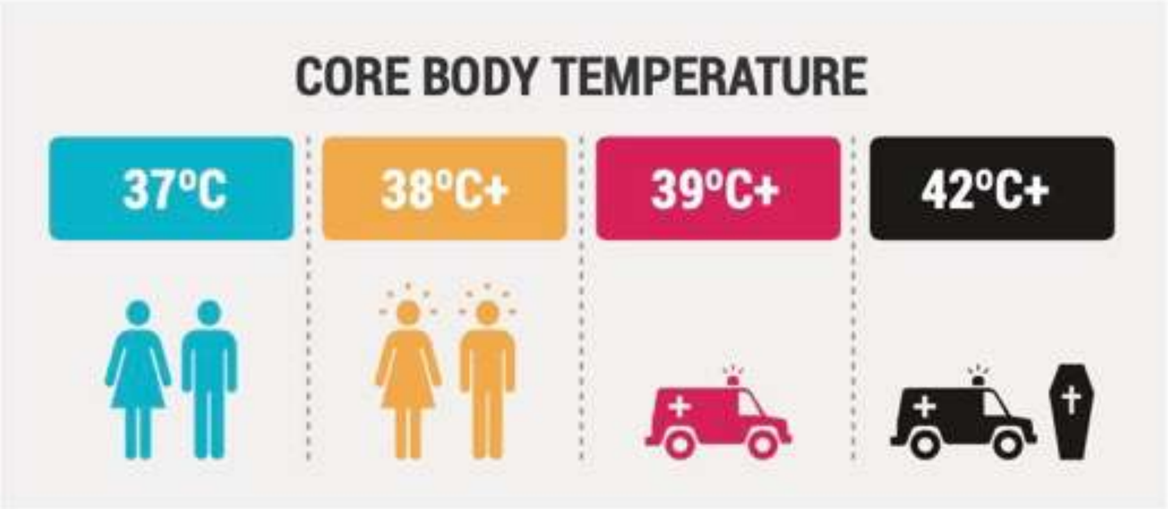


Figure 8 Source: Hughes and Michael, 2011

HEAT FAILURE PROBABILITY

Climate projections look at the changes in maximum temperature and increased frequency of hot days e.g. days over 35°C. This does not give a utility or agency an indication of the direct impact that increasing temperatures and hot days could cause. Therefore, these projections need to be translated into factors that impact the running and operation of infrastructure. For this purpose Failure Probability is used.

WHAT IS HEAT FAILURE?

Failure Probability is the annual probability of an event occurring that will cause the asset or its components to stop working aka a disruption. This can occur without damage.

E.g. an air conditioner might fail because the ambient temperature exceeds the operational threshold of its electronics.

WHY IS HEAT FAILURE IMPORTANT?

Failure probability is an important indicator especially for productive assets such as business premises or critical infrastructure where there may be significant lost income or customer disruptions when the asset stops working. Also, for air-conditioning, power, water or communications in homes where lives may be at risk.

HUMAN HEAT STRESS

" Hot days, hot nights and extended periods of hot weather, heatwaves, are one of the most direct consequences of climate change."
Climate Council, 2014

People enduring heat stress may be in extreme discomfort, may need to go to hospital and can die. People retreat to their homes when exterior temperatures and humidity reach levels that cause risk. In this project the Human Heat Stress (HHS) relates future projections of hot days and heat waves to the risks of heat stress events. In order to calculate HHS a number of climate and engineering factors are required. HHS uses projected days over 35°C, transfer ratios between external temperatures and a range for the modelled internal Thermal Discomfort Index (TDI) based on the archetypes.

THERMAL DISCOMFORT INDEX

TDI is a measure for heat stress that relates ambient temperatures external to a building, to the amount of discomfort experienced by the occupant. The higher the TDI, the greater the impact on the occupant.

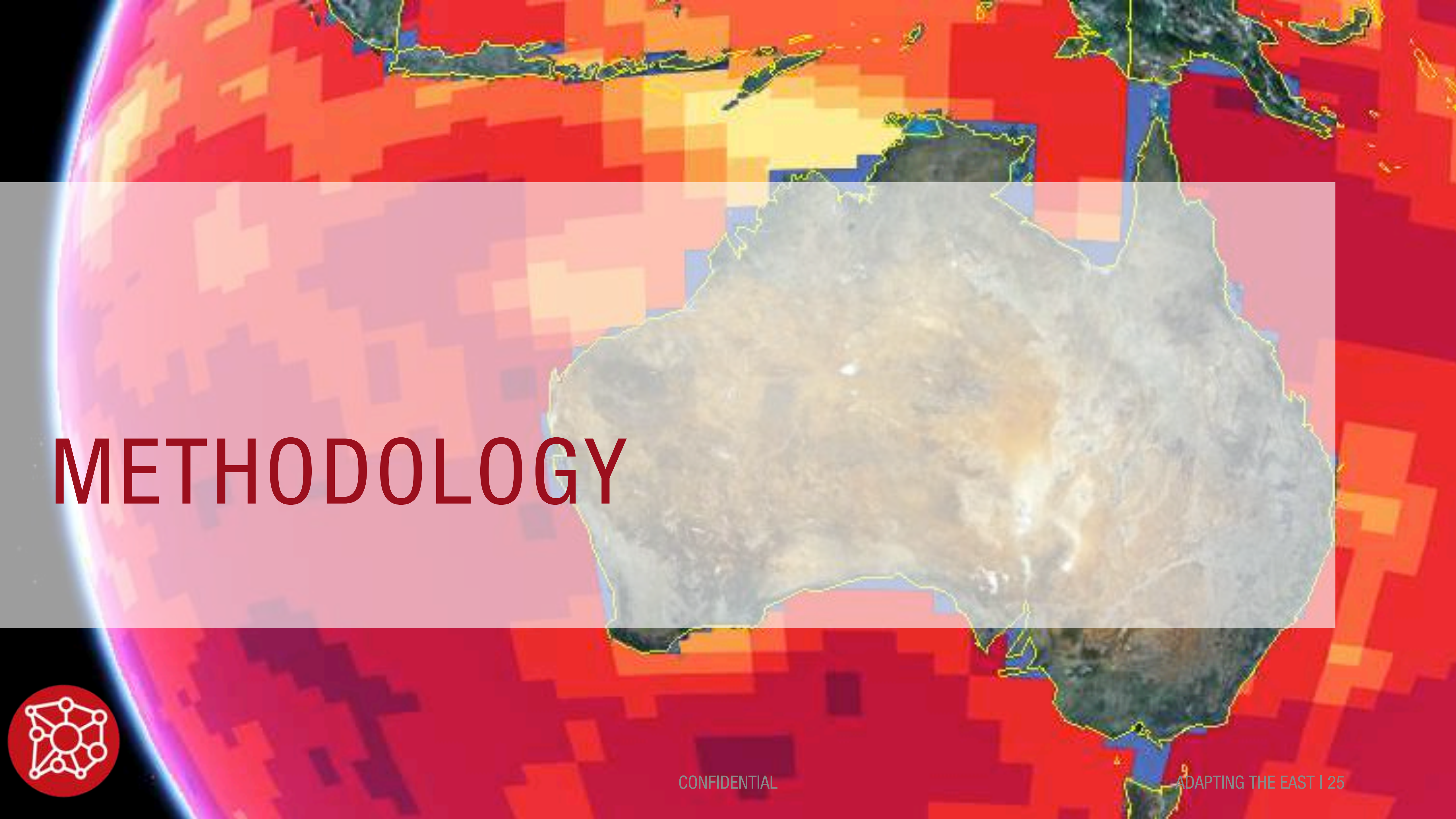
DEFINING HEAT STRESS EVENTS

The number of Heat Stress Events per year refers to events in which an occupant is exposed to a climate inside their dwelling which exceeds a Thermal Discomfort Index (TDI) of 28.

TEMPERATURE PROJECTIONS WITH CLIMATE CHANGE

The baseline thermal climate is taken from the nearest BoM station to each dwelling.

The climate change temperature projection used for this analysis is NARCliM GCM: MIROC3.2, RCM: R2



METHODOLOGY

CASE STUDY AREAS

18,073 representative structures were gridded across the 3 case studies within the ESRMP area. Each representative structure represents a different archetype*. The archetype used varies and was determined by land use and projected development source data provided by Sydney Water. The archetypes are:

1. Building
2. School
3. Park
4. Low Rise Unit Block
5. Town House Detached

Planning data and population projection data was used to allocate a count of people to each representative structure, each point has not been given the same number of people. Where no data was provided a default* was used. For example a park has a greater number of people than a building.

*See Appendix for Archetype detail.

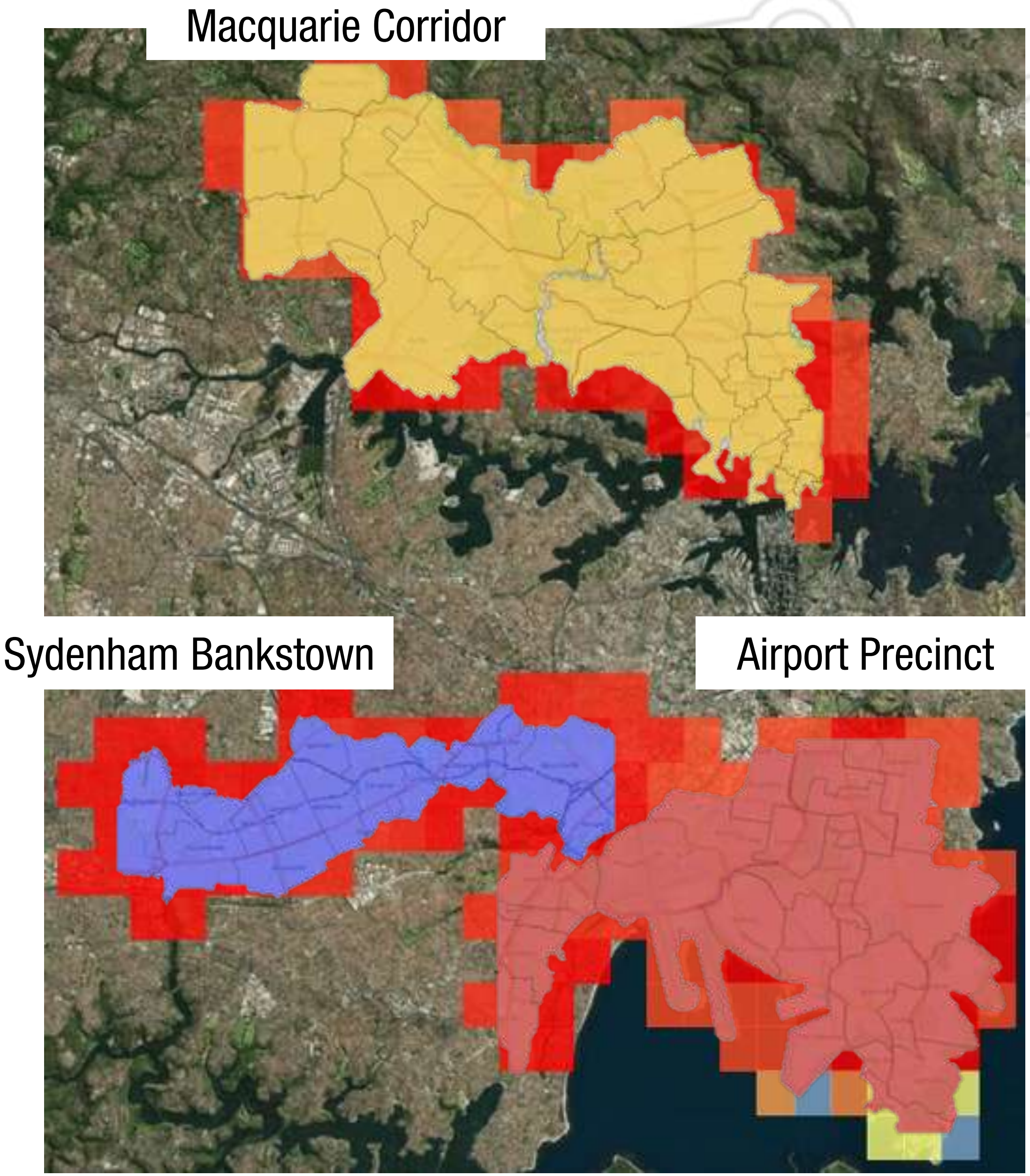


Figure 9 Case Study area outlines overlaid with XDI Globe Grid.

LAND USE PLANNING METHOD

The following provides a brief overview of the XDI Land Use Planning development process:

1. Establish a high-density representative asset grid.
2. Populate the grid with XDI standard archetypes for asset classes as defined by the most likely asset type present at the location.
3. Create a set of ‘risk tiles’ across the area, which aggregate proposed asset level risk to a resolution suitable for overview. Each tile will cover an area 500m^2.
4. Analyse each tile’s risk for future failure risk. Display the results in terms of risk fraction across the risk tiles.
5. Conduct adaptation sensitivity analysis for a proposed range of adaptation intervention/policies.

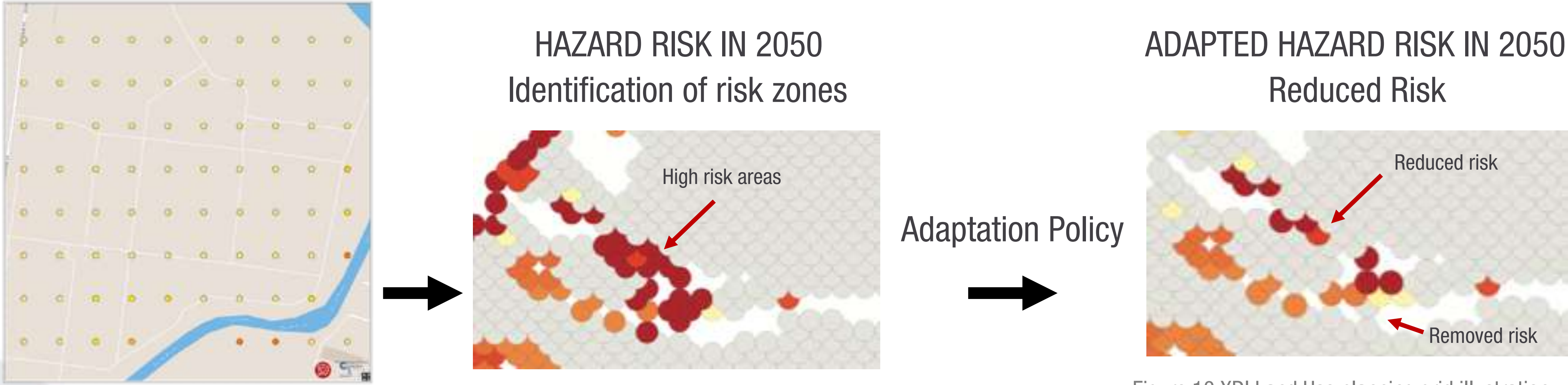


Figure 10 XDI Land Use planning grid illustration.

METHODOLOGY

CLIMATE RISK ENGINES

The Climate Risk Engines are purpose built to compute hypothetical future risks to a modelled asset archetype designed to represent individual property and infrastructure assets. The system enables each such asset to be stress-tested against a wide range of extreme weather and extreme sea events typical of its location. A range of future-looking scenarios can be applied that are consistent with different greenhouse gas emission scenarios, atmospheric sensitivity, adaptation pathways, building standards and planning regimes. The Climate Risk Engines combine engineering analysis with statistical analysis of historical weather and climate projections, and probabilistic methods for financial analysis of risk and value.

CLIMATE CHANGE MODELS

Changes in the composition of the atmosphere due to greenhouse gas emissions will change how the atmosphere and oceans behave. Therefore, the historical weather station statistics need to be adjusted to allow for climate change.

The Climate Risk Engines have access to a large number of data sets from the Coupled Model Inter-comparison Project (CMIP) in which participant organisations model the atmosphere under various Representative Concentration Scenarios (RCP). At a whole-of-atmosphere scale the General Circulation Models (GCMs) have a resolution down to about $100km^3$. With downscaling, Regional Climate Models (RCMs) include local topology and land surface information to provide weather parameters at higher spatial resolutions - between $5km^3$ and $50km^3$.

MATHEMATICAL ANALYSIS

The extreme weather and climate risks to an asset will depend on its exposure and vulnerability to each hazard, as well as the current and future severity and frequency of the hazard that may alter with climate change.

A REPRESENTATIVE ASSET ARCHETYPE

The system uses a representative asset that is based on nominal industry archetypes, but may include some customisation by the user. This Representative Asset type could be selected and tailored to represent a real asset at the same location or be created as an entirely hypothetical asset being placed in that location.

METHODOLOGY

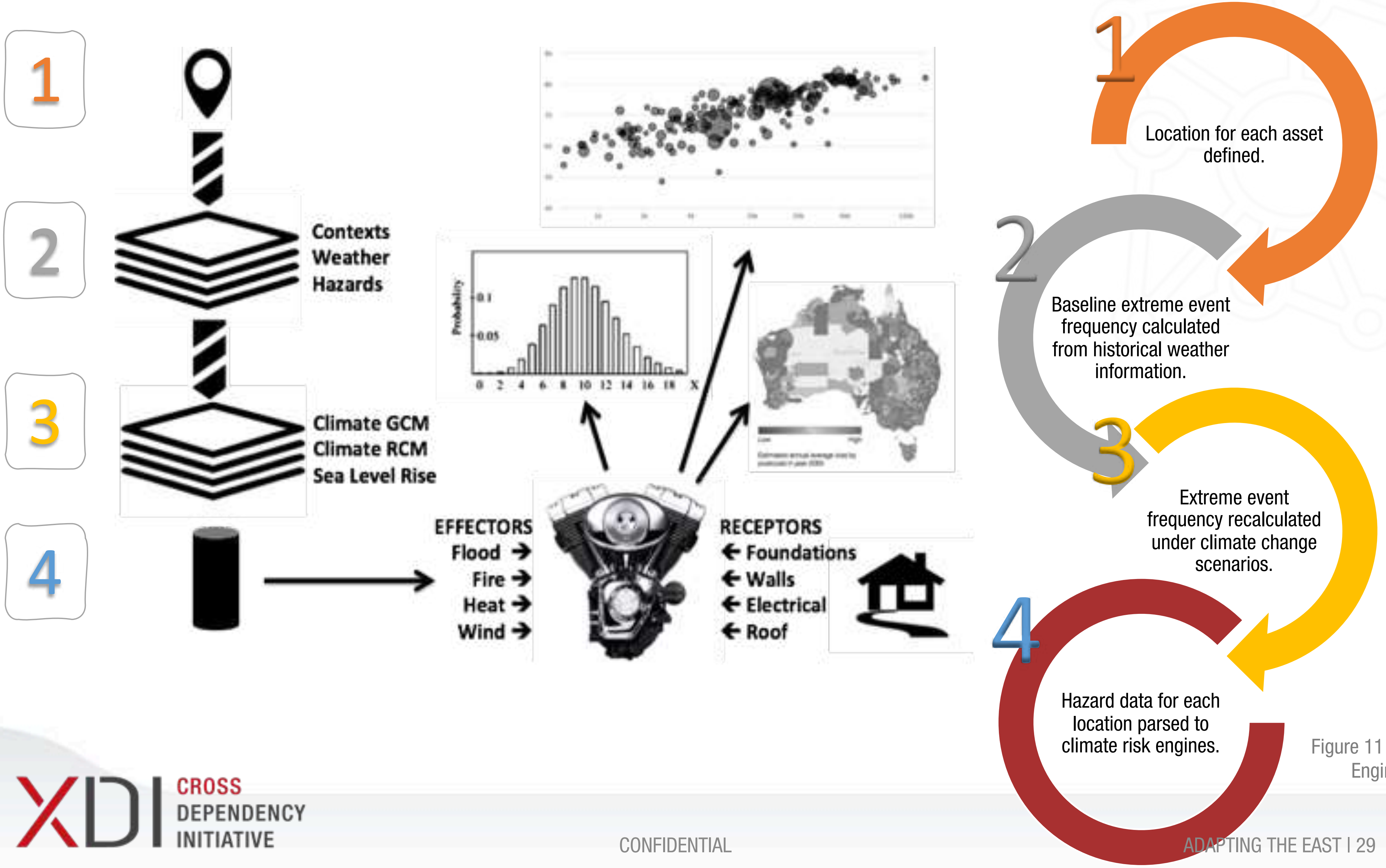


Figure 11 Climate Risk Engines Explained

METHODOLOGY

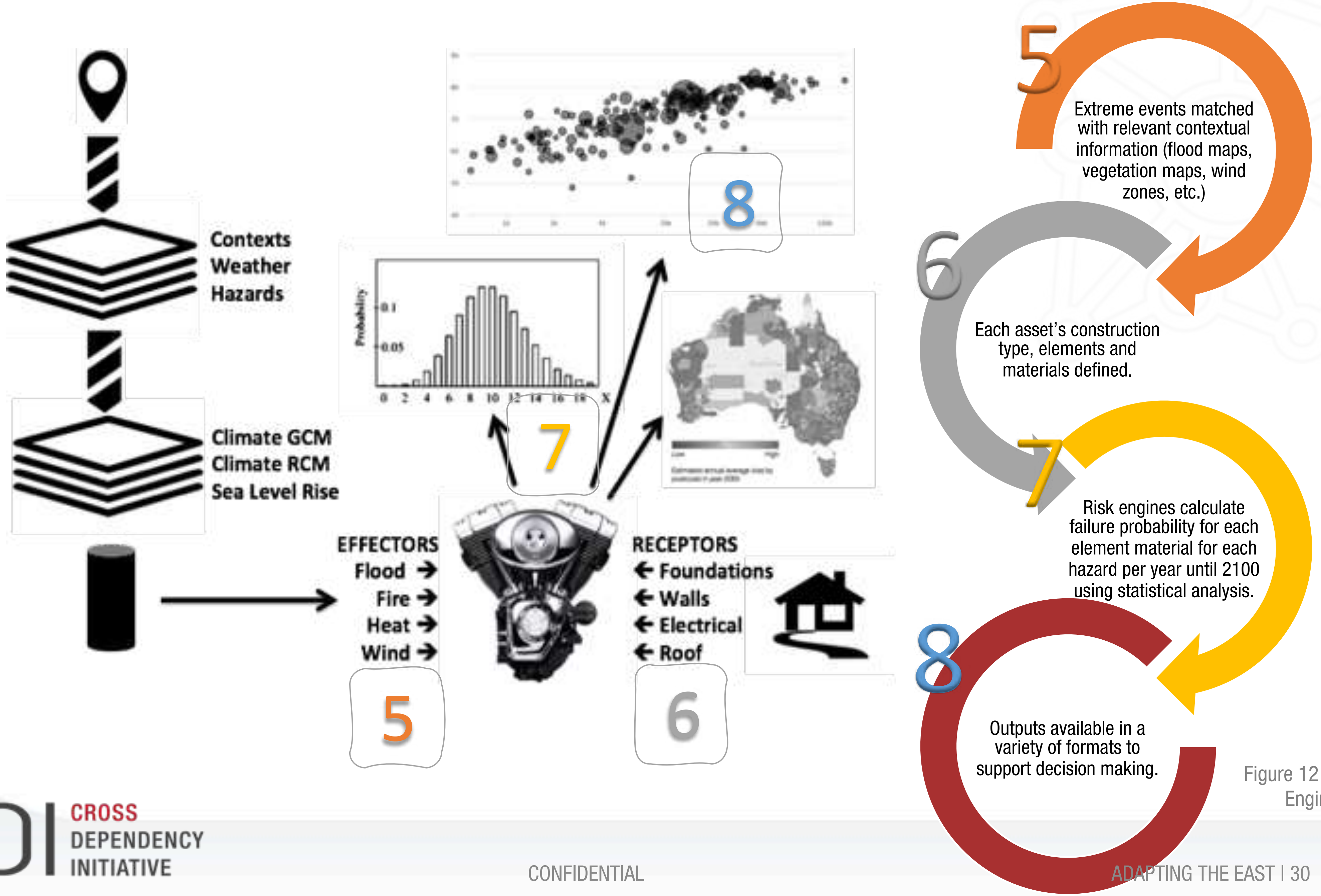


Figure 12 Climate Risk Engines Explained

BASELINE ANALYSIS

LAND USE PLANNING BASELINE ANALYSIS

- 18,073 representative structures were analysed for heat failure disruption probability and human heat stress events across the 3 case study areas.
    - 6,422 in the Airport Precinct; 7,694 in the Macquarie Corridor; 3,957 in the Sydenham-Bankstown
- 2 “Baseline” Datasets were developed using population projections provided by Sydney Water. These 2 datasets are based on population estimates at two time points:
    - **Population A** for the current population distribution (307,905 AP; 376,759 MC; 244,462 SB); and
    - **Population B** for the future (2050) population distribution (432,566 AP; 537,123 MC; 357,567 SB)
- All three case study areas have heat failure disruption probability and human heat stress events.
- All XDI Globe results are available to Sydney Water via the XDI Globe platform.

BASELINE HEAT FAILURE PROBABILITY

18,073 representative structures were analysed for heat failure probability across the 3 case study areas. All 3 case study areas show increasing heat failure probability. The current heat failure (2020) shows an already extreme heat failure probability i.e. >30%.

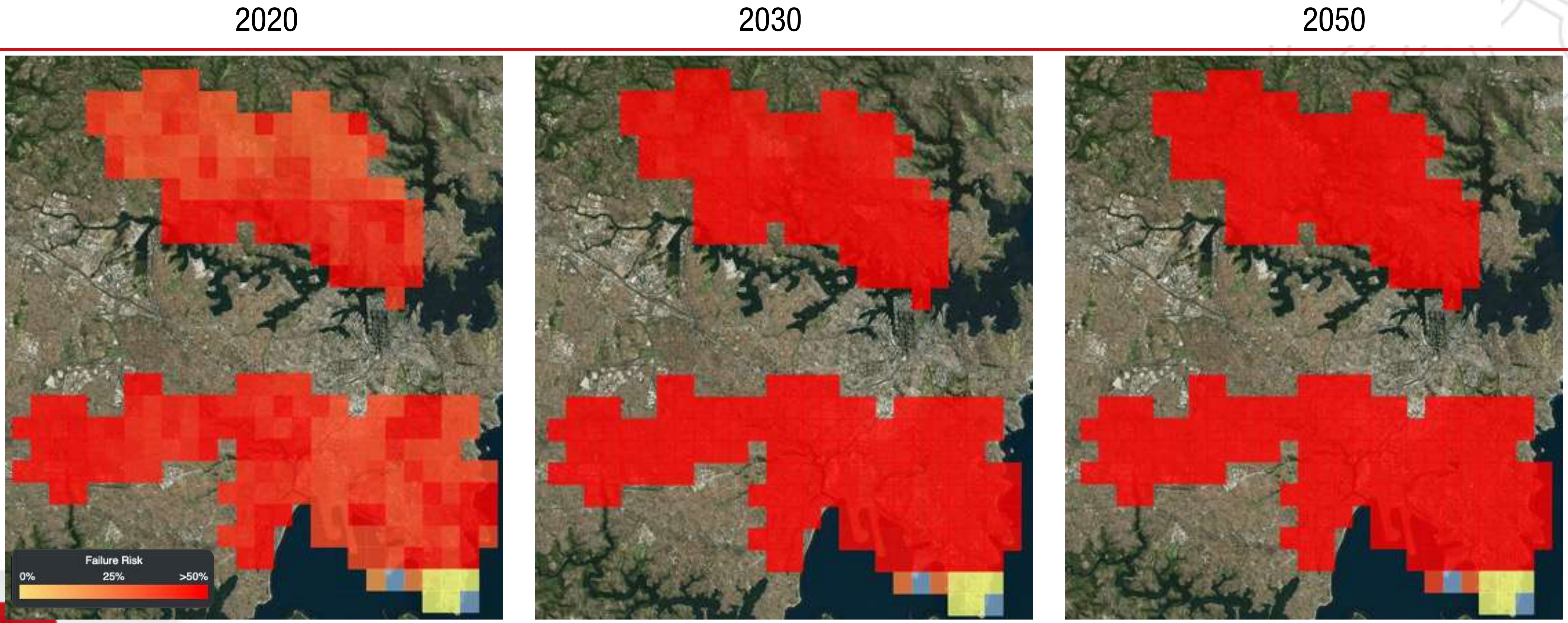


Figure 13 XDI Globe Heat FP%.

BASELINE HEAT FAILURE PROBABILITY

The Heat Failure Probability across Eastern Sydney indicates the current probability of disruption is at a level to justify significant immediate adaptation. The greatest driver of heat failure probability is temperature projections (see *climate cell variation*).

The Macquarie Corridor 2020 Failure Probability ranges from 29.9% to 65.0%, increasing to a range of 71.8% to 87.5% in 2050.

The Airport Precinct 2020 Failure Probability ranges from 35.6% to 88.6%, increasing to a range of 71.8% to 94.9% in 2050.

The Sydenham Bankstown 2020 Failure Probability ranges from 41.7% to 94.7%, increasing to a range of 78.5% to 99.9% in 2050.

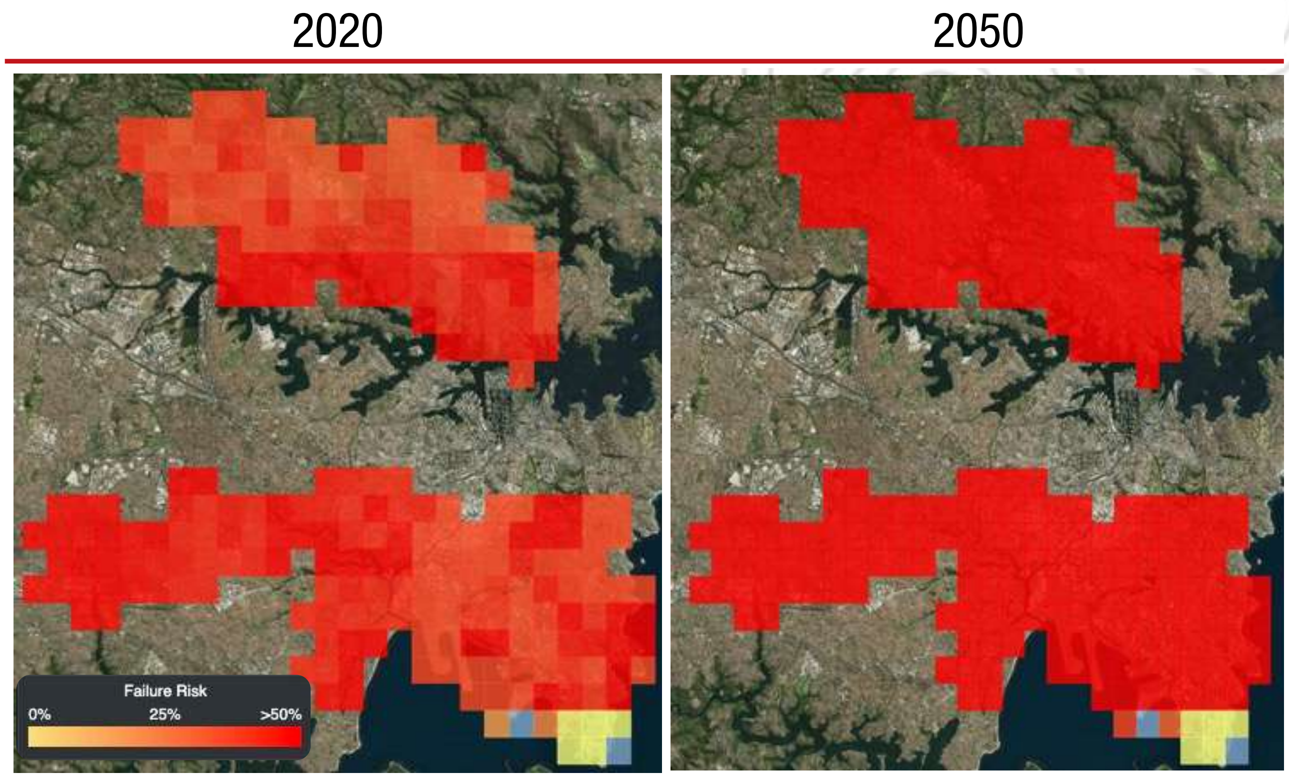


Figure 14 XDI Globe Heat FP%.

BASELINE HUMAN HEAT STRESS (HHS) EVENTS

All 3 case study areas show increasing in HHS but not uniformly, due to the archetype and population concentrations. 2050 HHS results show a significant proportion of high HHS i.e. >15 HHS events per person.

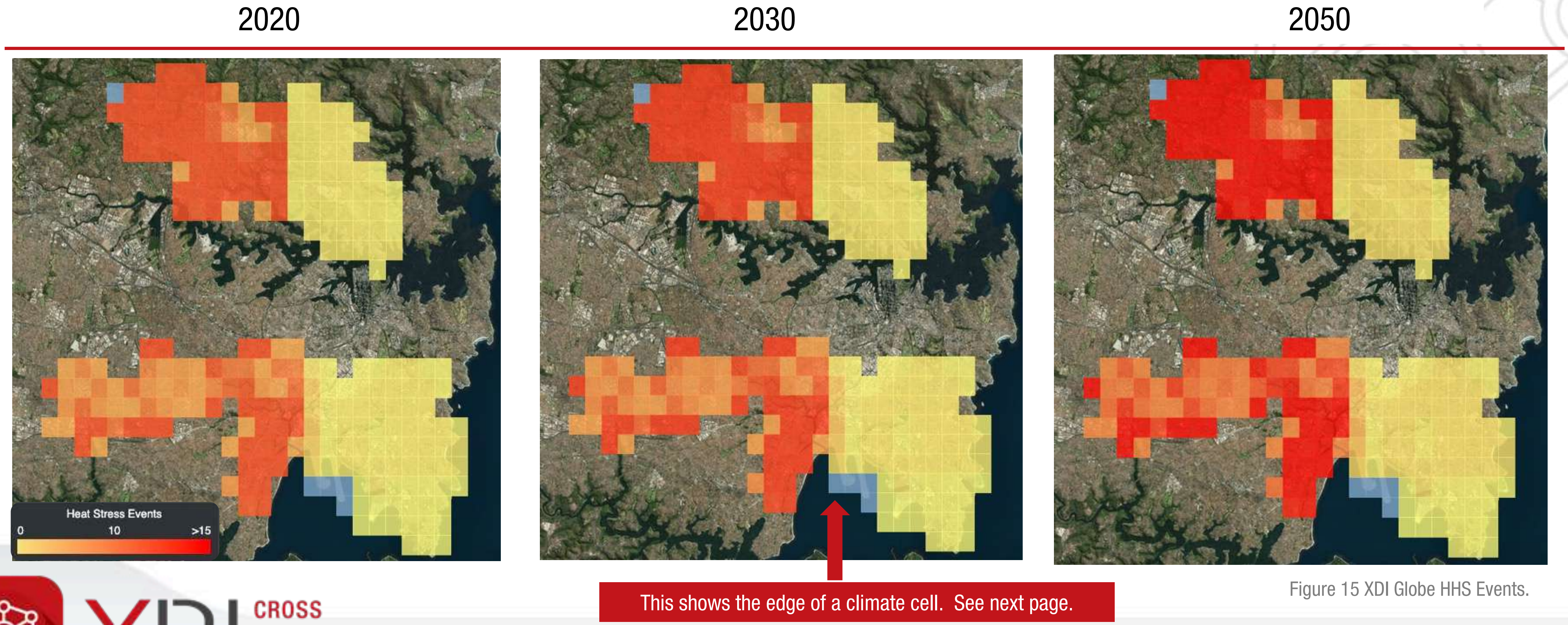
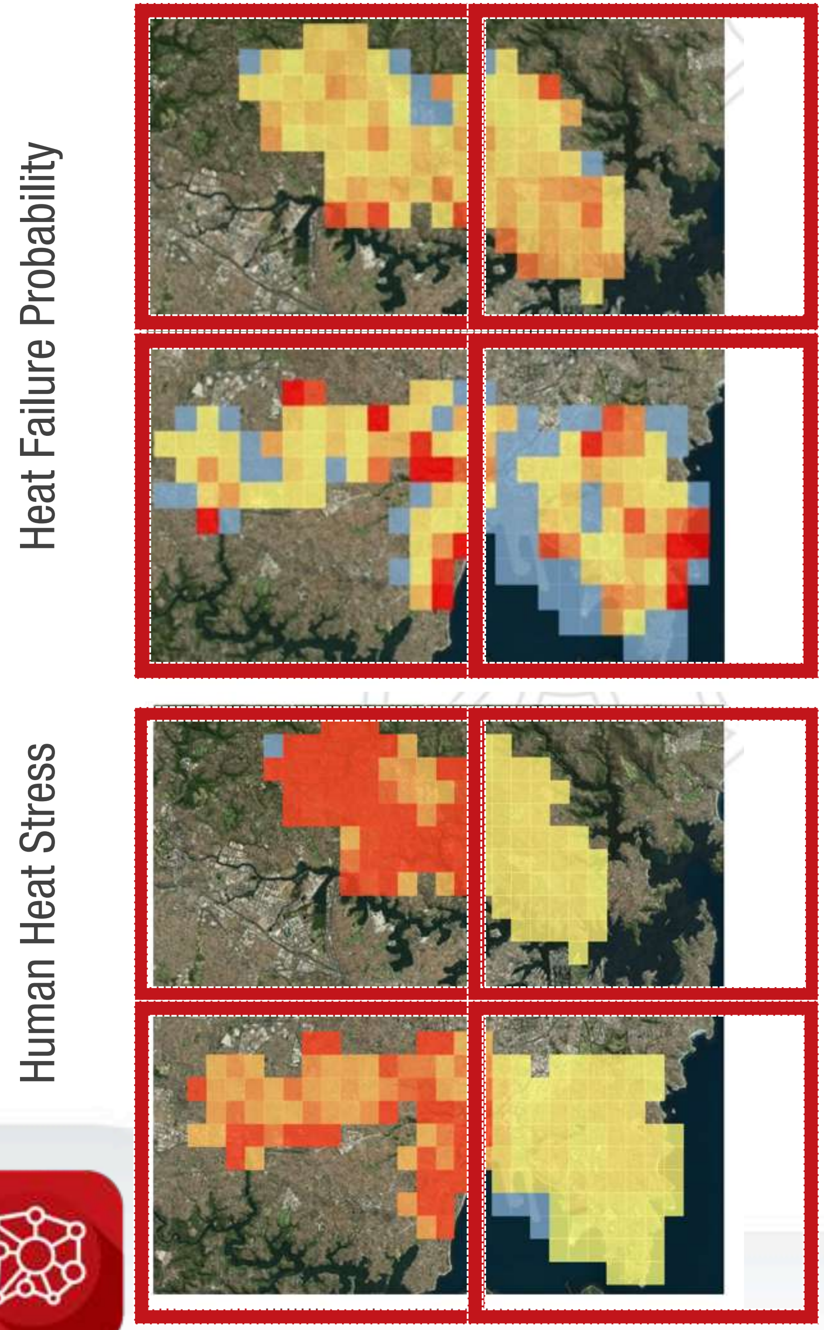


Figure 15 XDI Globe HHS Events.



Climate Cell Variation

Heat Failure Probability (top picture) is quite evenly distributed, whereas Human Heat Stress (bottom picture) shows a clear vertical line, with very little risk on the eastern side. This is explained by the NARCliM downscale grid squares (climate cell) – shown indicatively by the red boxes.

The squares on the right are highly coastal with the strong moderating influence of the ocean, reducing the average number of days over 35°C.

However, days over 40°C in Sydney (temperatures that cause failure) are due to summer winds from the west coming off the hot desert. These are not moderated by the prevailing ocean temperatures and therefore there is not distinction between inland (west) and the coast (east).

Figure 16 XDI Globe Climate Cell Explanation.

HUMAN HEAT STRESS EVENTS INCREASE

The dashed line represents Population B, with the solid line representing Population A.

The average number of HHS person events across the 3 case study areas shows comparatively the Sydenham-Bankstown (SB) case study area has the higher rate of impacted people, followed by Airport Precinct (AP) and then the Macquarie Corridor (MC) for both the Population A results and the Population B results.

The 2050 Population B average HHS person events:

- SB 238,382, ↑ 29% from 2020
- AP 152,436, ↑ 34% from 2020
- MC 94,916, ↑ 29% from 2020

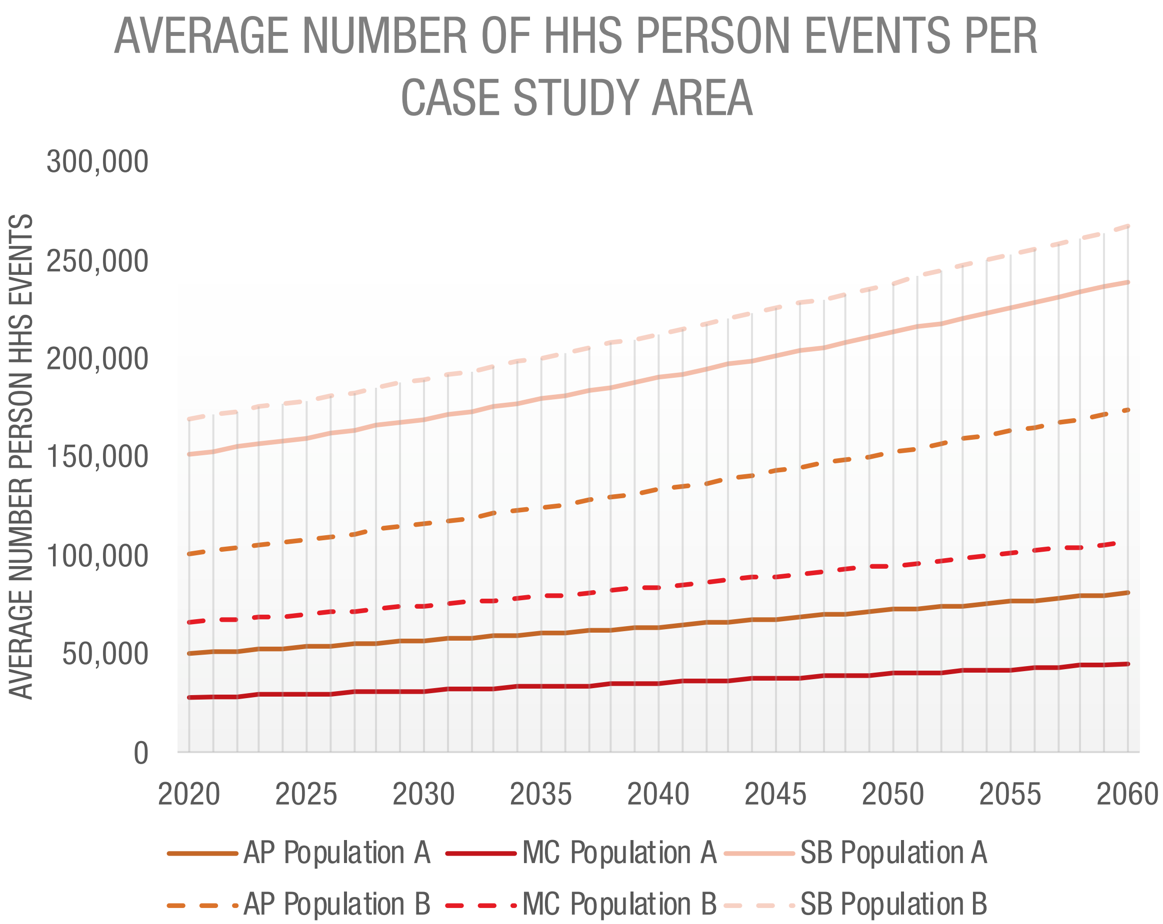


Figure 17 Average HHS per case study area chart over time.

XDI CROSS DEPENDENCY INITIATIVE

ADAPTATION ANALYSIS

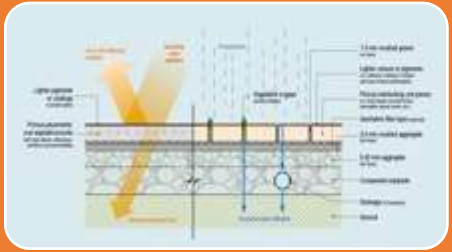
ADAPTATION PLANNING

- Climate Adaptation is acting to mitigate or manage risks and impacts.
- In this section, a number of suitable adaptations have been listed for their ability to reduce current and future human heat stress events, as well as heat failure disruption probability.
- The focus was on adaptation options that are applicable for this project and can utilise Sydney Water's ability to provide water and water infrastructure in the landscape.
- The list of various Adaptation measures has been prepared from the 'Urban Heat Island Mitigation Performance Index' Tool (UHI, 2020). It's not modelled output from this project and was not tested on selected case study areas under this project.
- Existing 'UHI mitigation techniques' include: **cool materials, urban vegetation, water and shading**.
- All naming is consistent with the 'UHI Heat Island Mitigation Performance Index' Tool.
- Please note that the effectiveness of each 'UHI mitigation technique' varies according to the location, urban context (density, scale) and climate zone.

ADAPTATION PLANNING

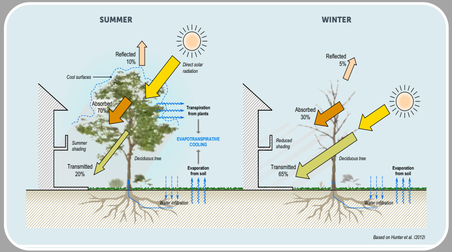
- The adaptations listed are based on ambient temperature reduction, not atmospheric. Ambient Temperature is within the direct vicinity of the adaptation and does not refer to a global temperature reduction e.g. the temperature reduction of standing under a tree, as opposed to standing in direct sunlight.
- The risk reduction analysis was performed from the current time (2020), assuming some of the adaptation can be implemented immediately. If implemented immediately the ambient temperature will decrease by the nominated amount right away.
- Using the XDI Land Use planning method and the research on effective ambient temperature reduction, the analysis adaptation results show a comparison of the different temperature reductions at all locations.
- By showing the different temperature reductions at all locations, the end-user can know how much reduction is effective to reduce the risk on assets and people.
- The desired level of temperature reduction can be achieved through a combination of suitable adaptation measures from the indicative list, based on the suitability of existing land use pattern for any specific grid/area. It’s a helpful indication of future land use planning features to achieve desired outcomes.

ADAPTATIONS EXPLAINED



Cool & Permeable Pavements [1]

- Achieves a 2.5°C direct Ambient Temperature reduction, 2°C Precinct level Ambient Temperature reduction and up to 33°C Surface Temperature reduction.
- Permeable Pavements allows water to drain and evaporate though the urban surfaces. Cool Pavement materials tend to store less heat compared with conventional products. Increased reflectance, emittance and permeability are basic characteristics of cool paving.



Street Trees & Planting [2]

- Achieves a 4°C direct Ambient Temperature reduction, 2°C Precinct level Ambient Temperature reduction and up to 15°C Surface Temperature reduction.
- Tree canopy cover in most of Australia's major cities is less than 20%. An additional 10% tree canopy coverage can be achieved by planting more trees in laneways and residential streets. Street tree canopy can be increased by planting shade trees along footpaths and street medians.

Water Features (Passive) [3]

- Achieves a 4.5°C direct Ambient Temperature reduction and up to 5°C Surface Temperature reduction.
- Passive systems include water bodies and features (i.e. fountains, lakes, rivers, ponds, ocean, marshes, wetlands, etc.) are efficient in reducing surface temperatures during the day (especially large water bodies).
- Passive evaporative cooling is an efficient cooling strategy in cities with dry summer climates.

[1,2,3] Urban Heat Island Mitigation Performance Index' Tool (UHI, 2020)

ADAPTATIONS EXPLAINED

Evaporative Cooling Systems (Active) [4]

- Achieves a 3-8°C Ambient Temperature reduction, 2°C Precinct level Ambient Temperature reduction and up to 15°C Surface Temperature reduction.
- Active systems correspond to evaporative/refrigerate air-conditioners such as multi-stage evaporative coolers, fine water sprays, and misting fans (with or without induced air velocity).

Dry Grasses [5]

- Achieves a 2°C Ambient Temperature reduction and up to 5°C Surface Temperature reduction.
- Natural turfs use similar principles for surface cooling through evapotranspiration. However, unlike trees they do not provide shade, but avoid heat radiation. Dry grasses need little or no irrigation.

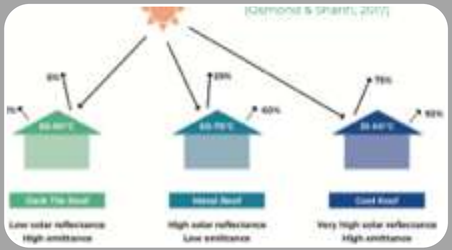
Irrigated Grasses [6]

- Achieves a 4°C Ambient Temperature reduction and up to 15°C Surface Temperature reduction.
- Natural turfs use similar principles for surface cooling through evapotranspiration. However, unlike trees they do not provide shade, but avoid heat radiation. Turf is highly dependent on availability of water for irrigation.

XDI CROSS DEPENDENCY INITIATIVE

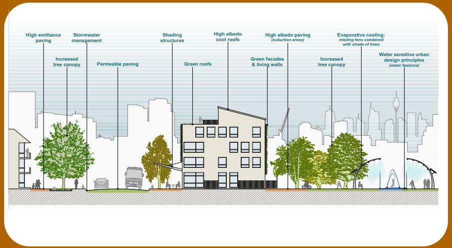
[4,5,6] Urban Heat Island Mitigation Performance Index' Tool (UHI, 2020)

COMBINATION ADAPTATIONS



Cool Roof + Cool pavement [7]

- Achieves a 1.5°C Ambient Temperature reduction.
- An increase of 10% of albedo on roofs can reduce air temperatures between 0.23°C and 0.62°C. Cool roofs can also decrease indoor temperatures of occupied spaces below by 1.2°C to 4.7°C.
- Cool roofs may incorporate Water Sensitive urban Design (WSUD) strategies to harvest rainwater that can be used for irrigation purposes.



Greenery + Cool Pavements + Water + Shading Devices [8]

- Achieves a 5°C Ambient Temperature reduction.
- The design of green open spaces should consider a higher proportion of vegetated spaces including lawn, shrubs, trees, water features, and permeable pavements than impervious surfaces.

Greenery + Green open spaces (grasses) [9]

- Achieves a 7°C Ambient Temperature reduction.
- In large open spaces, scattered trees should be preferably placed over or near vegetated surfaces with adequate irrigation.

XDI CROSS DEPENDENCY INITIATIVE

[7,8,9] Urban Heat Island Mitigation Performance Index' Tool (UHI, 2020)

ADAPTATION COMPARISON

The Adaptations from the Adaptation Explained section are listed below. The green tick ✓ indicates the cooling amount (ambient temperature reduction) that adaptation achieves in total. The subsequent Adaptation Results section correspond with the cooling amounts.

Adaptations	2°C	4°C	7°C
Cool & Permeable Pavements	✓	✗	✗
Street Trees & Planting	-	✓	✗
Water Features	-	✓	✗
Evaporative Cooling Systems	-	✓	✓
Grasses Dry	✓	✗	✗
Grasses Irrigated	-	✓	✗
Cool Roof + Cool pavement **	✓	✗	✗
Greenery + Cool Pavements + Water + Shading Devices **	-	✓	✗
Greenery + Green open spaces (grasses)**	-	-	✓

LEGEND

✓ ACHIEVE

✗ DOES NOT ACHIEVE

** Combination approaches may require collaborative adaptation planning between multiple stakeholders

XDI CROSS DEPENDENCY INITIATIVE

ADAPTATION RESULTS – 2°C Reduction on Failure

The adaptation analysis of a 2°C reduction on failure risk shows in the year 2050 heat failure is still a significant issue.

2020 | 2030 | 2050

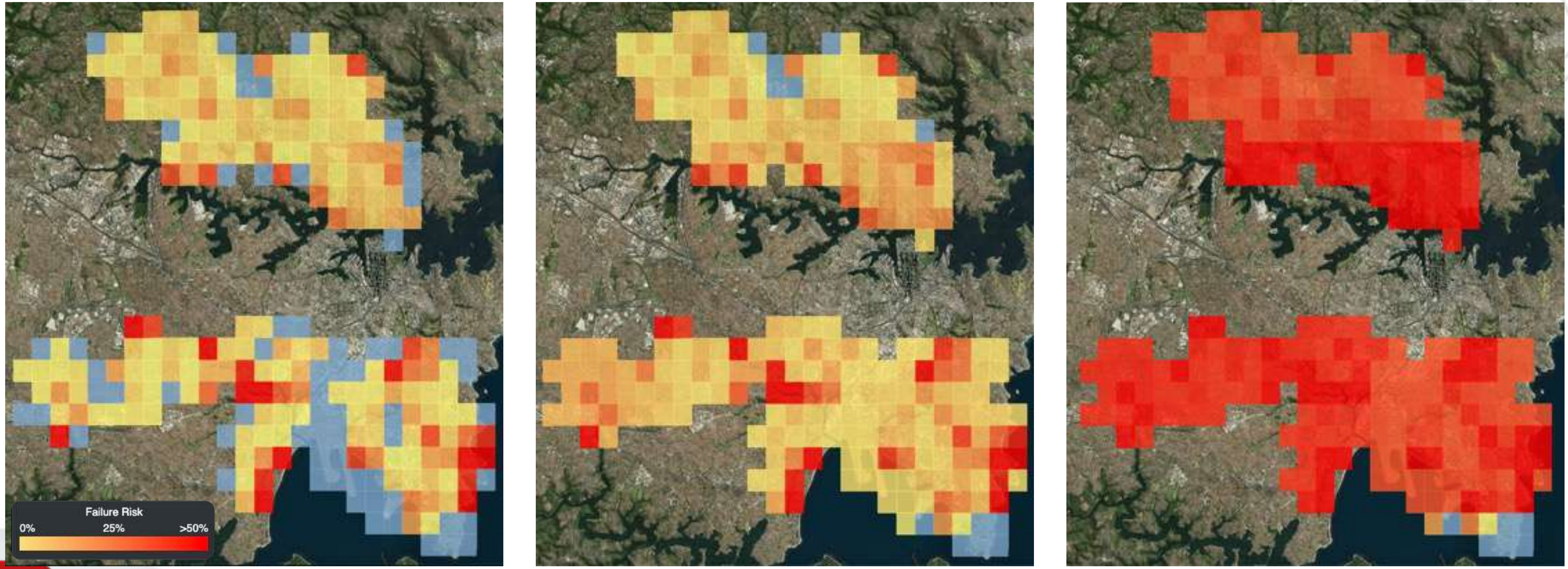


Figure 18 XDI Globe Heat FP% - 2°C Adaptation.

ADAPTATION RESULTS – 4°C Reduction on Failure

The adaptation analysis of a 4°C reduction on failure risk shows in the year 2050 heat failure has drastically reduced compared to the baseline and the 2°C reduction on failure risk.

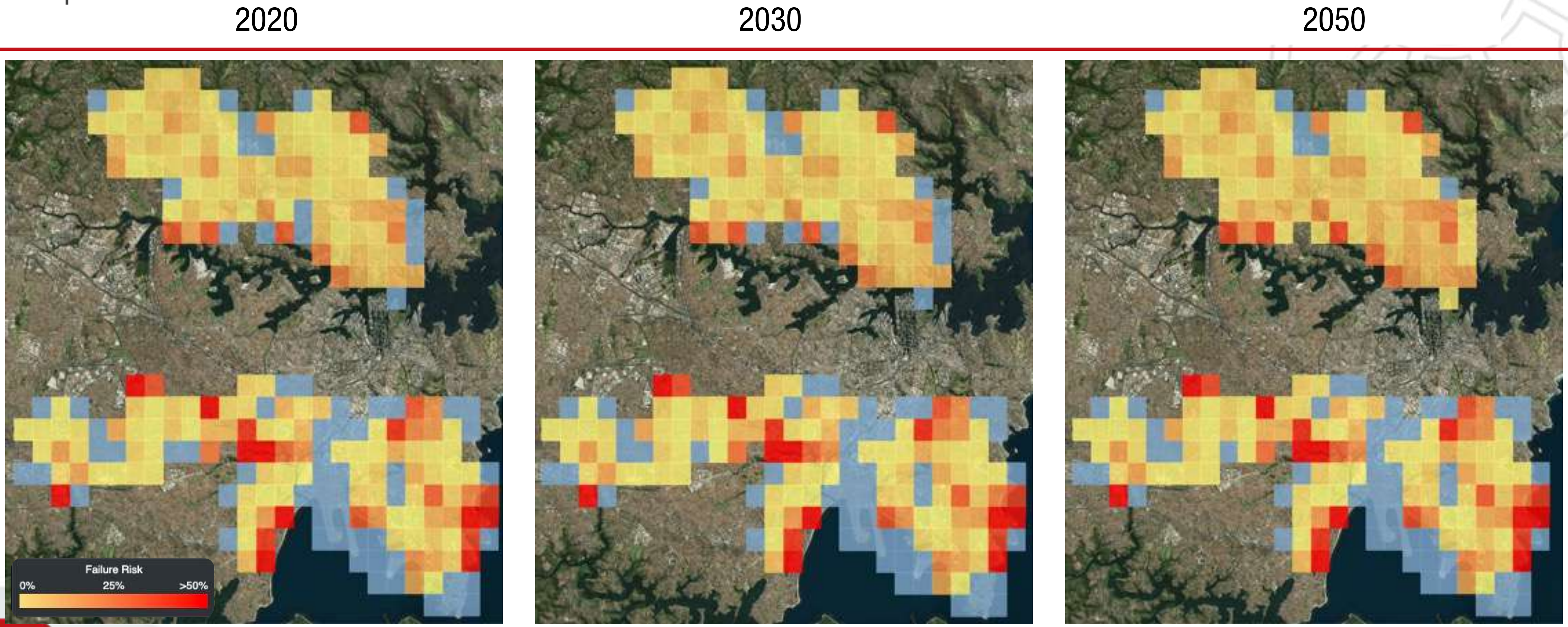


Figure 19 XDI Globe Heat FP% - 4°C Adaptation.

ADAPTATION RESULTS – 7°C Reduction on Failure

The adaptation analysis of a 7°C reduction on failure risk shows in the year 2050 a low heat failure across the majority of all 3 case study areas.

2020 | 2030 | 2050

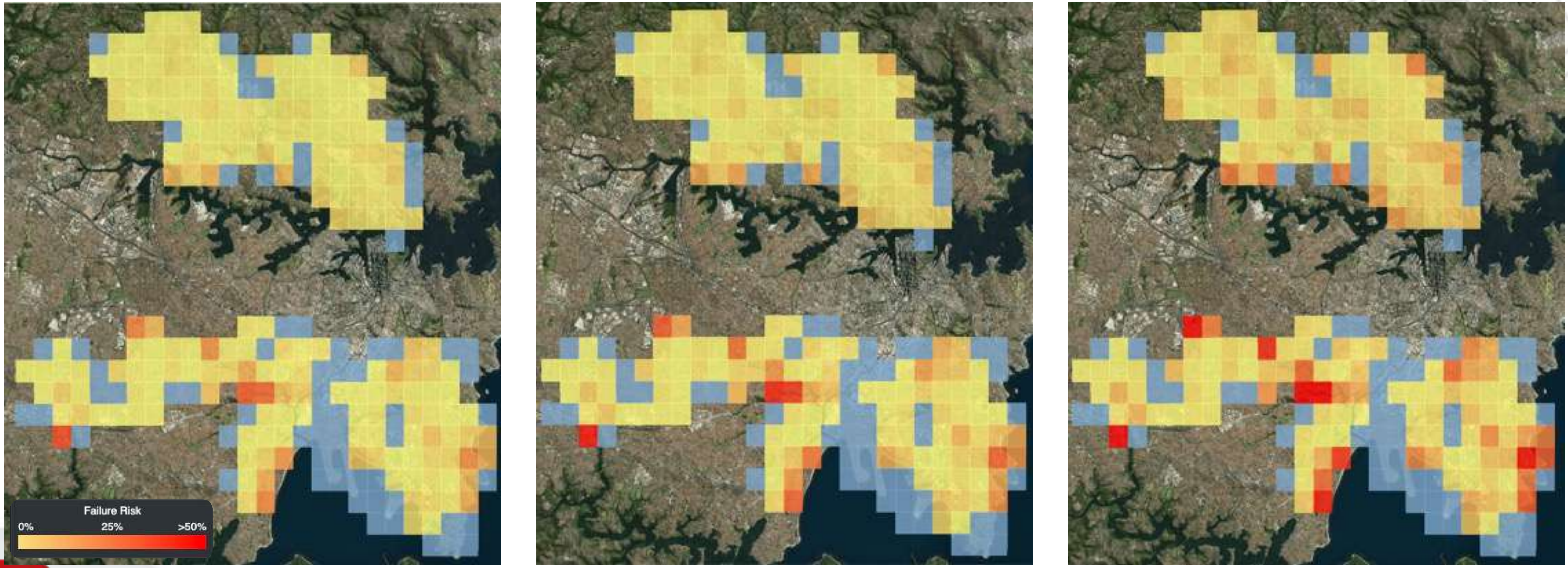


Figure 20 XDI Globe Heat FP% - 7°C Adaptation.

XDI CROSS DEPENDENCY INITIATIVE

ADAPTATION RESULTS
Heat Failure Comparison

The Adaptation comparison shows a minimum of 4 °C reduction is required in all 3 case study areas to ensure low failure risks in 2050.

It also highlights hotspots in the Sydenham-Bankstown and Airport Precinct that even in the 7°C reduction scenario, still return significant heat failure.

These areas, highlighted in black, may need further adaptation planning and responses.

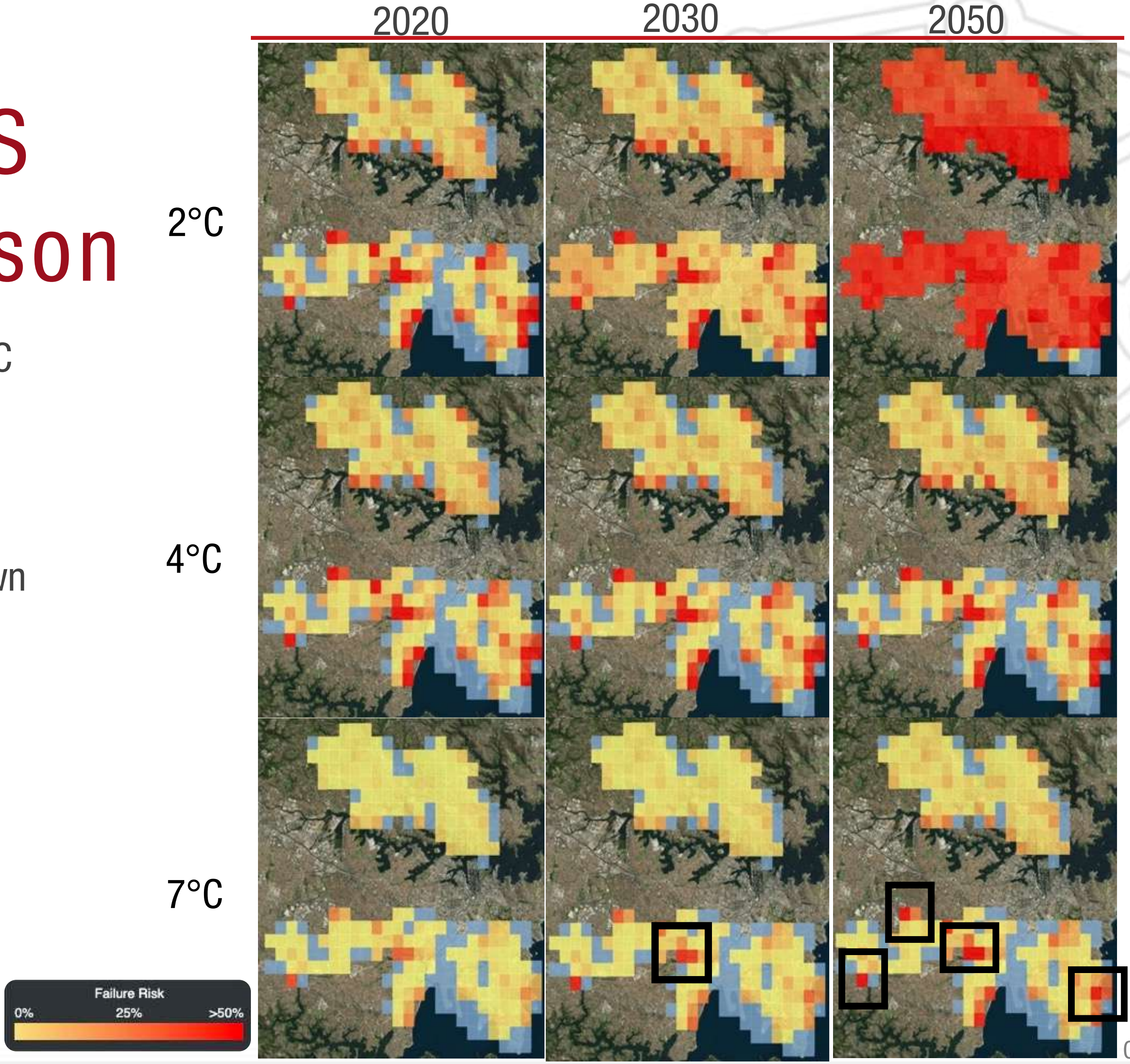


Figure 21 XDI Globe Adaptation Comparison.

ADAPTATION RESULTS 2050
Heat Failure Comparison

If we compare the 2050 Heat Failure Probability baseline results with the adaptation measures, overall the 7°C adaptation creates the most reduction across all 3 case study areas.

There are significant enough reductions using the 4°C adaptation for the Macquarie Corridor overall, especially the area highlighted by the black box. 4°C adaptation could also have a positive impact in targeted areas of the Airport precinct and Sydenham-Bankstown, as indicated by the yellow and light orange grid squares.

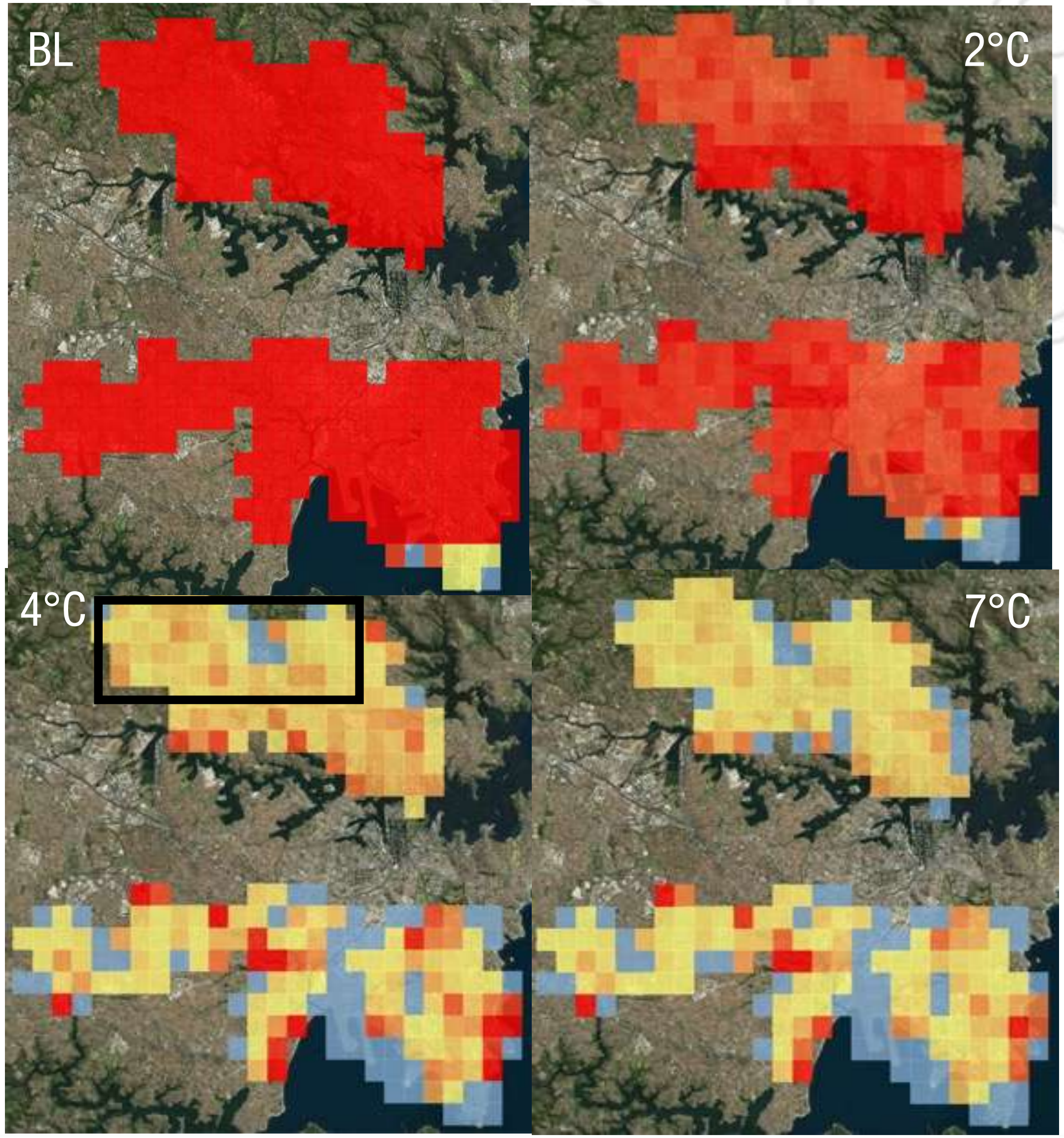


Figure 22 XDI Globe Adaptation Comparison, 2050 only.

HUMAN HEAT STRESS EVENTS INCREASE

There is a strong influence of climate change leading to more HHS events. Adaptation is therefore required to mitigate these impacts.

The average number of people impacted across the 3 case study areas increases by 42% for Population A over the period from 2020 to 2050, and increase by 45% for Population B over the same period.

Adaptation actions can reduce HHS events by approximately 48%.

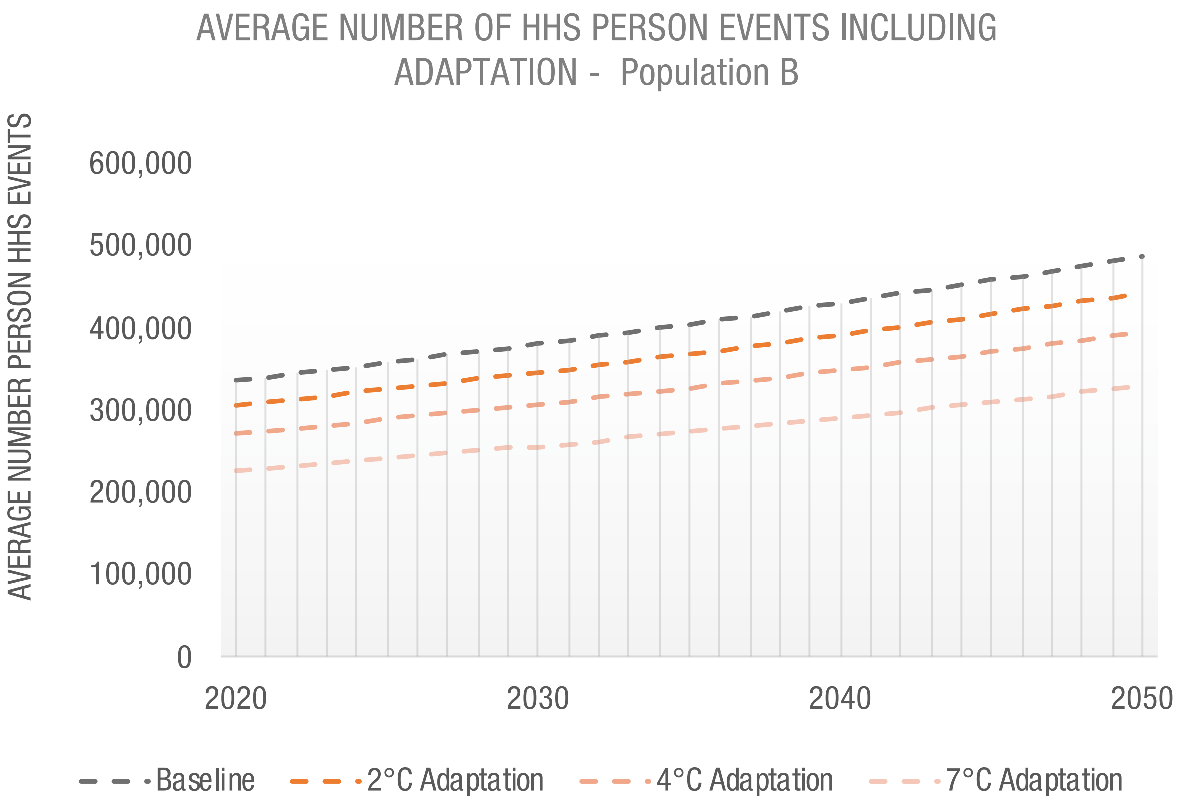


Figure 27 Population B Human Heat Stress events adaptation over time for all case areas.

HUMAN HEAT STRESS PER PERSON – 2°C ADAPTATION

The adaptation analysis of a 2°C reduction in ambient temperatures doesn't reduce the Heat Stress Events per person enough.

2020	2030	2050

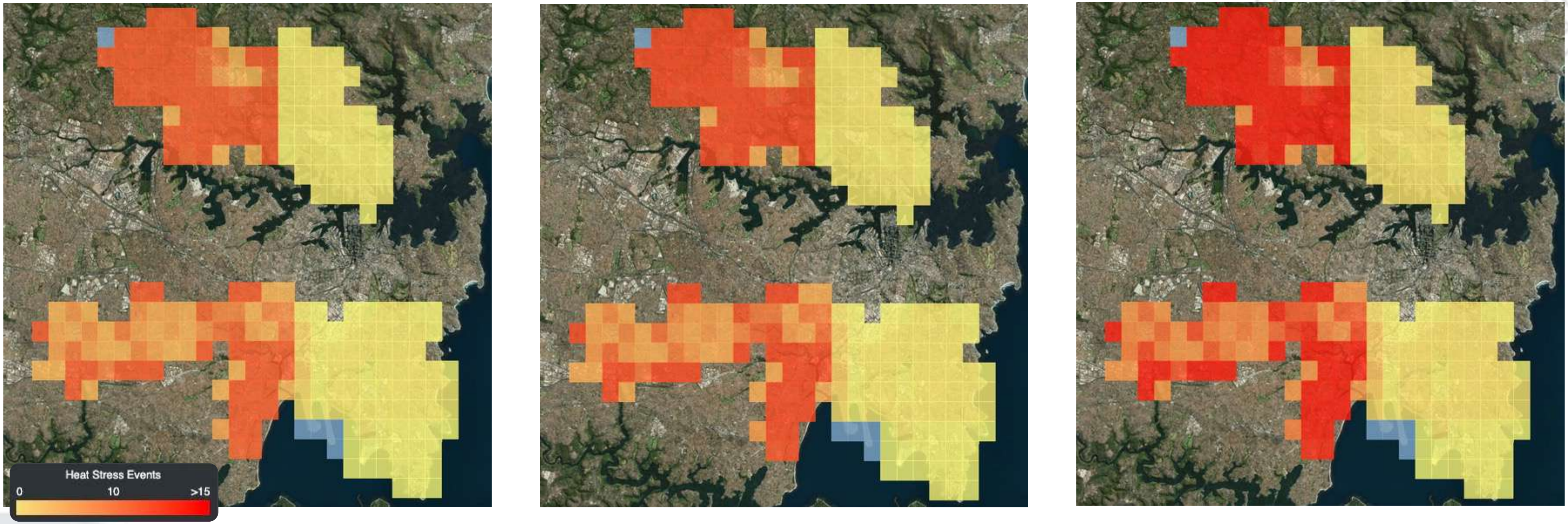


Figure 23 XDI Globe HHS Events - 2°C Adaptation.

HUMAN HEAT STRESS PER PERSON – 4°C ADAPTATION

The adaptation analysis of a 4°C reduction in ambient temperatures begins to reduce the Heat Stress Events per person.

2020 2030 2050

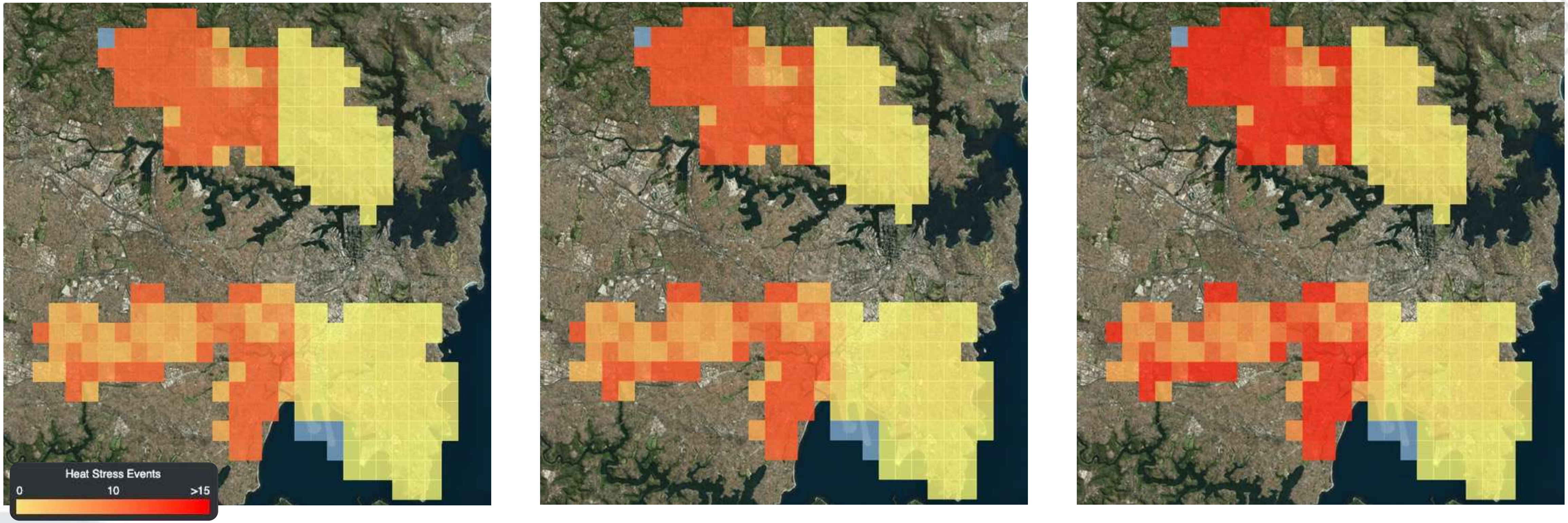


Figure 24 XDI Globe HHS Events - 4°C Adaptation.

HUMAN HEAT STRESS PER PERSON – 7°C ADAPTATION

The adaptation analysis of a 7°C reduction in ambient temperatures decreases the Heat Stress Events per person significantly, but there are still some substantial areas of impact.

2020 2030 2050

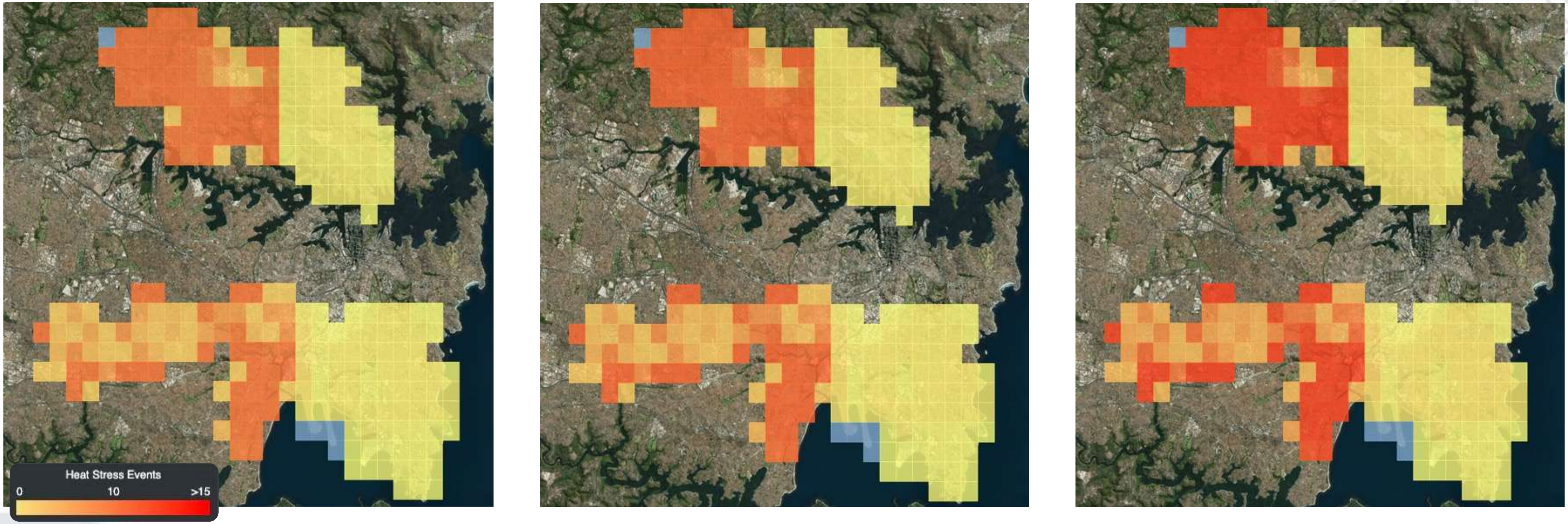


Figure 25 XDI Globe HHS Events - 7°C Adaptation.

ADAPTATION COMPARISON - HHS Events Adaptations

Shown are the Adaptation results for HHS person events in the years 2020, 2030 and 2050. The western side of the case study areas has a higher impact than the eastern side – as per the climate primer.

The 7°C heat change adaptation goes a long way toward reducing the impact in 2020 and 2030, but in 2050 the heat stress impact still increases, especially in the Macquarie Corridor.

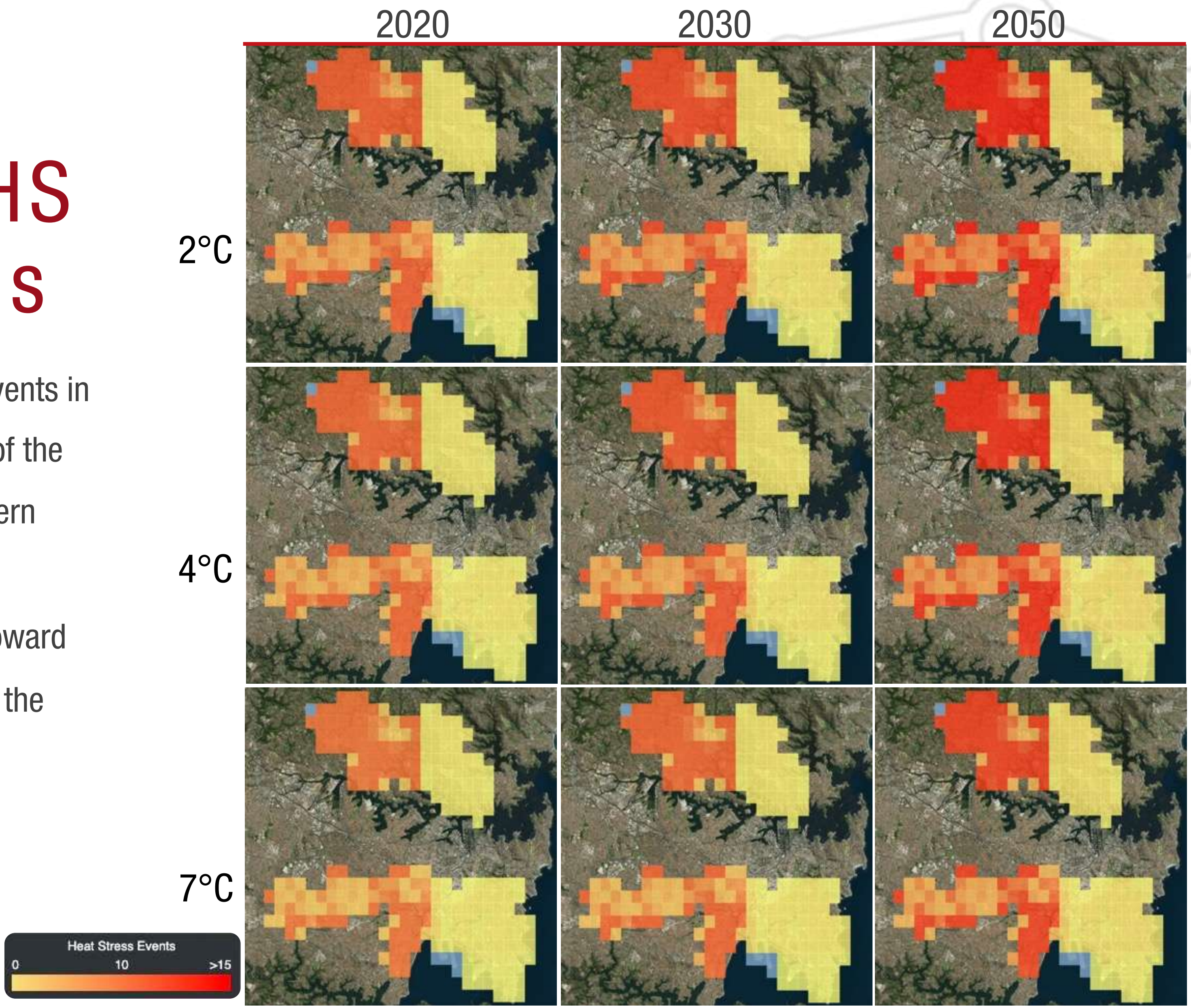


Figure 26 XDI Globe HHS Events Adaptation Comparison.

ADAPTATION ACTIONS BY AREA

The images to the right show the Baseline, 2°C adaptation, 4°C adaptation, 7°C adaptation for Population A (solid line), and Population B (dashed line). Population B is always greater than Population A as there are more people to be impacted.

- Across all adaptation options (including baseline) there is a strong influence of climate change leading to more heat stress events.
- As the level adaptation increases, the HHS person events decreases, to the point where the 7°C adaptation in the year 2050 for Sydenham-Bankstown is less than the Sydenham-Bankstown Baseline in the year 2020 for both the Population A (~150,000) and Population B (~170,000).

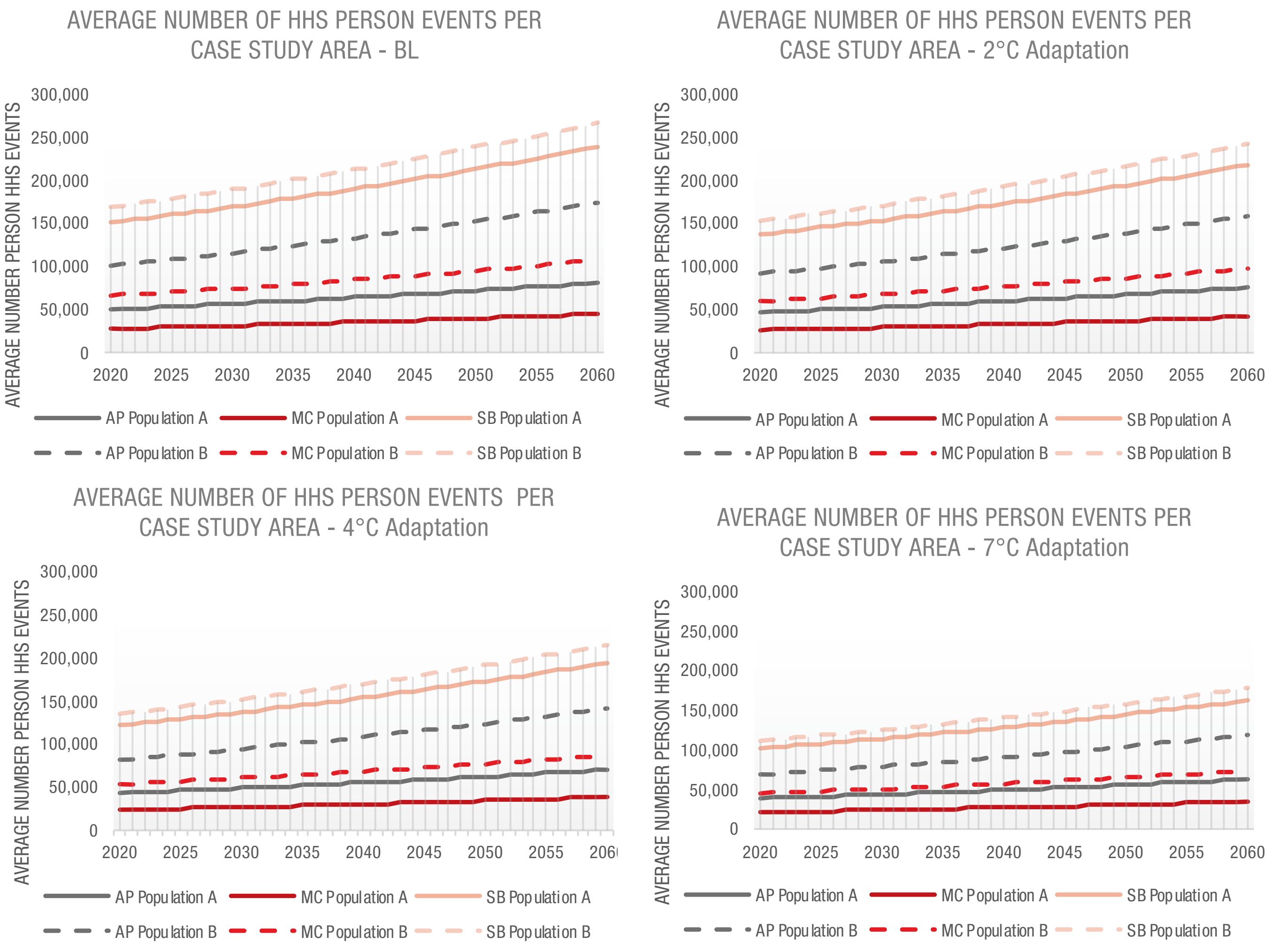


Figure 28 HHS adaptation chart comparisons over time.

CAN URBAN COOLING BE COST EFFECTIVE?

CONFIDENTIAL

IS URBAN COOLING COST EFFECTIVE?

Urban cooling can pay for itself 3 times over in avoided acute health costs alone. Further work should be undertaken to quantify the additional economic value.

COSTS

Urban cooling initiatives vary. Urban forests can be used in any street and has therefore been chosen to use as an example.
The annual cost of growing and maintaining an urban forest per year is about $13,000/KM^2. So an urban forest across all case study areas in the Eastern Sydney Region would cost $2.9m per year (including 25KL of water for irrigation).

ACUTE HEALTH BENEFITS

If we look only at the costs of acute health impacts – i.e. people calling an ambulance and going to hospital due to severe heat stress. A 4^{o}C urban cooling would avoid average $9.5m per year in hospital and ambulance costs across the 3 case study areas.

ADDITIONAL $ BENEFITS

There are a range of further financial benefits to the economy that would increase the return on investment for urban cooling. Including the avoidance of:

- ✓ Reduced work productivity
- ✓ Building cooling costs
- ✓ School and factory closures
- ✓ Reduced street trade
- ✓ Exacerbated Isolation & mental health

ASSOCIATED COSTS – URBAN FOREST

Moreland Council's Urban Forest Strategy[10] allocated budget for planting and maintaining its urban forest in 2017 was \$1million over a total area of 77.83km². We can estimated at \$12,848 per year for the cost of planting and maintaining a km² of urban forest.

The case study areas in the Eastern Sydney Region cover approximately 222.5km². Therefore, the estimated amount for planting and maintaining an urban forest across all case study areas is \$2,858,795/year.

Additionally, the total area would require irrigation. A study on water footprint of urban green spaces in Adelaide[11] notes that 111.4KL/km² of water consumption is required by urban greenery. Therefore, an estimated 25,000KL of water per year would be required across all 3 case study areas. Using Sydney Water recycled water cost of \$1.86/KL[12] for 25,000 KL/year, urban greening of this scale would cost approximately \$47,000/year.

[10] City of Moreland (2017)

[11] Nouri H., Borujeni S.C., & Hoekstra A.Y. (2019)

[12] Sydney Water (2020)

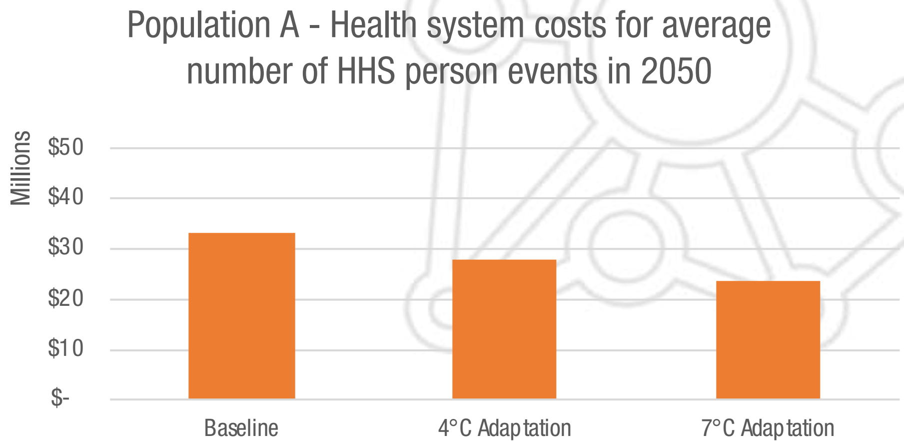
ASSOCIATED COSTS- HEALTH SYSTEM

Ambulance services NSW estimates a 2% likelihood of an individual being placed in an ambulance[13] during Heat Stress Events. The cost associated with an ambulance call out in NSW is $392[14] and the acute hospital fees are $4,680[15] per person.

The associated health system costs for Population A and B in 2050 can therefore be calculated by multiplying the 2% likelihood and the corresponding health costs, by the number of HHS events. Additionally, we can calculate the corresponding savings associated with the baseline analysis and the adaptation options.

	Population A		Population B	
Baseline	$ 33,324,593		$ 49,876,792	
4ºC	$ 27,696,866	(-$5,627,727)	$ 40,394,369	(-$ 9,482,423)
7ºC	$ 23,764,889	(-$9,559,704)	$ 33,735,509	(-$16,141,283)

NOTE: 2ºC not shown because urban forest corresponds to a minimum of 4ºC adaptation.



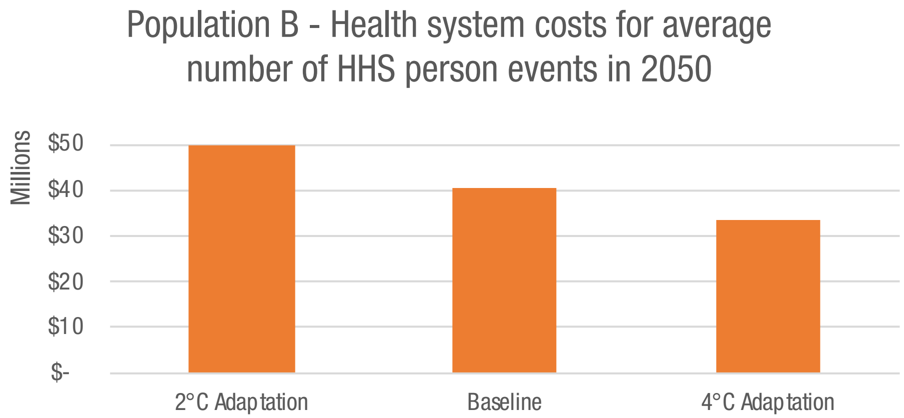


Figure 29 Population A and B average costs in million for BL, 4ºC and 7ºC.

[13] Australian Government Productivity Commission (2018)

[14] NSW Ambulance (2020)

[15] CANSTAR (2020)

URBAN FOREST AVOIDED COST PER CASE STUDY AREA

In 2050 for the 3 case study areas, 4°C Urban Forest Adaptation for Population B can **avoid a total** of $9.4m:

- $2,870,428 in the Airport Precinct area,
- $1,768,954 in the Macquarie Corridor area, and
- $4,735,802 in the Sydenham Bankstown area.

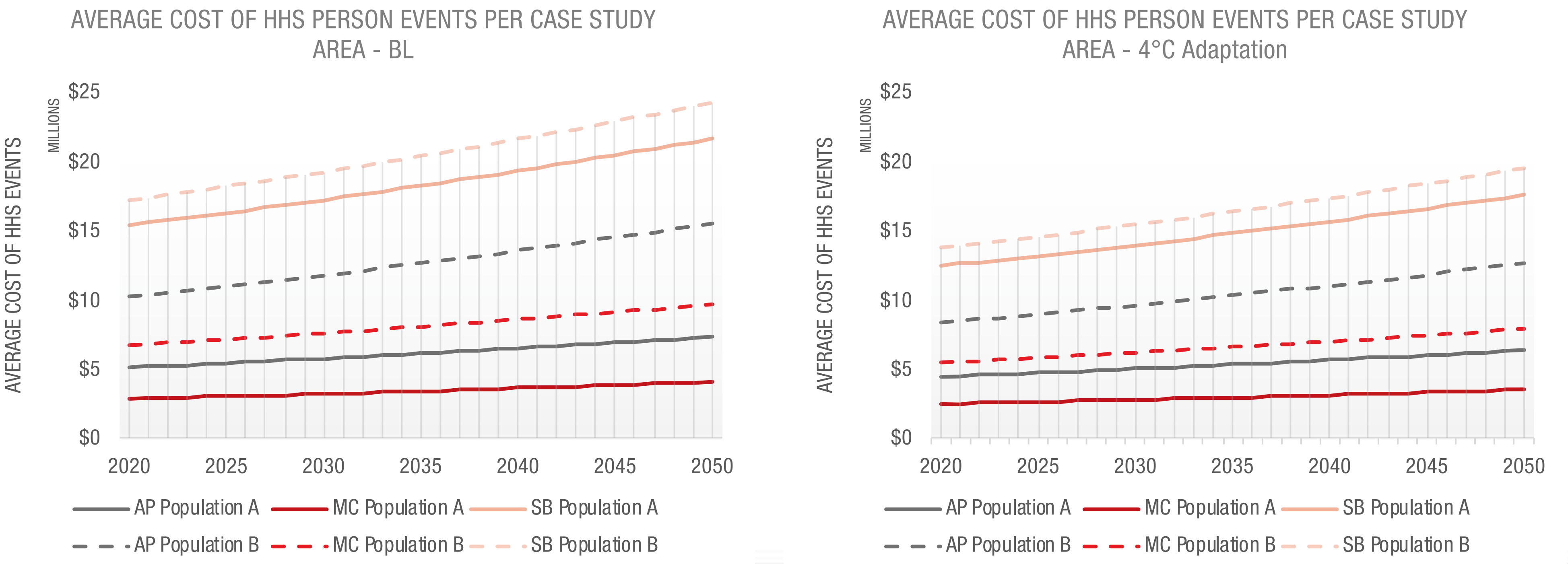


Figure 30 Cost Comparison of BL and 4°C Adaptation for each case study area.

RECOMMENDATIONS

RECOMMENDATIONS FOR SYDNEY WATER

Increasing urban heat is already resulting in adverse impacts on human health and asset performance in Eastern Sydney. These impacts are only going to intensify in future unless ambient temperatures are reduced significantly through implementation of heat adaptation measures. It is recommended that Sydney Water consider the following:

1. Any adaptation planning to reduce heat needs to aim to reduce ambient heat by a minimum of 4°C, where possible. Certain localised hotspots will require ambient heat reduction of more than 7°C to reduce heat-related impacts.

2. The selection of effective adaptation measures for localised application will require area-specific consideration based on the existing land-use pattern i.e. to reduce the temperature of Sydney Airport area (existing land use – impermeable paved area), a combination adaptation measure such as *Greenery + Cool & Permeable Pavements + Water + Shading Devices*, should be considered to achieve at least 4°C temperature reduction. For effective temperature reduction, this will require targeted and detailed land use planning, starting in the early stages of any proposed development.

3. Relevant agencies need collaborate on implementing adaptations. There is an opportunity for Sydney Water to actively support the water requirements for any adaptation measures e.g. water features or irrigated surfaces, which will have an immediate and effective reduction of the heat and heat-related impact in the Eastern Sydney region.

4. Design standards should stipulate that all new Sydney Water assets require a minimum temperature design threshold of 45°C to address the risk of heat failure disruption. Existing Sydney Water assets should be retro-fitted to a minimum of 45°C during standard maintenance cycles.

THE WAY FORWARD

The ‘Adapting the East’ report has outline a number of risks and adaptation measure that can be incorporated into planning works to ensure that the Eastern Sydney region is a safe, insurable and valuable area for living and working in the future.

- Detailed land use planning to incorporate site-appropriate adaptation to achieve the desired level of temperature reduction.
- Engage other agencies such as GSC and DPIE to further disseminate results & engage relevant authorities in collaborative adaptation planning.
- Conduct detailed Cost-Benefit Analysis for all adaption options, failure costs and avoided costs.
- Seek out collaborative adaptation opportunities where the costs can be split amongst multiple agencies where multiagency benefit is found.
- Sydney Water to raise awareness of temperature related risks in proposed developments and make proactive suggestions on ways to protect future residents by actively promoting adoption of temperature reduction adaptations that reduce risk.

APPENDIX

APPENDIX

1. Reporting
   - Glossary & Terms
   - Sources
   - References
2. Assumptions
   - Limitations from scope
   - Adaptations Temperatures
   - Adaptations Explained
3. Methodology
   - Climate projections
   - Archetypes
   - Human Heat Stress

APPENDIX

1. REPORTING

GLOSSARY & TERMS

- AMBIENT TEMPERATURE - The temperature of the air surrounding a component.
- ARCHETYPE – An Archetype is a representative asset that is based on nominal industry standard building codes and designs.
- ASSET – A piece of infrastructure at a location e.g. a pump station or a segment of road.
- BoM – Bureau of Meteorology
- GCM – Global Circulations Model
- HEAT – Extreme heat temperatures exceeding thresholds such as operational scope, causing failure.
- FAILURE PROBABILITY – Annual Probability that an asset will stop working with or without damage.
- HUMAN HEAT STRESS – Heat stress occurs when our body is unable to cool itself enough (e.g. through sweating) to maintain a healthy temperature.
- IPCC AR5 – Intergovernmental Panel on Climate Change Fifth Assessment Report
- NARCliM – NSW and ACT Climate Model Project is a research partnership between the NSW and ACT governments and the Climate Change Research Centre at the University of NSW. The NSW partners include Sydney Water, Sydney Catchment Authority, Hunter Water, NSW Department of Transport, NSW Department of Primary Industry and NSW Office of Water.
- RCM – Regional Circulation Model
- RISK FRACTION (also referred to as Value at Risk (VAR%)) – Total Risk Cost per year divided by the total asset value.

Sources

Data provided by Sydney Water

No	File Name	Date provided	File Description
1	Airport Precinct.TAB	16/1/20	CS area
2	ECON Corridor Suburbs_ac.TAB	16/1/20	
3	Final_Growth_data.TAB	16/1/20	population
4	GreenGridLinks_01pl_190219.TAB	16/1/20	
5	GreenGridLinksTopTen_01pl_190108.TAB	16/1/20	
6	Macquarie corridor.TAB	16/1/20	CS area
7	RE1ZonedLand_01pg_190219.TAB	16/1/20	asset type
8	RE2ZoneLand_01pg_190219.TAB	16/1/20	asset type
9	Sydney Bankstown corridor.TAB	16/1/20	CS area
10	TreeCanopy_01pg_190219.dTAB	16/1/20	
11	Naturalisation_Opportunities.TAB	23/1/20	
12	Potential Naturalisation Opportunities.TAB	23/1/20	
13	Sydney Water Naturalisation Planned projects_point.TAB	23/1/20	
14	Consolidated_UGI_HSGM_BTS.TAB	23/1/20	

External data sources

No	File Name	Date Sourced	File Description
15	SurfaceHydrologyPolygonsRegional.gdb	15/1/2020	Surface water hydrology for Australia
16	2019 NSW Pop Project LGA.xlsx	20/1/2020	Excel Population file
17	2019 Population Forecast for SA2.xlsx	6/1/2020	Excel Population file

XDI CROSS DEPENDENCY INITIATIVE

REFERENCES

Australian Government Productivity Commission (2018), Report on Government Services 2018; PART E, CHAPTER 11: Ambulance services 2018, https://www.pc.gov.au/research/ongoing/report-on-government-services/2018/health/ambulance-services

Barnett, G., Beaty, M., Chen, D., McFallan, S., Meyers, J., Nguyen, M., Ren, Z., Spinks, A., and Wang, X. (2013). Pathways to climate adapted and healthy low income housing. CSIRO report to NCCARF. https://www.nccarf.edu.au/sites/default/files/attached_files_publications/Barnett_2013_Climate_adapted_low_income_housing.pdf

CANSTAR (2020), How much does it cost to stay in hospital in Australia?, https://www.canstar.com.au/health-insurance/hospital-stay-cost/

City of Moreland (2017), Urban Forest Strategy 2017-2027, https://www.moreland.vic.gov.au/globalassets/key-docs/policy-strategy-plan/urban-forest-strategy-2017.pdf

Darryn McEvoy, Iftekhar Ahmed & Jane Mullett (2012) The impact of the 2009 heat wave on Melbourne's critical infrastructure, Local Environment, 17:8, 783-796, DOI: 10.1080/13549839.2012.678320

Hughes, L., McMichael, T., Australia, Department of Climate Change and Energy Efficiency. Climate Commission, 2011. The critical decade climate change and health.

Moreland Energy Foundation; MEF (2017), Solar and Retrofit Study. Melbourne: Point Advisory, pp.10-20.

Nouri H., Borujeni S.C., & Hoekstra A.Y. (2019), The blue water footprint of urban green spaces: An example for Adelaide, Australia, https://www.sciencedirect.com/science/article/pii/S0169204618304754

NSW Ambulance (2020), NSW Government Accounts & Fees, https://www.ambulance.nsw.gov.au/our-services/accounts-and-fees

Osmond, P., & Sharifi, E. (2017). Guide to Urban Cooling Strategies. Sydney. http://www.lowcarbon-livingcrc.com.au/sites/all/files/publications_file_at-tachments/rp2024_guide_to_urban_cooling_strate- gies_2017_web.pdf

PwC (PriceWaterhouseCoopers) (2011) Protecting human health and safety during severe and extreme heat events: A national framework. Report by PriceWaterhouseCoopers Australia for the Commonwealth Government, November 2011. Accessed at http://www.pwc.com.au/industry/government/assets/extreme-heat-events-nov11.pdf.

Stull, R. (2011). Wet-bulb temperature from relative humidity and air temperature. Journal of applied meteorology and climatology, 50(11), 2267-2269.

Sydney Water (2020), Prices for your business 2019-20, http://www.sydneywater.com.au/SW/accounts-billing/understanding-your-bill/prices-for-your-business/index.htm

Sydney Water. (2017). Cooling Western Sydney: A stra- tegic study on the role of water in mitigating urban heat Western Sydney. Sydney. The University of New South Wales, Sydney Water, CRC Low Carbon Living. https://www.sydneywater.com.au/web/groups/pub-licwebcontent/documents/document/zgrf/mty4/~e- disp/dd_168965.pdf

UHI (2020), CRC Urban Heat Island; Mitigation Performance Index, http://uhimitigationindex.be.unsw.edu.au/

APPENDIX

2. ASSUMPTIONS

ASSUMPTIONS – Limitations From Scope

- Does not cover coincident events such as 3 day heat events.
- All adaptations assume implementation from 2020 whereas in reality these mitigation measures take varied amounts of time to build and implement.
- Density increase between 2020 and 2050 population changes has been considered using increases in people present in the assets, not directly by increasing the number of assets used in the land-use planning method.

ASSUMPTIONS – ADAPTATION TEMPERATURES

Cool Roof + Cool pavement

- Maximum ambient temperature reduction between 0.35 and 0.91 °C [Green Future 2015].
- Average ambient temperature reduction up to 1.43 °C [Green Future 2015].

Greenery + Cool Pavements + Water + Shading Devices

- Maximum ambient temperature reduction between 1.4 and 5.8 °C [Green Future 2015].
- Average ambient temperature reduction between 0.6 and 2.4 °C [Green Future 2015].

Greenery + Green open spaces (grasses)

- Maximum ambient temperature reduction between 0.7 and 7.0 °C [Green Future 2015].
- Average ambient temperature reduction up to 3.7 °C [Green Future 2015].

Evaporative Cooling Systems

- Increased evaporative cooling should be strategically provided in public spaces by implementing passive and active systems. Passive systems include the provision of tree plantings and water features (fountains, lakes, ponds, rivers, etc.), while active systems correspond to evaporative/refrigerate air-conditioners such as multi-stage evaporative coolers, fine water sprays, and misting fans (with or without induced air velocity). The latter have proved effective in more humid regions [Koc 2018, CRC 2017].

Cool & Permeable Pavements

- An increase of 10% of albedo can reduce ambient temperatures between 0.27 °C and 0.9 °C [Santamouris et al. 2017].
- An increase of 10% of albedo of impervious surfaces can decrease daytime surfaces temperatures up to 0.18°C and night-time temperatures up to 0.22 °C [Matthias 2014].
- Cool pavements can decrease ambient temperatures up to 2.0 °C [CRC 2017].
- Cool pavements can reduce surfaces temperatures up to 33.0 °C while permeable paving up to 20.0°C [CRC 2017].

Street Trees & Planting

- Street trees can decrease ambient temperatures up to 4.0 °C [CRC 2017].
- Urban trees and hedges can cause a peak ambient temperature reduction between 0.1 and 7.0°C and a median maximum temperature drop of 1.5°C [Santamouris et al. 2017].
- Surface temperatures of well-irrigated grasses can be up 15.0 °C cooler than surrounding paved areas, while dry grasses only up to 5.0 °C [Koc 2018, CRC 2017].
- An increase of 10% in tree canopy cover can decrease diurnal surface temperatures up to 1.05 °C in summer and 0.25 °C in winter [Koc 2018].

Water Features

- Surface/running water can decrease surface temperatures by at least 5.0 °C [CRC 2017].
- An increase of 10% in the area of water surfaces can decrease daytime surface temperatures between 0.86 and 1.37 °C and increase night-time surface temperatures between 0.15 and 0.39 °C [Koc 2018].
- Water features can achieve a peak temperature reduction close to 4.5 °C [Koc 2018].

SOURCE: UHI 2020 http://uhimitigationindex.be.unsw.edu.au/mitigation/index.html#

ASSUMPTIONS – ADAPTATIONS EXPLAINED

Street Trees & Planting

Street trees and plants can positively moderate the urban microclimate of urban canyons and significantly reduce surface and ambient temperatures and improve outdoor thermal comfort. Nevertheless, a unique design, pattern and palette of tree plantings should respond to particular characteristics (i.e. street orientation, level of pedestrian activity, sense of place, character, and type of surrounding activities/uses) and street sections (i.e. widths and heights of frontages). Accordingly, five 'planting schemes' have been generally defined according to typical urban areas found in cities [City of Adelaide 2019]:

1. Civic and commercial streets
2. Mixed-used streets
3. Suburban streets
4. Industrial streets
5. Historic streets

In addition, three main planting types with anticipated canopy covers are proposed as general guidelines to accommodate trees according to street sections, available space for plantings (considering ground, underground and overhead constraints) and amount of shading required [City of Melbourne 2019]:

1. Minimum canopy cover (≤20% of the street)
2. Moderate canopy cover (20-40% of the street)
3. Large canopy cover (≥40% of the street)

A combination of planting schemes (1-5) and canopy covers (A-C) enables a more versatile and flexible design and distribution of trees in different urban contexts (i.e. 1A corresponds to a civic and commercial street with a canopy cover of 20%). Specific planting configurations would depend on certain constraints (i.e. footpath widths, traffic lanes, light-rail/tram routes, etc.).

SOURCE: UHI 2020 http://uhimitigationindex.be.unsw.edu.au/mitigation/index.html#

Water Features & Evaporative Cooling

The excess heat of the urban environment can be effectively dissipated by using natural heat sinks that usually present much lower temperatures than the surrounding ambient air. Water bodies act as major heat sinks as they are excellent heat absorbers, and along with natural ground cover (i.e. pervious surfaces), can be implemented for passive cooling dissipation to decrease cooling loads of buildings, reduce surface temperatures and improved outdoor thermal comfort [Santamouris et al. 2017, Koc 2018, Natural resources 2019].

Since water properties clearly contrast with those of land (terrestrial) surfaces, water features (i.e. fountains, lakes, rivers, ponds, ocean, marshes, wetlands, etc.) are the most efficient in reducing surface temperatures during the day (especially large water bodies). However, they provide a relative heating effect during the night which is a condition that is more desirable in winter seasons [Santamouris et al. 2017].

On the other hand, as water needs energy to change phase from liquid to vapour, evaporative cooling refers to the process of removing heat from the atmosphere through evaporation .

Green open spaces (grasses)

Green open spaces (including trees in open spaces) have numerous of benefits including climate moderation (reduction of air and surface temperatures), improved outdoor thermal comfort and amenity, increased biodiversity value, improved human health and social cohesion, energy savings, enhanced air quality, among many others. In this sense, green open spaces should be a primary aspect to consider in the design of any urban development, as it is highlighted as a mainstream strategy to mitigate UHI more effectively.

Cool & Permeable Pavements

A cool pavement can be defined as a street pavement that absorbs less solar radiation than a traditional dark-coloured concrete or asphalt pavement. Significant advances in the development of 'cool pavements' have been achieved in recent years and two main technologies are already available to be implemented in urban development. On one hand, developments can apply cool pavements with a high solar reflectivity and high emissivity characteristics that cause a minimal glare effect on pedestrians. On the other hand, there are 'water retention pavements' that use the infiltrated water to decrease surface and near-surface air temperatures through evaporation. A detailed list of different cool pavements and technologies and their application on the built environment is presented in the 'Guide to urban cooling strategies' developed by Osmond, P., & Sharifi, E. (2017) (page 18) [CRC 2017].

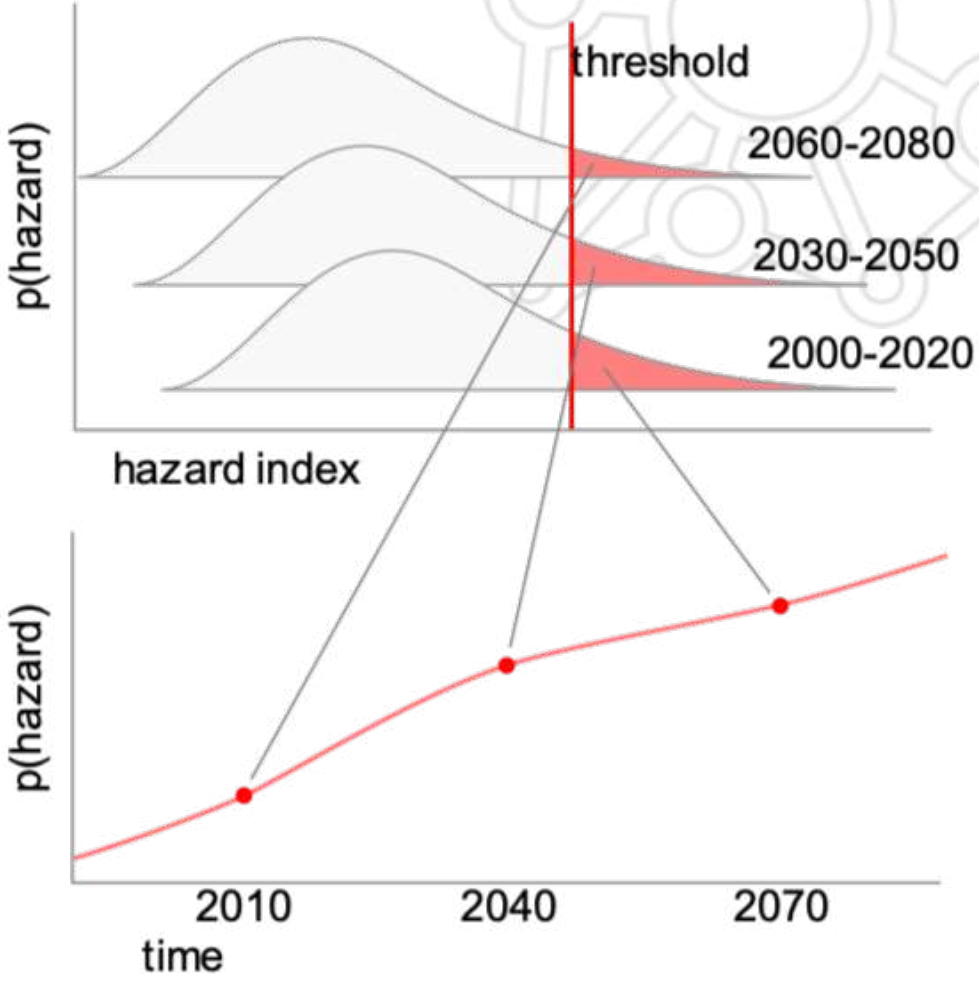
APPENDIX

3. METHODOLOGY

METHODOLOGY

HOW DO WE USE CLIMATE PROJECTIONS?

- Calculate annual indices, e.g. – flood: max 24-hour precipitation – Fire: # days over HDW threshold
- Estimate distributions of indices over 20 year periods (legacy)
- Bias correct distributions with observations
- Calculate annual probability of exceeding thresholds
- Calculate trends in those probabilities



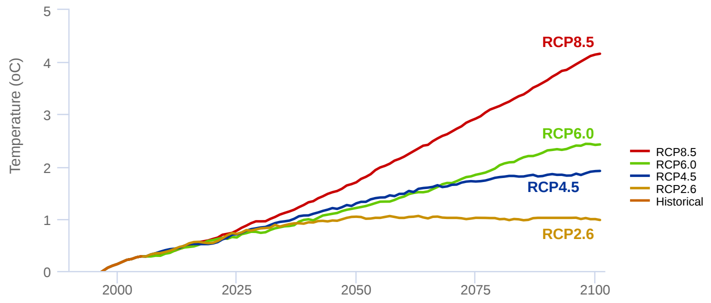
XDI CROSS DEPENDENCY INITIATIVE

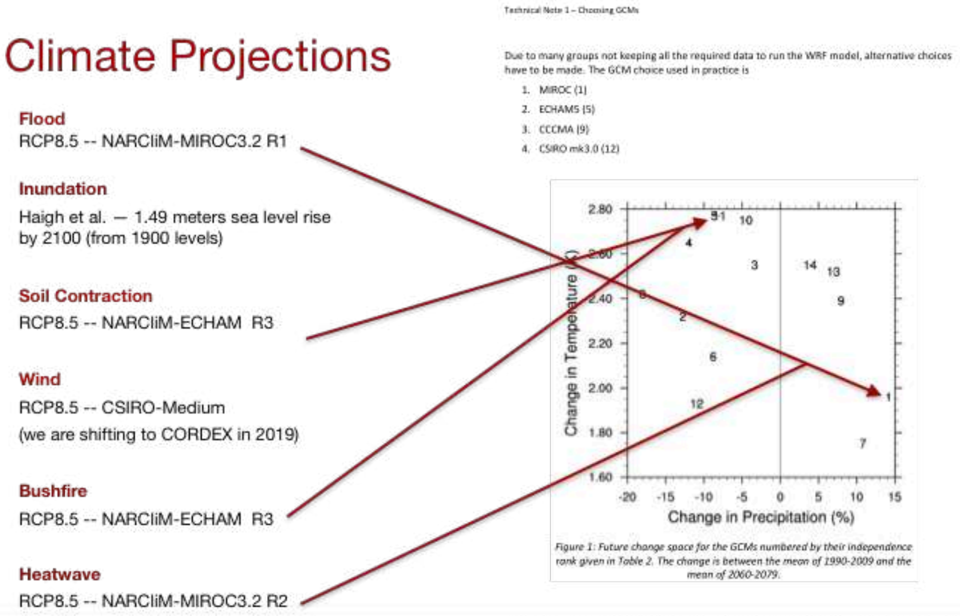
METHODOLOGY

THE CES CLIMATE SETTINGS

Intergovernmental Panel on Climate Change Climate (IPCC) Projections:

The IPCC fifth assessment report (AR5), considers a number of Representation Concentration Pathways (RCP), representing future scenarios for annual carbon emissions, and the associated warming relative to pre-industrial times. RCP 8.5 is representative of a high emissions scenario and is broadly consistent with current trajectories, and temperature rises of 4°C by 2100.





Source: https://www.ccrc.unsw.edu.au/sites/default/files/NARCliM/publications/TechNote1.pdf

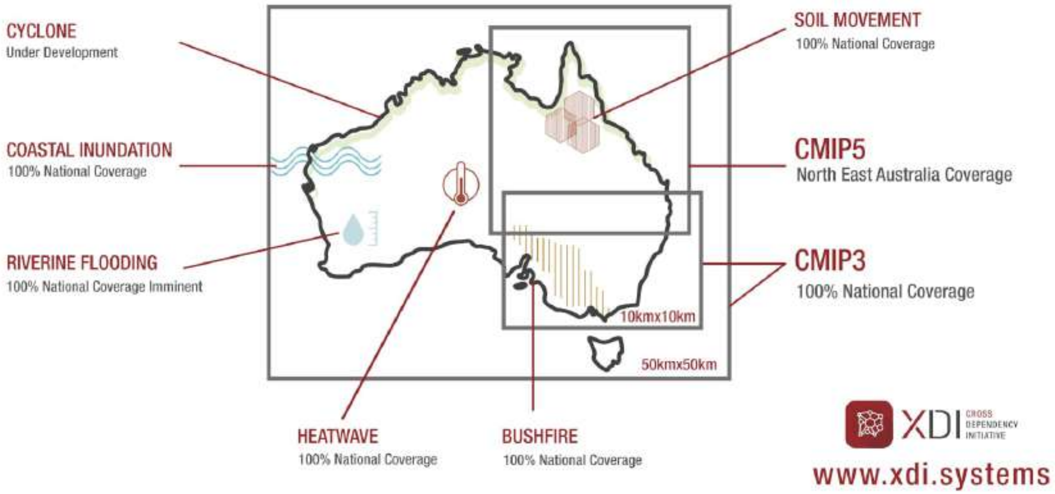
XDI CROSS DEPENDENCY INITIATIVE

M E T H O D O L O G Y

THE CES CLIMATE SETTINGS

Climate Model Coverage:

CMIP - Coupled Model Intercomparison Project Phases



The ces analysis uses:

RCP 8.5 for Global Climate Models (GCMs) & Regional Climate Models (RCMs).

ARCHETYPES

Archetypes define a schematic model of a standard representative asset:

- Includes building elements (e.g. roof, walls, foundations, electricals), and
- The materials they're made of (e.g. brick, timber, steel, plastic).
- Each element/material has different exposures and vulnerabilities.
- Elements are inter-dependent. Failure and damage cascade up chain of dependencies.

Archetypes used in this project:

1. Building | School
2. Park
3. Low Rise Flat
4. Town House

ARCHETYPE	REPLACEMENT COST	NEW LIFETIME (IN YEARS)	HEAT THRESHOLD (º C)
Council Building	$500,000	70	42
School	$5,000,000	100	40
Park	$200,000	200	35
Low Rise	$5,000,000	50	42
Town House	$500,000	50	40

Figure 39 Key default Archetype values

METHODOLOGY

ARCHETYPES - Building | School

4 Key Archetypes Described

4.1 Council Buildings – CBLG – Archetype ID 208

The Council Buildings archetype can summarised by the key points below:

- Can include building types like library, community centre, depot, town hall, or child care centre.
- Buildings range from 2 storeys to 9 storeys high
- Majority of building types have a mechanical lift
- An ecological element is not included in the archetype (e.g. trees and plants)
- Main elements are mechanical (lifts or HVAC), information (internet and telephones), civil (structure of the building), electrical (switchboard) and electronic.

4.1.1 STANDARD ELEMENTS

Using the construction diagrams provided by CoS, the Council Buildings archetype has been configured to include the following elements:

- Civil
- Electrical
- Electronic
- Information
- Mechanical

In the case where the asset owner doesn't provide the asset material and elevation, default values for each of these elements are derived from the same diagrams and additional resources provided (for material definitions see Appendix 1: Material definitions). In this case the following values have been assigned to the archetype Council Buildings.

Table 1 Archetype specifications for Council Buildings broken into identified element per material and height

Element	Material	Height (metres relative to ground)
Civil1	CN1	0.6 metres
Civil2	CN1	-2.5 metres
Civil3	STG	2.8 metres*
Electrical	ELE	0.95 metres
Electronic	ELE	1.05 metres
Information	COP	0.95 metres
Mechanical	STE	0.6 metres

*To FCL - Multiplied Per storey to obtain building height

4.1.2 Council Buildings – CBLG – Archetype ID 208 (cont'd)

Figure 1 Council Buildings as-constructed diagrams used to develop the archetype (City of Sydney, 2001)

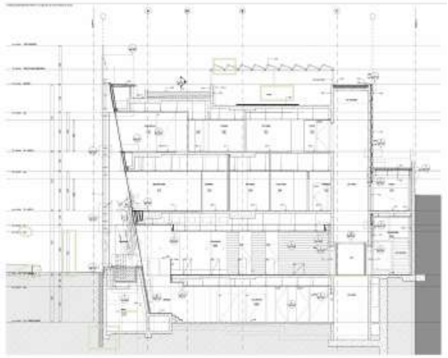


Figure 2 Council Buildings as-constructed diagrams used to develop the archetype (City of Sydney, 2010).

CROSS DEPENDENCY INITIATIVE

ARCHETYPES - Park

4.6 Parks Complex – PRKC – Archetype ID 204

Parks Complex is defined by the following properties:

- Iconic parks that contain complex elements, which can include irrigation systems that have potable and non potable water.
- Complex parks may include digital connectivity
- For events complex parks have access to three phase power and temporary connections to sewer.

Topics to consider further for Failure Modes for parks:

- What causes a park to fail? In what scenario would the park become unusable or would require action to enable access.
- Does the park create revenue for the council and therefore if it 'fails' does this impact financially on the council in one way or another e.g. fines, license breaches or income from events.

4.6.1 STANDARD ELEMENTS

Using the construction diagrams provided by CoS, the Parks Complex archetype has been configured to include the following elements (see Appendix 2: Archetype Detail for more on the element specifications):

- Civil
- Electrical
- Ecological
- Electronic
- Mechanical

In the case where the asset owner doesn't provide the asset material and elevation, default values for each of these elements are derived from the same diagrams and additional resources provided (for material definitions see Appendix 1: Material definitions). In this case the following values have been assigned to the archetype Parks Complex.

Table 5 Archetype specifications for Standard Parks Complex broken into identified element per material and height

Element	Material	Height (metres relative to ground)
Civil1	CN1	0 metres
Civil2	CN1	- 0.4 metres
Civil3	TMB	3 metres
Electrical	ELE	1.1 metres
Ecological	GT1	0 metres
Electronic	ELE	0.3 metres
Mechanical	STG	0.3 metres

4.6.2 Parks Complex – PRKC – Archetype ID 204 (cont'd)

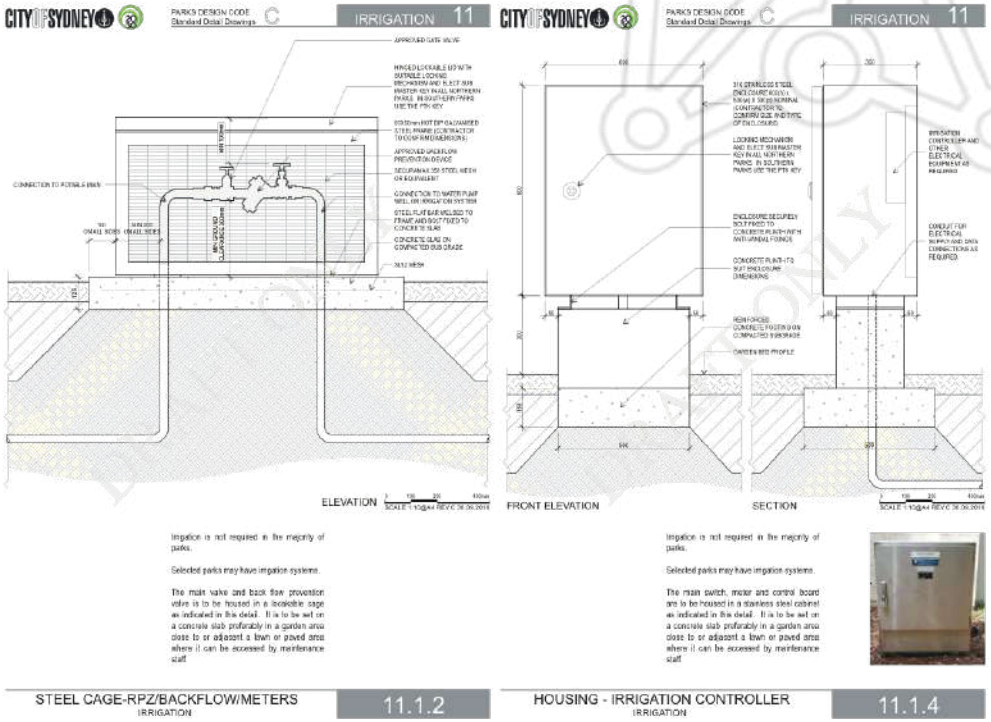


Figure 6 Typical Parks - Irrigation, used for archetype development (City of Sydney, 2016).

METHODOLOGY

ARCHETYPES – Low Rise Flat

Low Rise Flat

A Low Rise Flat Archetype is defined by the following properties:

- Built between 1950's to 1980's
- Ranging from 2 to 4 stories
- Brick or concrete construction with modest amounts of glazing
- Foundation made of reinforced concrete
- Floor and wall structures made of concrete
- Gable roof with a 25˚ pitch
- Concrete tile roofing
- No wall insulation
- 1 kitchen and bathroom per unit
- FFL is 0.37m elevated from NGL
- Windows are 0.41m above FFL
- Roof is 2.55m above FFL
- Basement assumed to be present

Figure 7 Typical Low Rise Flat property used for Archetype development.

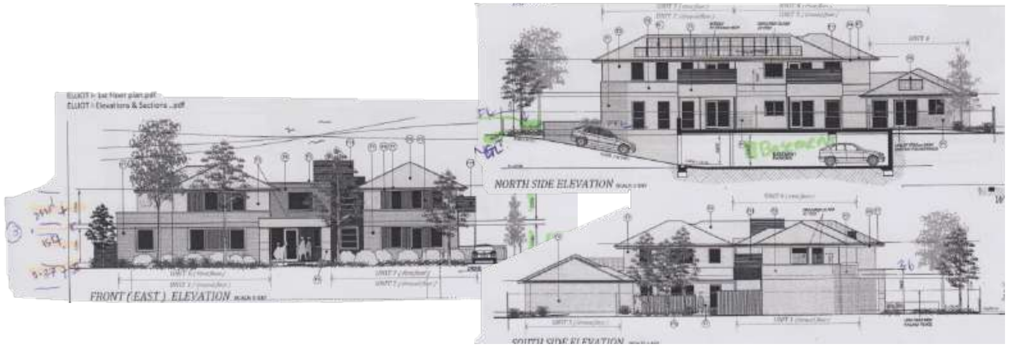


Figure 8 Low Rise Flat property As Constructed diagrams used to develop the Archetype.

M E T H O D O L O G Y

ARCHETYPES – Town House

Detached House

A Detached House Archetype is defined by the following properties:

- Single detached house
- Built from the 1950's onwards
- Can be either brick veneer, timber clad with either a tile or tin roof
- Timber clad on stumps or brick veneer on slab
- One storey building
- External hot water system
- Porch present
- 1 kitchen and bathroom
- Floor is elevated 0.588m from the NGL
- Windows are elevated 0.95m above FFL
- Roof is 2.585m above FFL

Figure 1 Typical Town House used for Archetype development.

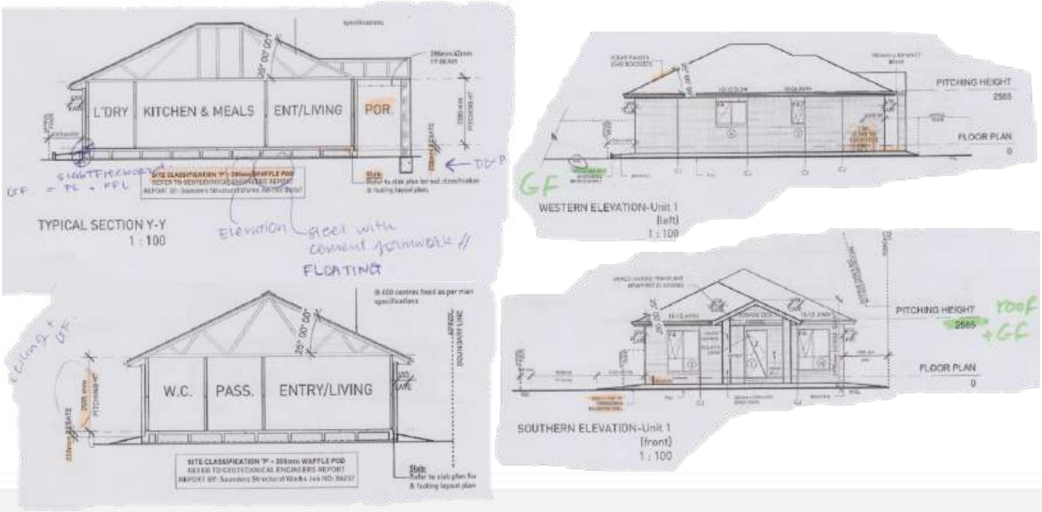


Figure 2 Town House As Constructed diagrams used to develop the Archetype.

METHODOLOGY

HUMAN HEAT STRESS

Discomfort Index (DI) is a measure for heat stress. It is based on air temperature and humidity. Climate data provides information on outside temperatures; however, the Heat Stress method looks at internal DI. Depending on the construction type of a dwelling there is a difference in its ability to insulate the occupants from external temperatures.

The method developed uses the MEF results (MEF 2017) for DI to relate future projections of hot days and heat waves to the risks of heat stress incidence per occupant. This uses projected days over 35°C, transfer ratios between external temperatures, a range of internal DI based on the archetypes and the ability to include assumptive or empirical relationships between heat stress, DI and accumulated heat stress. Number of heat stress events per occupant (y) is a function of the number of days over 35 degrees, the type of dwelling and the number of occupants.

$$y=[(p \times d^{2})+(h \times c \times s) \times d] \times n$$

y = Number of Heat Stress events per occupant

p = Non-Linear Constant (defaults to 0.001)

d = Number of days over 35 degrees per year

h = Hours over 35 degrees (defaults to 5.5)

c = The Internal DI hours to External 35 Degree hours ratio (IE ratio) (high, medium or low range)

s = The Linear Probability of Heat Stress Event per Event of DI > 28 (defaults to 0.1)

n = Number of occupants

XDI CROSS DEPENDENCY INITIATIVE