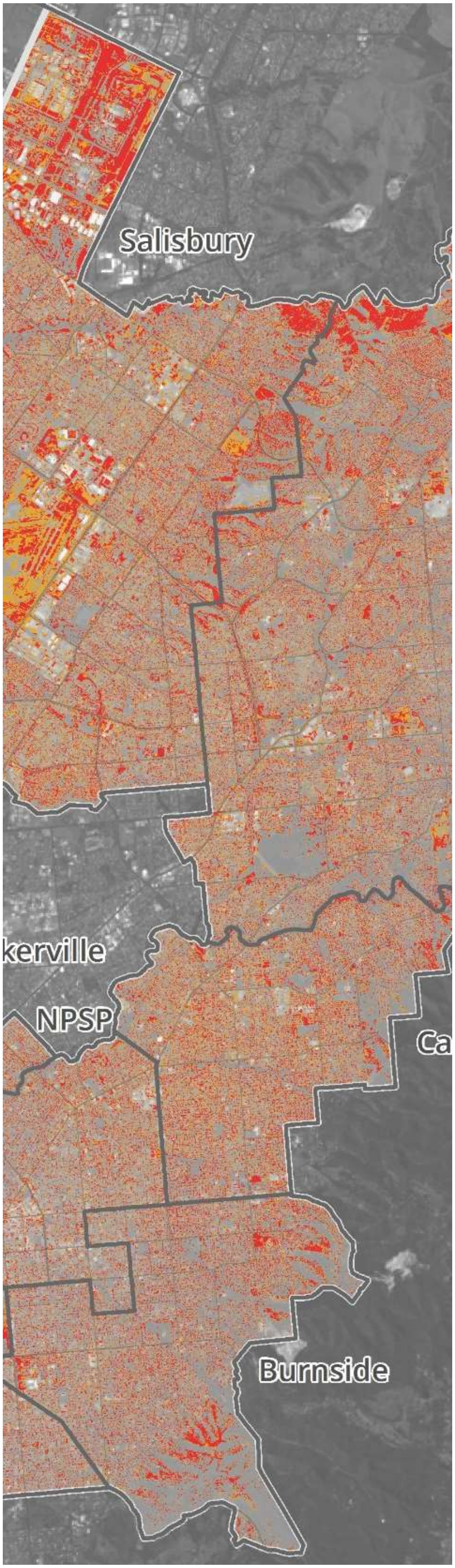

Collaborative Heat Mapping for Eastern and Northern Adelaide

Project report

November 2018

seed
consulting services

Collaborative Heat Mapping for Eastern and Northern Adelaide

Project report

prepared for the Eastern Region Alliance of Councils, the City of Salisbury and, and the Adelaide Mount Lofty Ranges Natural Resources Management Board

Prepared by:
Seed Consulting Services
106 Gilles Street, Adelaide, South Australia 5000
P. +61 8 8232 4823
W. www.seedcs.com.au

In collaboration with:
EnDev Geographic, AeroScientific and Monash University

Citation: Seed Consulting Services, EnDev Geographic and Monash University (2018). Collaborative Heat Mapping for Eastern and Northern Adelaide Report. Prepared for the City of Unley on behalf of the Eastern Region Alliance of Councils and the City of Salisbury.

Document Control

Document information

Information	
Document Owner	City of Tea Tree Gully
Project ID	826 East Heat
Last Saved Date	Monday, 12 November 2018
File Name	DRAFT Eastern and Northern Adelaide region heat mapping - Final report 230918

Document history

Version	Issue date	Changes
Version 1	23 September 2018	NA
Final	12 November 2018	Client feedback incorporated

Disclaimer

The information contained in this Seed Consulting Services (Seed) report is given in good faith and has been derived from sources believed to be reliable and accurate. Seed accepts no legal liability for the accuracy of field data, analytical results or mapping data provided as part of this report or for any associated loss in productivity, business or such like through third part use of this data.

Seed accepts no legal liability for failure of third parties to obtain any necessary government or other agency permits or approvals with respect to any issue raised in this report where approvals may be required.

The material and opinions in this report may include the views or recommendations of third parties, which may not necessarily reflect the views of Seed, or indicate Seed’s recommendation regarding a particular course of action. Seed does not provide advice of an investment or commercial valuation nature. Seed does not accept any liability for investment decisions made on the basis of environmental or other information provided in this report.

Contents

Executive summary

The Resilient East councils and the City of Salisbury engaged Seed Consulting Services, working in partnership with EnDev Geographic, AeroScientific and Monash University, to undertake urban heat mapping and vegetation data collection for the settled areas in the Eastern and Northern Adelaide Regions.

This report presents the final results of the project analysis, focusing on heat exposure results across the region, case studies of land use and material types on surface temperature, the intersection between heat exposure and social vulnerability, and microscale climate measurements.

Flyover

The heat maps that form the basis of this report were produced from airborne thermal data collected during a series of flyovers. The trigger for undertaking the flights was two or more consecutive days with air temperatures above 33°C. Daytime thermal data were collected on 10 March 2018 between 11:30 am and 4:00 pm and nighttime thermal data were collected beginning 10 March at 11:00 pm and concluding 11 March 2018 at approximately 3:30 am. The resulting dataset provide a snapshot of the land surface temperature across the region during the day and nighttime.

Temperature during flyover

The daytime thermal map of the Study region displays a 50°C range of land surface temperatures produced by a correspondingly diverse range of land surfaces. The average daytime land surface temperature for the region measured 37.6°C, with a maximum of 61.4°C occurring at highly localised sites. Of the nine councils included in the study area, Salisbury was the warmest, averaging 38.9°C, over 1.3°C above the regional average.

The nighttime land surface dataset recorded an average temperature of 18.5°C, a full 5°C cooler than the ambient air temperature, suggesting that, in general, the study area land surface is fairly effective at releasing its heat after sundown. The nighttime thermal map reveals a distinctly different pattern of heat than the daytime map. As expected, impermeable, hard surfaces including roads and parking lots emerged as some of the hottest features at night.

Hotspots

Hotspots, identified as areas of any size that are more than 2°C warmer than average help to understand which specific land surfaces are contributing to urban warming. Across the study area, 36.8% of the land surface qualified as a hotspot, equating to 114 km^2 of the land surface. To explore the spatial patterns of hotspots, extreme hotspots (areas above 4°C) were also investigated. Across the study area, over 19% of land classified as an extreme hotspot. Within the study area, 20% of the land registered as a nighttime hotspot (>2°C), and only 3% measured as an extreme hotspot (>4°C).

Urban heat islands

Urban heat islands are those areas that are 125 m x 125 m in size and that are at least 2°C above average. They can lead to a disproportionate build-up of urban heat, often in areas that are not readily able to release that heat effectively.

Within the study region, daytime urban heat islands (>2°C) covered 13.6% of the land, equating to 42.1 km^2, and extreme urban heat islands (>4°C) covered 3.4% of the land, equating to 10.7 km^2. The pattern of heat islands changes drastically in the nighttime thermal data following the changing pattern of hot spots. Regionally, 7.5% of land fell within a nighttime heat island, but results varied greatly by council.

Surface material relationships and case studies

The results of this analysis mainly reflects the expected patterns of impervious surfaces (roads and parking lots) being hot, irrigated green spaces being very cool, and buildings presenting a range of responses based on their material composition. However, there was a warm response of non-irrigated, non-treed, open space and bare ground; in some areas, these surfaces register as hotter than concrete.

Complementing the broad analysis of the relative temperature of land use types were case studies, which highlighted specific features of note that can inform future urban design decisions, for example:

- artificial turf creates a much hotter playing surface than living, irrigated turf;
- tree lined streets have lower average temperatures than those without trees;
- WSUD features, in addition to improving the water quality of stormwater runoff, can create localised cool features along roads;
- bikeways can benefit from consideration of different road surface materials and vegetation in close proximity to cyclists;
- incorporation of trees and shadesails into playgrounds can reduce the increased heat caused by surfaces such as rubber softfall, bitumen and concrete; and
- the use of bitumen versus concrete can significantly impact the amount of heat absorbed by car parking areas during the day time.

Microscale climate measurements

The purpose of the microscale climate measurements was to provide some limited validation and comparison of the surface temperature data collected by aircraft and to link those observations to meteorological observations relevant to human thermal comfort on the ground. The key findings of the ground truthing analysis, which was conducted on a grassed, irrigated open area, a sealed carpark and a heavily tree-shaded grassed environment next to the City of Tea Tree Gully offices, are:

- broad land surface temperature patterns derived from aircraft or satellite remote sensing cannot be directly applied to explain surface temperatures at the microscale, or to air temperatures;

- considerable microclimatic differences can be seen across relatively short distances, depending on such variables as exposure, surface materials and water availability. The resulting differences in surface energy budget are manifest in microscale differences in temperature, humidity and wind speed, and ultimately in human thermal comfort; and

- this report confirms the critical benefits of irrigated green infrastructure, and especially of tree shade, in providing human thermal comfort benefits in warm to hot summer conditions.

Social vulnerability

Overall, 44% of the areas identified as having day time urban heat islands also contained socially vulnerable people. The patterns of heat islands and social vulnerability fall into two categories. The first is where heat island areas, mainly influenced by industrial areas, the airport, and dry open space along the hills face zone, have small populations and generally low social vulnerability. The second more important category though are smaller decentralized heat islands that are dispersed across the study area. While each council has urban heat islands that contain socially vulnerable populations, this issue is of greatest significance for Campbelltown, and Tea Tree Gully.

There were a number of specific suburbs that contain urban heat islands and that had a high degree of social vulnerability. In particular, nearly all of the heat islands in Campbelltown coincided with areas of high social vulnerability. However, Salisbury had a higher total number of socially vulnerable people living within heat islands.

Future drivers

Given that urban heat islands are a relative measure, climate change will not necessarily increase the area effected by urban heat, however, the intensity of heat in these areas will likely increase. Notably though, the extent of change in average temperatures is less than the surface temperature differences, for example, between dark impervious surfaces and green infrastructure.

Urban infill is another major driver of urban heat islands. The replacement of green open space in private backyards with roofs and surrounding impervious surfaces is already leading to an increase in the urban heat island effect. This study provides case studies of how differing density of development can influence heat accumulation, and reinforces the findings of similar analysis conducted in Western Adelaide.

Mitigating urban heat islands

It is recommended that the following general strategies for mitigating urban heat islands be considered:

1. despite the pressure from infill, the amount of green space and tree cover should at least be maintained, and preferably increased to provide cooling benefits;

2. where feasible, areas of dry grass and/or bare ground should be irrigated to reduce their day time warming effect;

3. green infrastructure such as trees, grass and raingardens should be used to shade bitumen covered surfaces such as major and minor roads, bikeways and footpaths.

Where feasible, this green infrastructure should be irrigated in order to maximise its cooling effect;

4. where feasible the carriage way for main roads should be narrowed, stormwater treatment devices installed, and road pavement changed to lighter materials or painted with lighter colours;

5. councils maximise the cooling benefit from existing green cover by ensuring sufficient irrigation is provided to urban forests and other green infrastructure networks where available, such as from recycled stormwater;

6. light coloured roofs be encouraged in residential and industrial areas over dark coloured roofs, or where feasible rooftop gardens can be incorporated into the design of multi-story structures such as car parks and apartments;

7. material selection is carefully considered in the design of recreation areas for the young and elderly, with substrates such as artificial turf and rubber softfall covering used only after consideration of how heat absorption can be offset such as through the use of shade sails or nearby irrigated vegetation; and

8. guidelines be developed for the amount of green space and landscaping required and building materials to be used in medium and high density developments, noting their potential to develop into significant heat islands. This should be done in the broader context of the planning and building codes being developed as part of the current planning reform process in South Australia.

1 Introduction

1.1 Background

Urban heat islands are areas that retain more heat than the surrounding landscape. The presence of urban heat islands is a key concern for Local Government given that extreme heat leads to greater mortality in our community than any other natural hazard. This is especially so for vulnerable members of the community. Green infrastructure, including grassed areas and trees on public and private property can help to moderate surface and air temperatures and thus reduce the impact of the urban heat island effect. Other treatment options include greater use of cooler surfaces, such as for roofs and roads.

As the climate changes, concerns about the urban heat island effect are growing especially because of the predicted impacts on vulnerable members of the community. The importance of addressing urban heat islands and investing in green infrastructure is a priority under the Resilient East and Adapting Northern Adelaide Regional Climate Change Adaptation Plans.

The Resilient East councils and the City of Salisbury engaged Seed Consulting Services, working in partnership with EnDev Geographic and AeroScientific to undertake urban heat mapping and vegetation data collection for the settled areas in the study region. Seed also worked with Monash University to undertake microscale climate measurements. The purpose of this was to provide some limited validation and comparison of the surface temperature data collected by aircraft and to link those observations to meteorological observations relevant to human thermal comfort on the ground.

1.2 Objectives and structure

The primary objectives of the project were to:

- undertake detailed urban heat mapping across the study region to identify the location and characteristics of urban heat;
- obtain data which provide a better understanding of how the study region is currently affected by urban heat; and
- identify key factors that influence temperatures across the councils at the local scale, such as urban design and spatial geometry.

The key desired outcomes for the project included to:

- increase understanding of heat to determine key risks across the Study region;

- raise awareness about the potential impacts of urban heat, and how this may translate to future scenarios which forecast increased density, a more compact urban form and increased population across the region; and

- support informed decision-making in relation to urban form and green infrastructure.

This report presents the final results of the project analysis, focusing on heat exposure results across the region, case studies of land use and material types on surface temperature, the intersection between heat exposure and social vulnerability, and microscale climate measurements.

The report is supported by a number of Attachments which provide further data and information on the underlying methods. In addition to this report, the following data packages have been delivered to each council:

- High resolution (2 m) daytime absolute thermal data (geotiff);
- High resolution (2 m) nighttime absolute thermal data (geotiff);
- Very high resolution (0.15 m) 4-band imagery data (geotiff);
- Very high resolution (0.30 m) canopy data (binary);
- Very high resolution (0.45 m) normalized difference vegetation index (NDVI) data (geotiff);
- Daytime urban heat island (125 m x 125 m) with attributed social vulnerability data (vector); and
- Nighttime urban heat island (125 m x 125 m) with attributed social vulnerability data (vector).

NB. Councils are referred to by their locality rather than full name throughout this document e.g. “Burnside” instead of the “City of Burnside”.

2 Responding to urban heat

2.1 Urban heat island and hot spot identification

The heat maps that form the basis of this report were produced from airborne thermal data collected during a series of flyovers with a fixed wing aircraft. The trigger for undertaking the flights was two or more consecutive days with air temperatures above 33°C. Daytime thermal data were collected on 10 March 2018 between 11:30 am and 4:00 pm and nighttime thermal data were collected beginning om 10 March 2018 at 11:00 pm and concluding on 11 March 2018 at approximately 3:30 am. The data were collected using a Piper PA28-161 aircraft fitted with a FLIR model A615 thermal imaging sensor, flown at an altitude of 3,000 m resulting in 2 m x 2 m resolution datasets.

In assessing the impact of urban heat on landscapes, built environment, and liveability, it is important to assess how individual features reflect and absorb heat, and how that heat aggregates into larger areas of built-up heat. Thermal patterns in the urban landscape can be viewed as urban heat islands (areas at least 125 m x 125 m) and localised hot spots (areas at least 2 m x 2 m) that appear to be greater than 2°C above the baseline average temperature for the region. Heat islands reveal where heat has built up and permits a deeper understanding of where heat is likely to cause the most severe impacts. Hot spots display intricate patterns of heat and allow for exploration of how different surfaces contribute to heat build-up. This multi-scale analysis investigates both where heat islands occur and how the underlying hot spots drive them, then informs which general areas should be prioritised and what specific changes will be most effective.

Due to the variability of weather conditions and the importance of local conditions in driving heat accumulation, it is not possible to know what the normal, natural temperature should be for a given area. Instead, this work compares the observed heat against the regional average temperature (or baseline temperature) which results in a more conservative, but more robust estimate of urban heat islands.

The regional average is used as a baseline temperature against which relative heat impacts are measured. The baseline temperature then becomes more accurate with larger study areas, providing greater confidence for a study of this size. Additionally, because the data is collected over a period of hours (~4 hours) during which the temperature changes, the baseline temperature is calculated as a rolling zonal average where a new average is calculated for every three flightlines (~30 minutes) and used to identify the relative heat for each zone. The result is hotspot and heat island maps that present a balanced picture of relative thermal performance, identifying them as areas hotter than their local average, thus accounting for the impact of overflight time, clouds, and other changing conditions including elevation.

2.2 Understanding urban heat in Eastern and Northern Adelaide

A suite of analyses were conducted to understand the impact of land surface materials on the thermal landscape. These analyses include land use analysis, NDVI assessment, tree canopy mapping, social vulnerability analysis, and a series of case studies to investigate individual impacts of certain features useful for planning. The results of these analyses present an in-depth understanding of what drives urban heat, who experiences its impacts, and where mitigation actions should be targeted.

A more detailed description of the methods used for conducting the analysis is provided in Attachment 1. A map of NDVI for the region and tree canopy are provided in Attachments 2 and 3, respectively. Detailed discussion of these mapping outputs is not provided in this report.

The data collected describes the land surface temperature of the study area which directly influences air temperature. Air temperature, however, is influenced by a range of other factors such as local wind patterns, proximity to water, building shadows, urban wind-tunnelling, fountains (which have a cooling effect), and air conditioners, traffic exhaust, and other sources of waste heat which have a warming effect.

For the purposes of this study, ground truthing was undertaken to provide an insight into the relationship between air and surface temperature (Section 4). However, region wide surface temperature information provides an appropriate and sufficiently reliable indicator on which to base recommendations about where to prioritise heat mitigation activities. This is because it reflects locations where air temperature and absorbance of solar radiation is high, which impacts directly on human thermal comfort (Matzarakis, et al., 2007 in Norton, et al., 2015).

2.3 Framework for identifying priority urban heat mitigation areas

Specific locations can be identified for heat mitigation activities by identifying areas with the largest numbers of people that may be exposed and/or are vulnerable to excessive urban heat. A priority neighbourhoods framework (Norton, et al., 2015) has been adapted to guide the presentation of results for this project. Summarised in Figure 1, this framework seeks to identify areas of heat exposure, behavioural exposure and social vulnerability, and where they intersect, to determine the location of priority areas for mitigation actions.

This report presents quantitative data to inform identification of areas of heat and social vulnerability exposure. Behavioural exposure is considered qualitatively by describing areas of outdoor activity in land use management and building material selection e.g. playgrounds, bikeways, sporting fields, pedestrian thoroughfares.

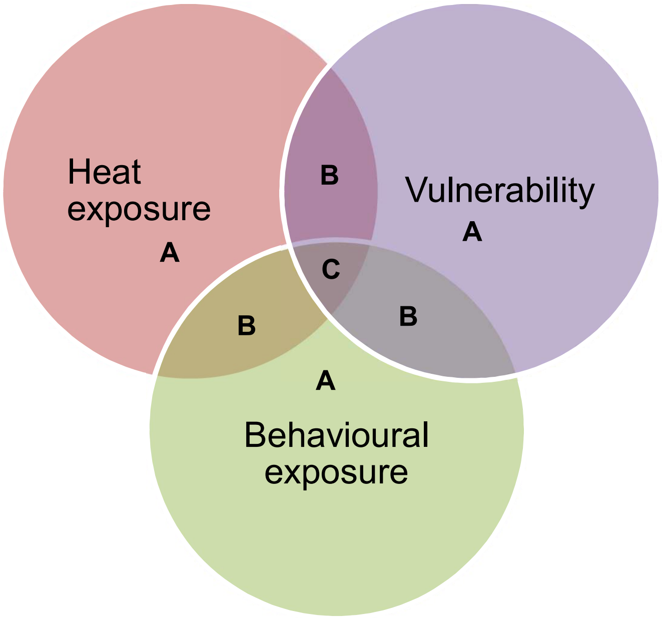

Figure 1. Framework to identify priority neighbourhoods for heat mitigation activities. Factors required to identify neighbourhoods of high (C), medium (B) and moderate (A) priority for urban green infrastructure (UGI) implementation for surface temperature heat mitigation. The key factors are high daytime surface temperatures (heat exposure) intersecting with areas with more vulnerable sections of society (vulnerability) and identifying the zones of high activity (behavioural exposure) in this area. (Norton, et al., 2015)

3 Identifying priority areas

3.1 Heat exposure

3.1.1 Temperature during flyover

The maximum air temperature on 10 March 2018 reached 36.6°C at Parafield Airport (BOM station number 023013). Although this was a very warm day satisfying all of the preflight weather requirements (clear, dry, and calm day preceded by two days above 33°C), it was only the 26th warmest day of the summer season (November 2017 – April 2018). The nighttime minimum air temperature at Parafield Airport only dropped to 23.6°C, making it the 15th warmest night of that same season. The summer season was also exceedingly dry with Parafield Airport only recording 3.4 mm of rain throughout February 2018, 82% lower than the monthly average of 18.8 mm (BOM 2018). The persistent warmth and dryness of the landscape is likely to have had a pronounced influence on how some landscapes retained and released heat. This context is important in interpreting the larger thermal patterns.

3.1.2 Hot spots and thermal analysis

3.1.2.1 Daytime thermal results

The daytime thermal map of the study area displays a 50°C range of land surface temperatures produced by a correspondingly diverse range of land surfaces (Figure 2). Generally, warmer areas are found in the northern parts of Salisbury and Tea Tree Gully, mostly correlating with larger expanses of open non-irrigated natural areas and industrial environments. In contrast, the coolest areas were over and near water bodies. The Councils of Burnside, Tea Tree Gully, Salisbury, and Adelaide exhibit the largest temperature ranges of the nine councils due to topographical variation, size, and the prominence of substantial water bodies. The other councils, Unley, Norwood Payneham & St Peters, Prospect, Campbelltown, and Walkerville had a more even sub-urban residential landscape resulting in a smaller range of observed temperatures.

The average daytime land surface temperature for the region measured 37.6°C, with a maximum of 61.4°C occurring at highly localised sites most likely representing exhaust gases vented from industrial processes (Table 1). Cooler temperatures down to 10°C were observed over some water features and deeply recessed areas of hilled areas, specifically quarries.

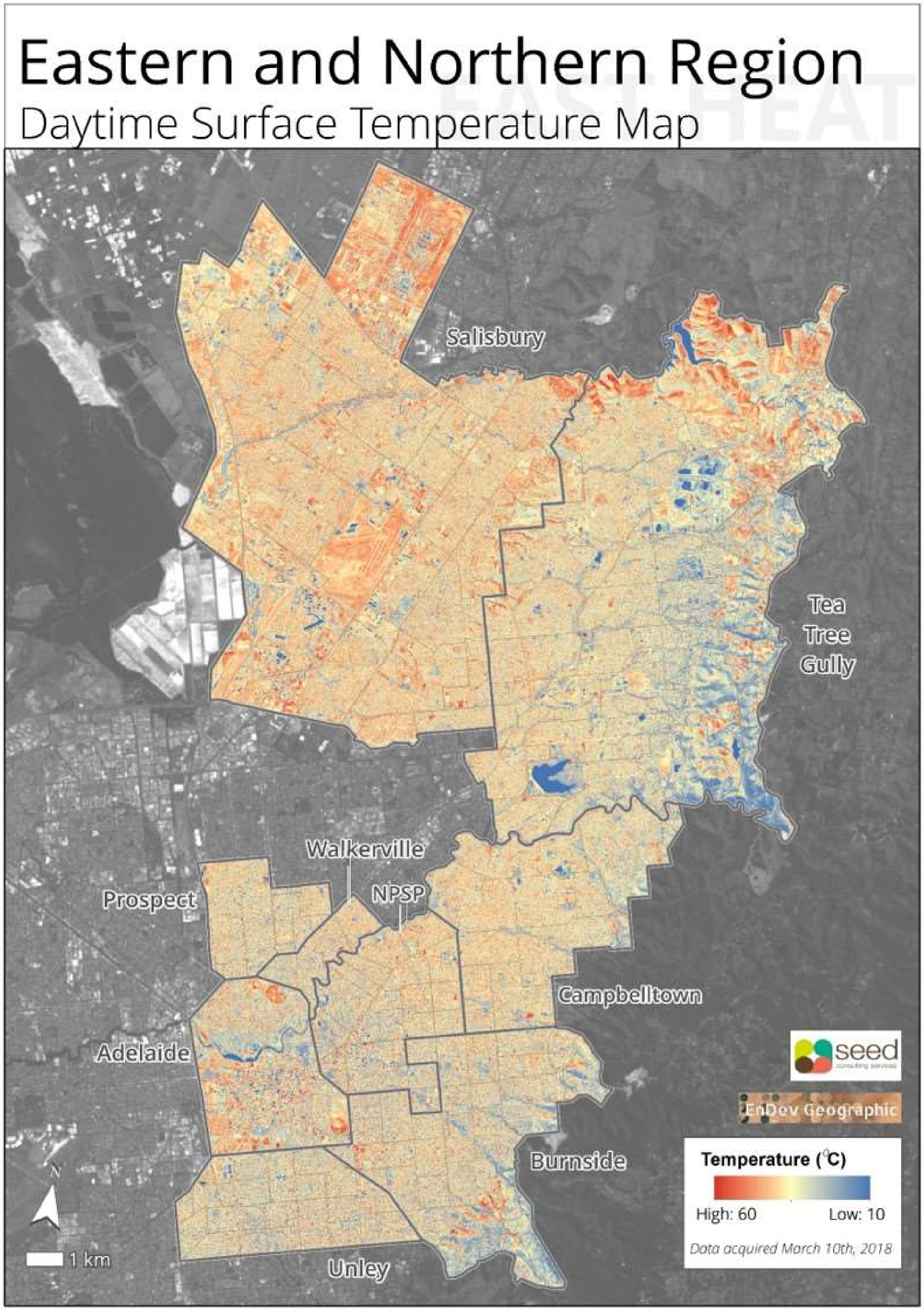

Figure 2. Daytime thermal map - Eastern and Northern Region.

	Average Daytime Temperature (Ranking)	Average Nighttime Temperature (Ranking)
Eastern and Northern Region	**37.55 (C°)**	**18.45 (C°)**
Salisbury	38.86 (1st) *hottest*	17.91 (7th)
Prospect	37.55 (2nd)	17.89 (8th)
Walkerville	37.44 (3rd)	18.02 (6th)
Campbelltown	37.39 (4th)	18.95 (2nd)
Norwood Payneham & St Peters	37.32 (5th)	17.65 (9th)
Adelaide	37.16 (6th)	18.33 (4th)
Unley	36.85 (7th)	18.07 (5th)
Tea Tree Gully	36.61 (8th)	18.88 (3rd)
Burnside	36.46 (9th)	19.54 (1st) *hottest*

Table 1. Average day and night land surface temperatures for each council.

Of the nine councils included in the study area, Salisbury was the warmest, averaging 38.9°C, over 1.3°C above the regional average (Table 1). Five of the councils were within 0.5°C of average with only Unley, Burnside, and Tea Tree Gully measuring more than 0.5°C cooler than the regional average.

Thermal maps for each council are provided in Attachment 4 and the hottest suburbs by council are provided in Attachment 5.

3.1.2.2 Daytime hotspots

Hotspots, identified as areas of any size that more than 2°C warmer than average, help to understand which specific land surfaces are contributing to urban warming. Across the study area, 36.8% of the land surface qualified as a hotspot, equating to 114 km^2 of the land surface (Figure 3, Table 2). Among the individual councils, Salisbury had the largest area of hotspots with 43% (45 km^2) of its analysed land area being more than 2°C above average. Parafield Airport, large expanses of open, non-irrigated land, large exposed roads, railroads, and parking lots were the predominant drivers of hotspots. Campbelltown and Tea Tree Gully followed with 37% of their lands occupied by hotspots, with Tea Tree Gully experiencing significant hotspots among the northern treeless expanses. Adelaide and the adjacent councils exhibited a lower proportion of hotspots, with 31% of Adelaide classifying as a hotspot, down to Unley which only had 26%.

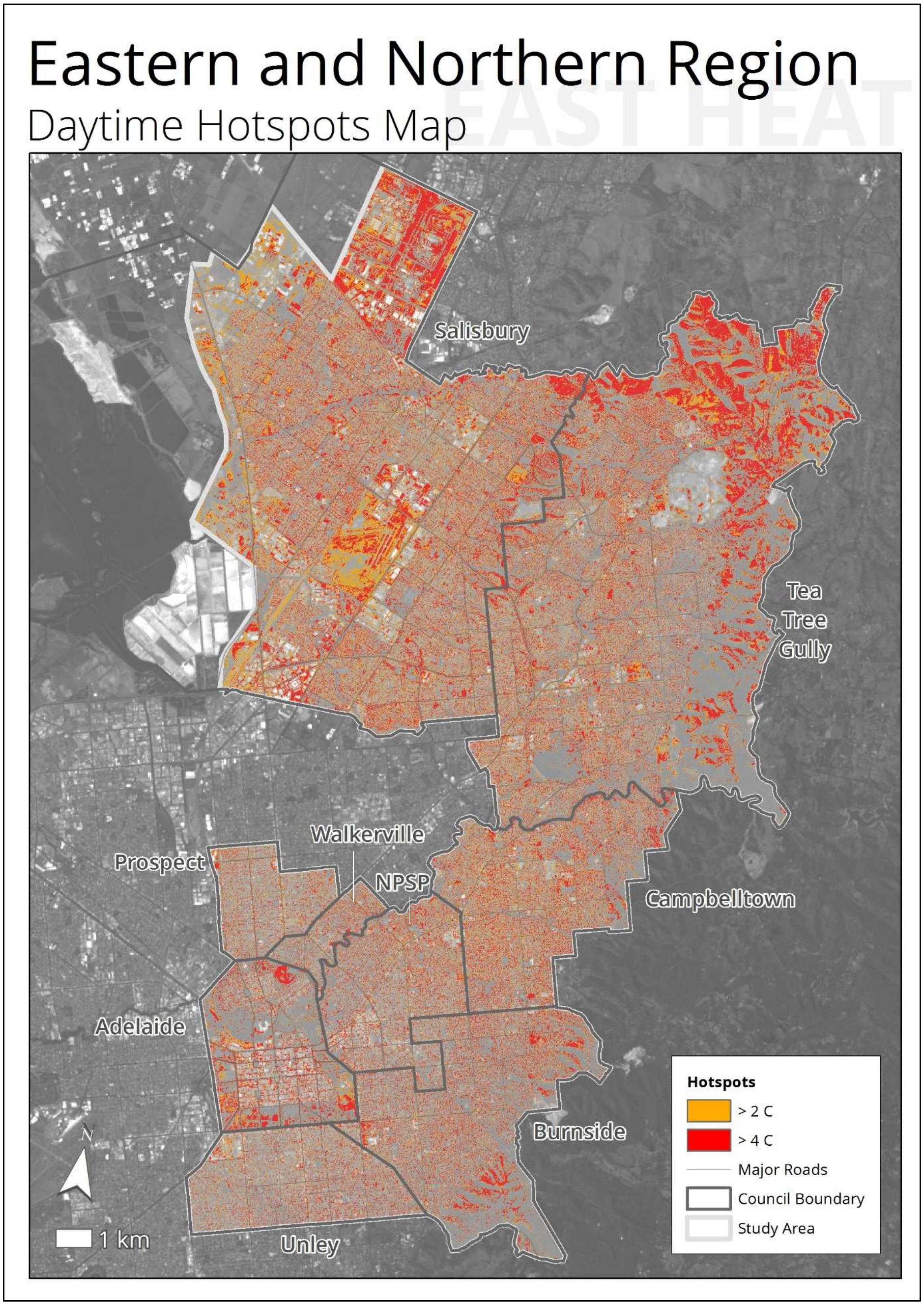

Figure 3. Daytime hotspots map - Eastern and Northern Region.

	DAYTIME			NIGHTTIME			
	Average Daytime Temperature (C°)	Hotspot Area **(>2C)** sqkm	Extreme Hotspot Area **(>4C)** sqkm	**Average Night Temp (C°)**	Hotspot Area **(>2C)** sqkm	Extreme Hotspot Area **(>4C)** sqkm	Total Area sqkm
Eastern and Northern Region	**37.6** **(C°)**	14.00 (36.82%)	60.21 (19.44%)	**18.5** **(C°)**	62.16 (20.07%)	9.18 (2.96%)	309.59
Adelaide	**37.2** (6th)	4.80 (31.42%)	2.85 (18.64%)	**18.3** (4th)	4.28 (28.02%)	1.49 (9.77%)	15.27
Burnside	**36.5** (9th)	7.81 (28.43%)	4.40 (16.01%)	**19.5** (1st) hottest	8.73 (31.76%)	0.99 (3.6%)	27.48
Campbelltown	**37.4** (4th)	9.11 (37.43%)	4.57 (18.77%)	**19.0** (2nd)	5.23 (21.48%)	0.37 (1.52%)	24.34
Norwood Payneham & St Peters	**37.3** (5th)	4.74 (31.29%)	2.42 (15.96%)	**17.7** (9th)	3.27 (21.59%)	0.70 (4.58%)	15.16
Prospect	**37.6** (2nd)	2.30 (29.46%)	1.03 (13.17%)	**17.9** (8th)	1.98 (25.3%)	0.41 (5.29%)	7.81
Salisbury	**38.9** (1st) hottest	45.46 (42.81%)	22.20 (20.9%)	**17.9** (7th)	19.69 (18.54%)	3.45 (3.24%)	106.17
Tea Tree Gully	**36.6** (8th)	34.89 (36.6%)	20.31 (21.3%)	**18.9** (3rd)	14.15 (14.84%)	0.59 (0.62%)	95.33
Unley	**36.9** (7th)	3.80 (26.35%)	1.88 (13.08%)	**18.1** (5th)	4.01 (27.81%)	1.01 (7%)	14.40
Walkerville	**37.4** (3rd)	1.07 (30.01%)	0.54 (15.19%)	**18.0** (6th)	0.79 (22.08%)	0.16 (4.5%)	3.57

Table 2. Hotspot areas and extreme hotspot areas for the region and each council.

To explore the spatial patterns of hotspots, extreme hotspots (areas above 4°C) were also investigated. Across the study area, over 19% of land classified as an extreme hotspot. Tea Tree Gully had the highest proportion of extreme hotspots for any council with 21% of its land surface falling into that category. This is driven by the strong thermal signal from the exposed dry natural areas in the council's northeast. Unley had the lowest area of extreme hotspots with 13% of its land exhibiting 4°C warming or more.

3.1.2.3 Nighttime thermal results

The nighttime land surface dataset recorded an average temperature of 18.5°C (Table 1), a full 5°C cooler than the ambient air temperature, suggesting that in general, the study area land surface is fairly effective at releasing heat after sundown. However, some land surfaces in the built environment retain heat much longer than others causing prolonged warming into the nitghttime.

The nighttime thermal map reveals a distinctly different pattern of heat than the daytime map (Figure 4). As expected, impermeable hard surfaces including roads and parking lots emerge as some of the hottest features at night, especially within the Adelaide CBD. However, less expected is a strong warming signal generated along the front of the Adelaide Hills in Burnside, Campbelltown, and Tea Tree Gully. It is understood that a similar result was observed for the Resilient South het mapping analysis and this will be considered further in the preparation of the full project report.

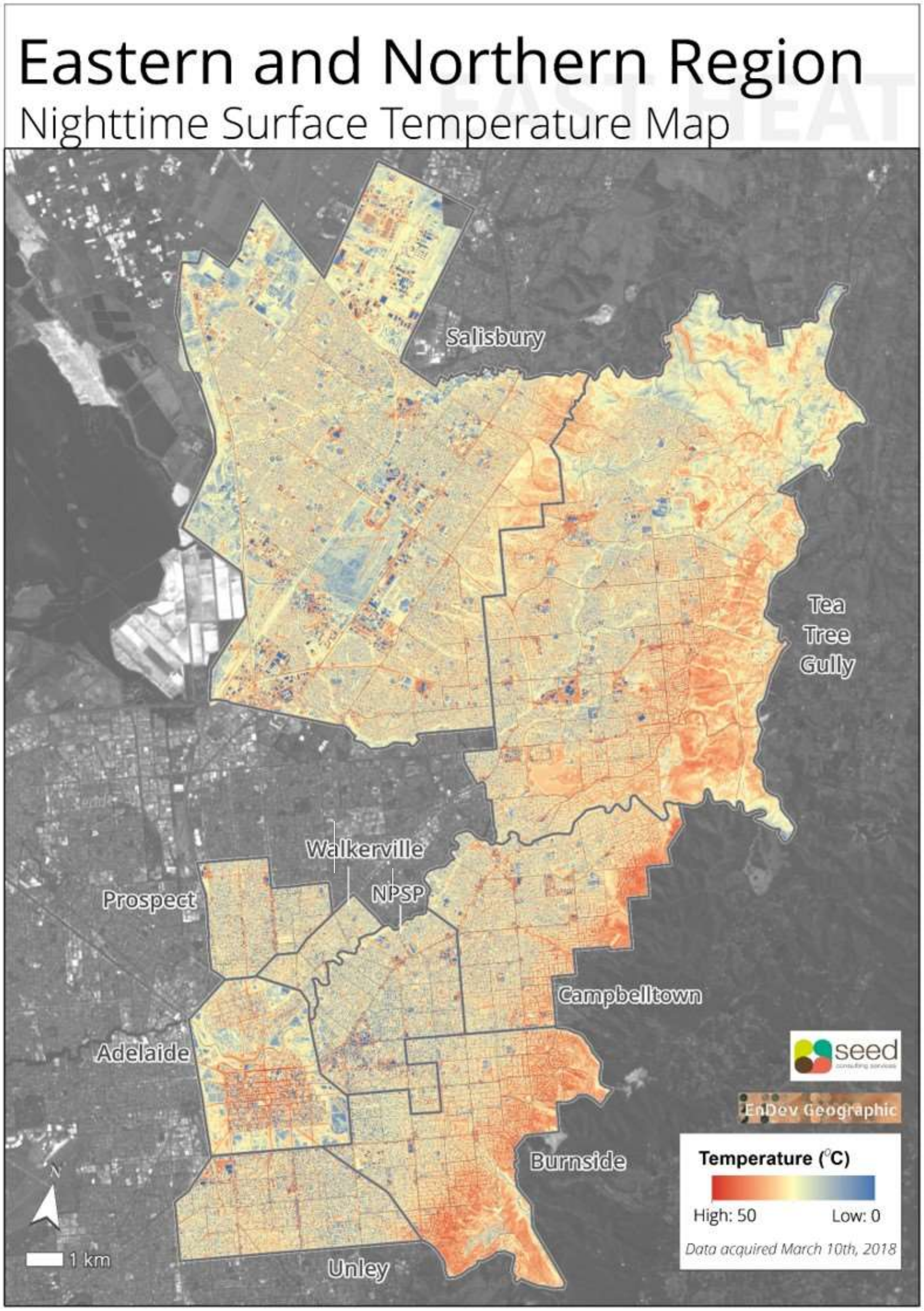

Figure 4. Nighttime Thermal Map - Eastern and Northern Region.

Among the councils, Burnside went from the coolest council during the day, to the warmest at night with an average temperature greater than 1°C above the regional average, owing in large part to the pronounced warming from the hills face zone. Similarly, Campbelltown and Tea Tree Gully were the second and third warmest councils because of this same pattern, averaging 0.5°C warmer than the baseline temperature. Norwood Payneham & St Peters was the coolest at 0.8°C below average.

3.1.2.4 Nighttime hotspots

Within the study area, 20% of the land registered as a nighttime hotspot (>2°C), and only 3% measured as an extreme hotspot (>4°C) (Figure 5, Table 2. Hotspot areas and extreme hotspot areas for the region and each council.). Within the councils, Burnside, Adelaide, and Unley had the highest proportion of nighttime hotspots recording 32%, 28%, and 28%, respectively. Tea Tree Gully has the lowest number of nighttime hotspots covering less than 15% of its land, and virtually no extreme nighttime hotspots (<1%). Adelaide has the highest proportion of extreme nighttime hotspots with 10% of its land cover remaining at >4°C. While Burnside had the highest proportion of 2°C nighttime hotspots, it does not maintain a high proportion of extreme hotspots (<4%, 6th among councils).

3.1.3 Urban heat island analysis

Hotspots reveal the local drivers of urban heat by revealing the thermal performance of individual land use features. Well dispersed hotspots have a minimal impact on overall urban heat, but concentrations of hotspots - especially those caused by features not traditionally recognized as causing hotspots - lead to a disproportionate build-up of urban heat, often in areas that are not readily able to release that heat effectively. This concentration of urban heat results in urban heat islands, or areas larger than 125 m x 125 m and warmer than 2°C above average.

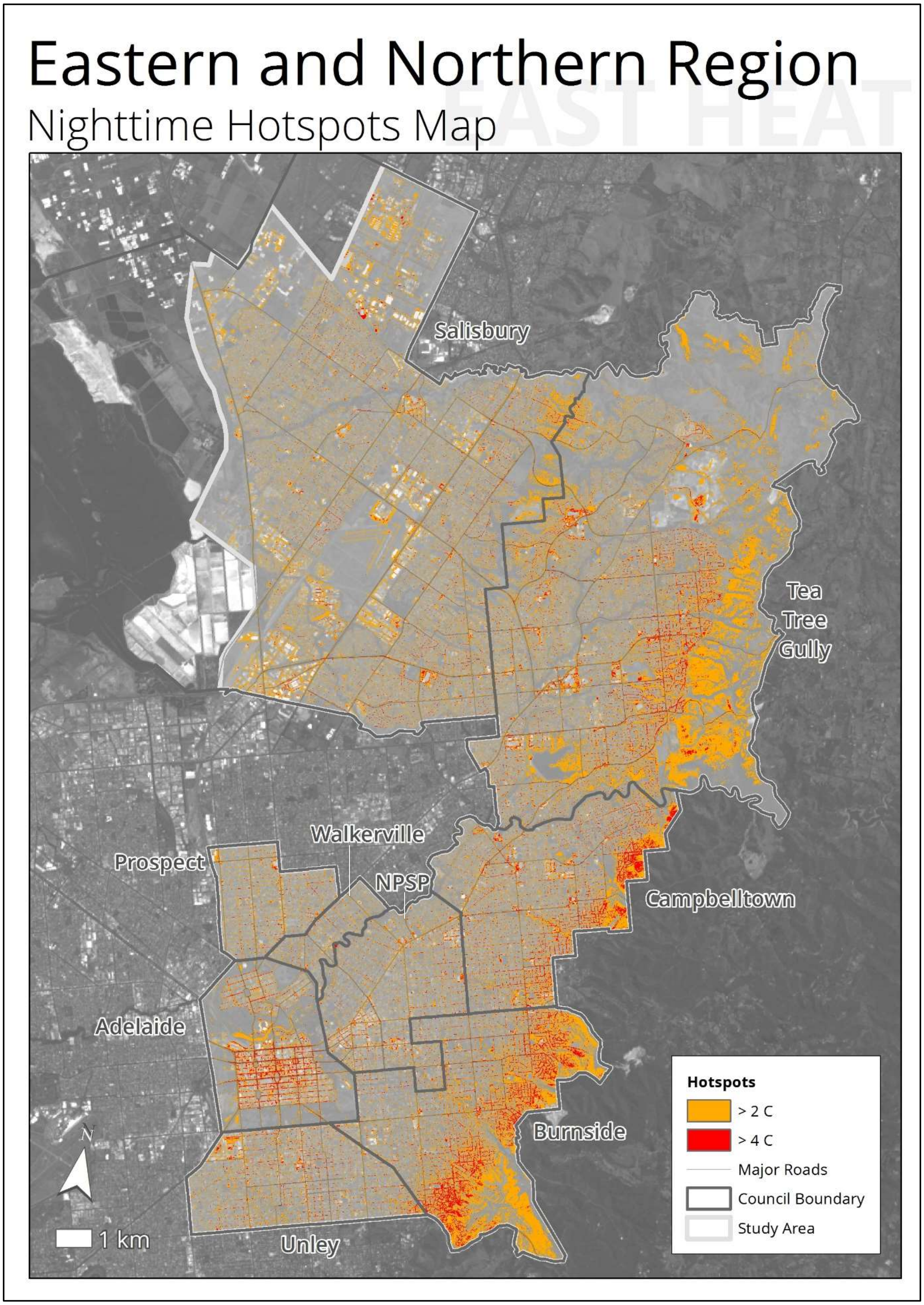

Figure 5. Nighttime Hotspots Map - Eastern and Northern Region.

3.1.3.1 Daytime urban heat islands

Within the study region, daytime urban heat islands (>2°C) covered 13.6% of the land, equating to 42.1 km^2, and extreme urban heat islands (>4°C) covered 3.4% of the land, equating to 10.7 km^2 (Figure 6, Table 3). Among the councils, Salisbury and Tea Tree Gully had the highest portions of heat islands covering 18.5% of their area. Tea Tree Gully also experienced the highest number of extreme heat islands covering 7% of its area. Adelaide and Campbelltown had a medium range of heat islands with 7.6% and 8.4%, respectively. Most of the councils adjacent to the CBD experienced limited daytime heat islands.

	DAYTIME			**NIGHTTIME**			
	Average Daytime Temperature (C°)	Urban Heat Island Area **(>2C)** - sqkm	Urban Heat Island Area - Extreme **(>4C)** sqkm	**Average Night Temp (C°)**	Urban Heat Island Area **(>2C)** - sqkm	Urban Heat Island Area - Extreme **(>4C)** sqkm	Total Area sqkm
Eastern and Northern Region	**37.6 (C°)**	42.13 (13.6%)	10.65 (3.44%)	**18.5 (C°)**	23.22 (7.5%)	0.26 (0.08%)	309.59
Adelaide	**37.2** (6th)	1.17 (7.63%)	0.14 (0.9%)	**18.3** (4th)	0.61 (4%)	- (0%)	15.27
Burnside	**36.5** (9th)	1.12 (4.09%)	0.18 (0.67%)	**19.5** (1st) hottest	9.21 (33.52%)	0.03 (0.12%)	27.48
Campbelltown	**37.4** (4th)	2.05 (8.41%)	0.11 (0.44%)	**19.0** (2nd)	2.98 (12.25%)	0.20 (0.83%)	24.34
Norwood Payneham St. Peters	**37.3** (5th)	0.24 (1.56%)	- (0%)	**17.7** (9th)	0.02 (0.14%)	- (0%)	15.16
Prospect	**37.6** (2nd)	0.10 (1.26%)	0.02 (0.19%)	**17.9** (8th)	0.03 (0.33%)	- (0%)	7.81
Salisbury	**38.9** (1st) hottest	19.69 (18.54%)	3.34 (3.14%)	**17.9** (7th)	0.99 (0.93%)	- (0%)	106.17
Tea Tree Gully	**36.6** (8th)	17.64 (18.5%)	6.87 (7.2%)	**18.9** (3rd)	9.20 (9.65%)	0.02 (0.01%)	95.33
Unley	**36.9** (7th)	0.07 (0.45%)	0.00 (0%)	**18.1** (5th)	0.17 (1.21%)	0.01 (0.08%)	14.40
Walkerville	**37.4** (3rd)	0.06 (1.58%)	- (0%)	**18.0** (6th)	0.00 (0.03%)	- (0%)	3.57

Table 3. Urban heat island areas for the region and by council.

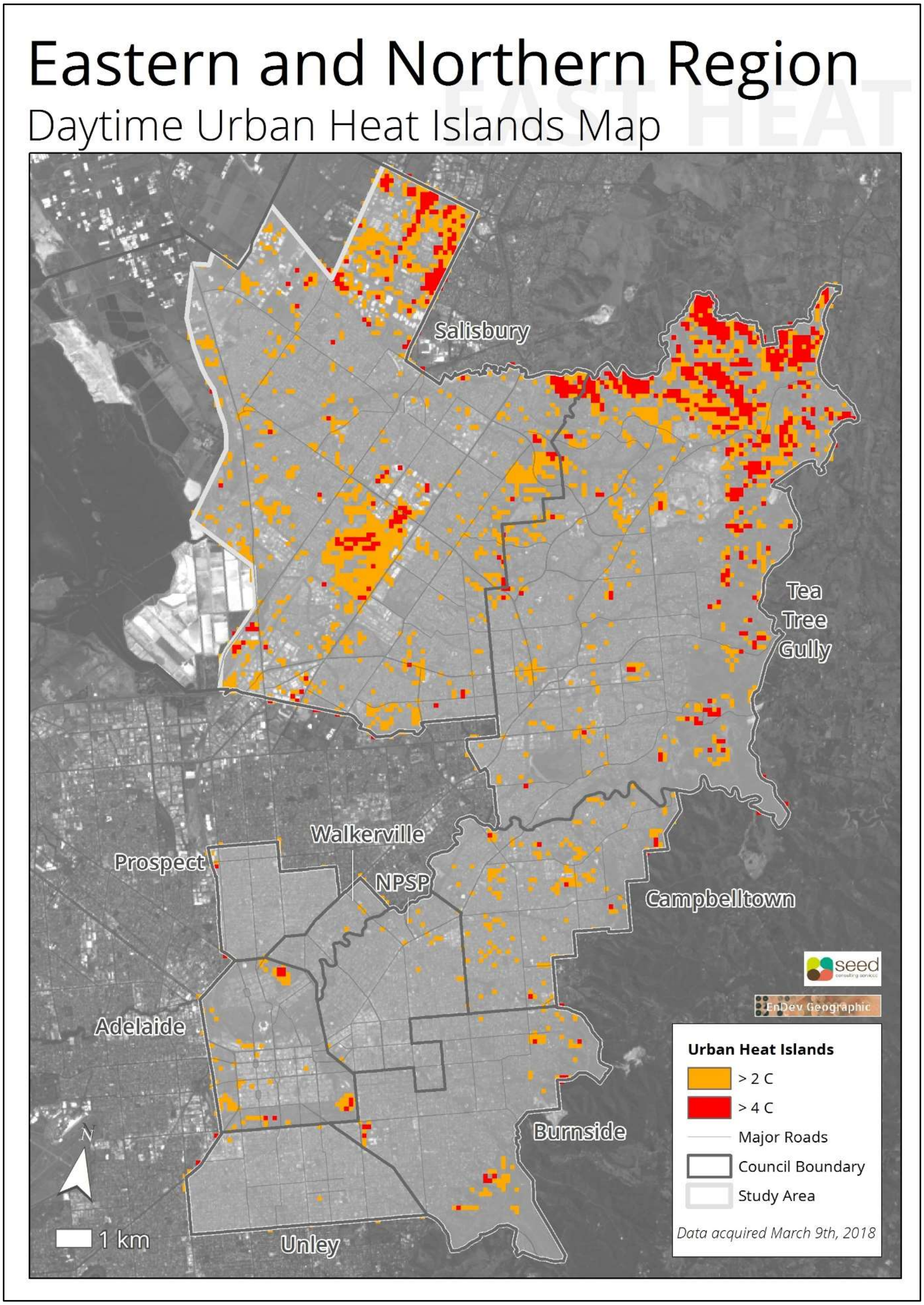

Figure 6. Daytime urban heat island map - Eastern and Northern Region.

3.1.3.2 Nighttime Urban Heat Islands

The pattern of heat islands changes drastically in the nighttime thermal data following the changing pattern of hot spots. Regionally, 7.5% of land fell within a nighttime heat island, but results varied greatly by council (Figure 7, Table 3). While Tea Tree Gully remained above the regional proportion of nighttime urban heat islands with 9.7%, Burnside emerged as the warmest council with 33.5% of its area registering as a nighttime heat island. Campbelltown recorded 12% of its land as a heat island, and Adelaide registered 4% coverage of nighttime heat islands. All of the other councils experience 1% or less of nighttime heat islands, and virtually no extreme heat islands existed in this region at night.

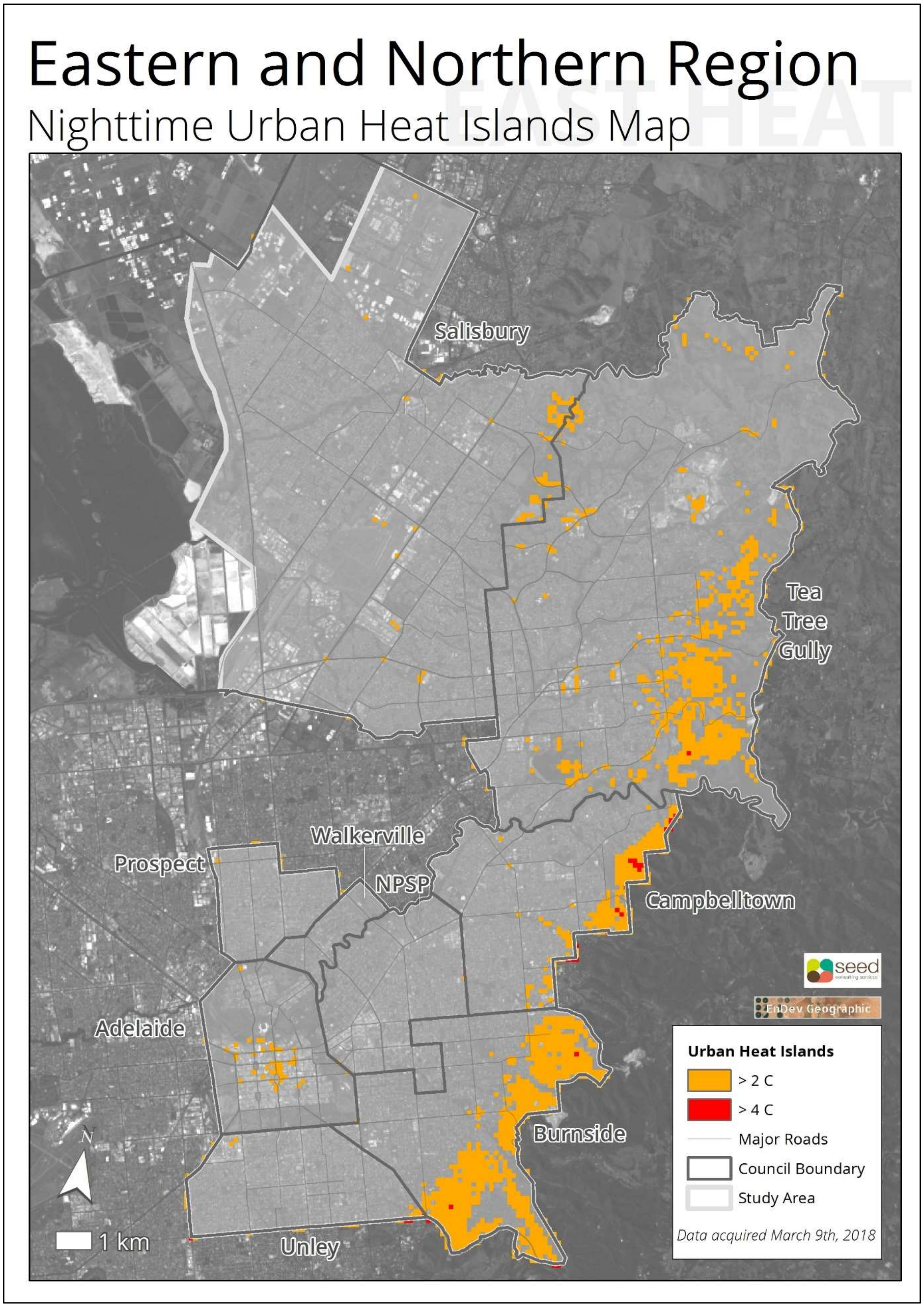

Figure 7. Nighttime Urban Heat Island Map - Eastern and Northern Region.

3.2 Contributing factors of urban heat

3.2.1 Land use analysis

A key step in developing effective mitigation strategies is to understand how different land uses contribute to hotspots, and therefore heat islands. This was done by analysing the relative thermal performance of 1,100 individual land use points across a range of 18 land use classes which provided insight into the composition of the thermal landscape.

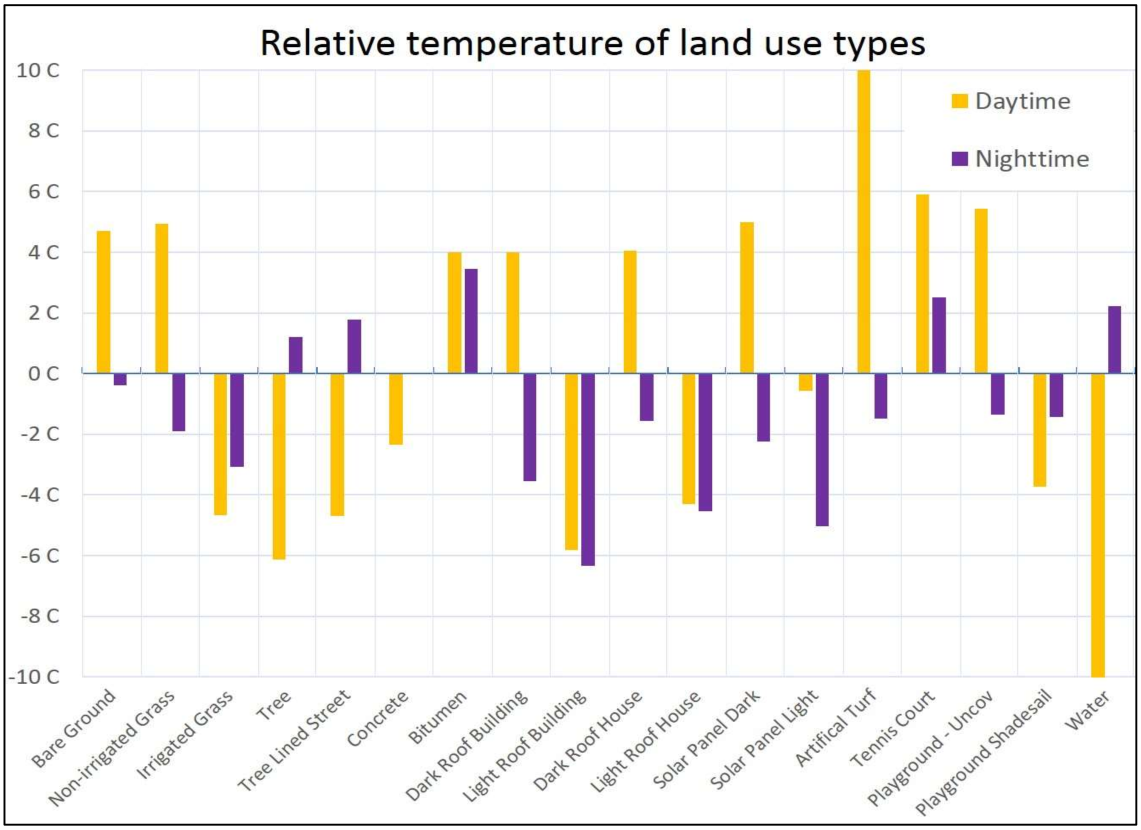

Figure 8. Land use analysis results showing the relative temperature difference of various land uses during the day and night.

The hottest surface type assessed in this analysis was artificial turf. The 13 examples of artificial turf analysed were 11.5°C above average, which was 5°C warmer than any other surface type. Water was the coolest land surface type providing on average 12°C of cooling during the day, followed by trees as the second coolest land surface type (Figure 8, Table 4).

Land uses fell into four categories of thermal performance. Irrigated grass, shadesails, and light coloured roofs and buildings provided the strongest and most consistent cooling signals across the landscape being ~4°C or greater cooler during the day, and sustained ~2°C or greater cooling during the night. These are land use surfaces that routinely and consistently provide a reliable cooling resource regardless of conditions. The second class of land use performance provided cooling during the day and a slight warming during the night.

Land use thermal performance		
Cool day, cool night	**Day (°C)**	**Night (°C)**
Light Roof Building	-5.81	-6.34
Irrigated Grass	-4.68	-3.07
Light Roof House	-4.30	-4.53
Shadesails	-3.72	-1.44
Cool day, warm night		
Water	-12.05	2.23
Trees	-6.12	1.22
Tree-lined Streets	-4.70	1.78
Warm day, cool night		
Artificial turf	11.54	-1.49
Bare playgrounds	5.44	-1.36
Non-irrigated grass	4.94	-1.90
Bare ground	4.72	-0.37
Dark Roof House	4.06	-1.56
Dark Roof Building	4.00	-3.55
Warm day, warm night		
Bitumen	3.99	3.46

Table 4. Thermal effect of land uses.

This class included trees, tree-lined streets, and water. These land uses all provide insulating effects that are highly effective in heat island mitigation and also provide resilience towards extreme heat events. The third category of land use performance was warm during the day but cooled quickly into the nighttime. This category includes bare ground and non-irrigated grass, dark roofed houses and buildings, artificial turf, and uncovered playgrounds; all areas that absorbed heat during the day but released their heat very quickly after sundown. These surfaces are referred to as *low-intensity hotspots*. *High-intensity hotspots* are those that are hot during the day and continue to release heat during the night, and form the final category of land uses, of which the predominant land use was bitumen.

Some additional land uses were also analysed that do not make up a major portion of the land cover, but are important in land use decision making. For instance, solar panel installations on both dark and light roofs generally had the same thermal performance as their surrounding roof type, but they did tend to exacerbate those characteristics. Solar panels on dark roofs made the roofs hotter during the day and night, and solar panels on light roofs provided cooling during both day and nighttime but presented an extra strong cooling signal at night. Tennis courts were also assessed and found to provide strong warming during both the day and night, similar to that of bitumen which is assumed to be the dominate surface type, but the thermal performance will vary with respect to tennis court type. Additionally, concrete, while being a hard, impervious surface also tends to be much lighter in colour than bitumen, and therefore reflects and dissipates a substantial portion of thermal energy. In this analysis, examples of concrete recorded a slightly cooler-than-average surface temperature during the day, and no significant effect during the night.

Other patterns of interest include the contrast between vegetation types. Particularly, irrigated versus non-irrigated grass presented a marked contrast with irrigation making a 9°C temperature difference. While this highlights the effectiveness of irrigation as a short-term cooling mechanism, it also highlights the vulnerability of irrigation-reliant cooling as future water restrictions could lead to one of the coolest surfaces becoming one of the hottest. In contrast, trees provide a sustained buffer against extreme heat events regardless of conditions.

3.2.2 Case Studies

Ten case studies were developed to explore the role of local scale land use choices in driving and mitigating heat. All land surface temperatures discussed in the case studies are relative to the average temperature recorded across the study area, focusing on the relative impact of landscapes' contribution in terms of degrees Celsius warming and cooling.

The images presented for the case studies combine aerial imagery and surface temperature maps, with the discussion focus contained inside the highlighted area of each image.

3.2.2.1 Playgrounds and parks (Soldier's Memorial Garden, Prospect)

Playgrounds represent a prominent feature of shared-use urban spaces and are often used by children who are more vulnerable to heat exposure than adults less than 75 years of age. Soldier's Memorial Garden in Prospect provides a case study of how park-scale land uses influence thermal landscapes and exposure.

The playground surfaces within Soldier's Memorial Garden are primarily covered with woodchips with a small area of rubber softfall, some grass, and concrete paths. The playground is mostly well-shaded by a large shadesail and numerous trees which limit the direct sun exposure. The playground is also surrounded by irrigated greenspace. The broader area contains large tennis courts and is surrounded by roads.

Of the exposed playing surfaces, the dark-coloured highly absorptive softfall measured 8°C warmer than average, while woodchips measured 1°C cooler than average. The shade coverings provided relief for the heat with the shadesail and trees measuring 4°C and 7°C cooler than average, respectively. The irrigated grass areas provided additional areas with 6°C of cooling. In the broader area, nearby tennis courts and bitumen produced 5°C and 6°C warming, respectively.

Overall, the playground itself displayed an average land surface temperature 4.2°C cooler than average. (For comparison, uncovered playgrounds in the land use analysis (section 3.2.1) averaged 5°C warmer than average). The area including the playground and the immediate park area (small white box, Figure 9) measured 3.5°C cooler than average, while the broader park area (including tennis courts and intersecting roads) were only 2.5°C cooler than average. These results suggest that landscape decisions to include shading and cooling features such as trees, shadesails, and irrigated vegetation in the areas surrounding playgrounds have the ability to effectively mitigate otherwise severe hotspots that may develop in areas frequented by children.

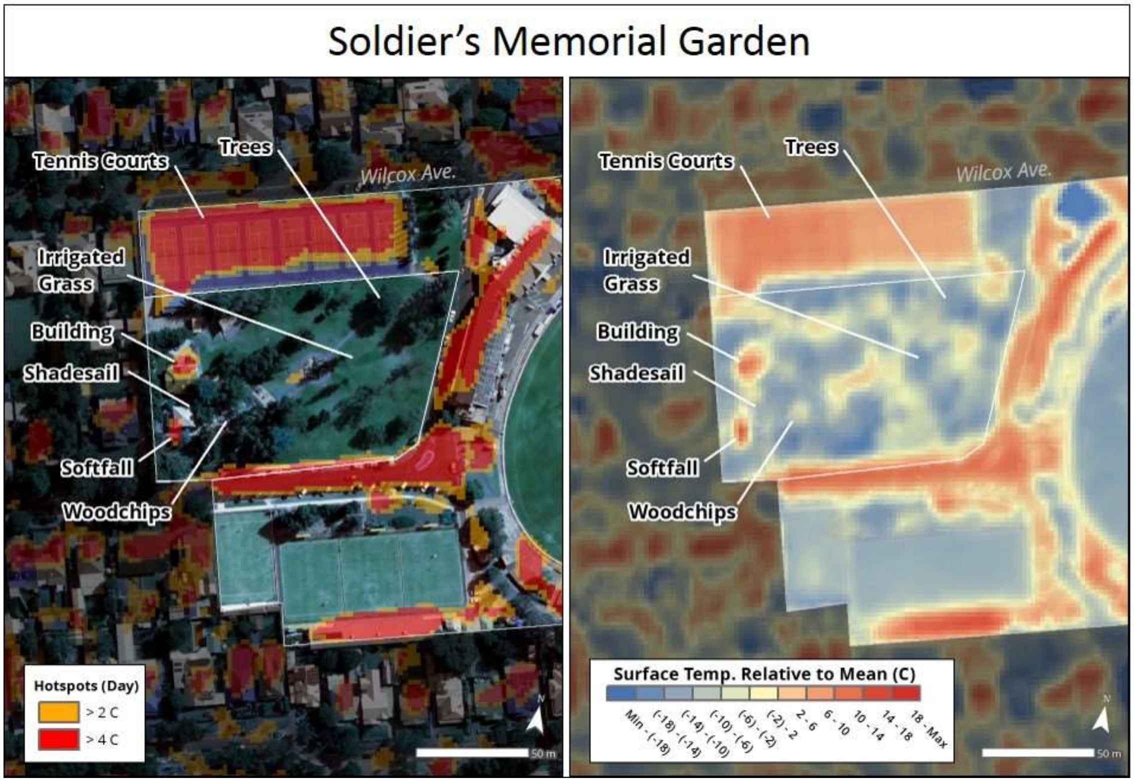

Figure 9. Case study 1: Daytime surface temperatures (right) of various playground features at Soldier's Memorial Garden, Prospect and their proximity and contribution to hot spots (left).

3.2.2.2 Irrigated grass versus non-irrigated grass (Adelaide Parklands)

Treed areas, parklands, and green space provide a general cooling effect on the landscape, but the presence of irrigation can produce dramatic changes in the distribution heat. The effects of irrigation are explored through a comparison of the minimally-irrigated Victoria Park area and heavily-irrigated Pulteney Grammar sports fields by looking at NDVI, a measure of plant cover, density and greenness, and daytime land surface temperature.

The NDVI map of Victoria Park (Figure 10a) shows three distinct categories of land cover: partially-irrigated grass, non-irrigated grass, and impervious surfaces. The partially vegetated and treed areas are the coolest features in this landscape (Figure 10b) averaging 4°C cooler than average. However, the other two categories have a pronounced warming signal with the bitumen measuring 3°C above average, and the non-irrigated areas measuring 6°C above average. The extreme heat conditions present in non-irrigated grass and barren areas are a product of an unusually hot and dry summer which makes these areas some of the hottest surfaces in the landscape during the daytime, however the heat is quickly dissipated and non-irrigated grassed areas provide a cooling effect at night (Figure 10c).

In contrast, the well-irrigated grass present in the Pulteney Grammar sports fields produce lush vegetation (Figure 10d) which results in a cooler landscape during the day (Figure 10e). The partially-irrigated grass areas produce a warming signal consistent with Victoria Park (>5°C), but because these areas are smaller and interspersed with trees and irrigated areas, the overall impact is much less pronounced. The overall daytime temperature of the entire Pulteney Grammar sports fields (highlighted area in Figure 10) is 3°C cooler than the entirety of Victoria Park, and 4.9°C cooler when considering only the grass areas.

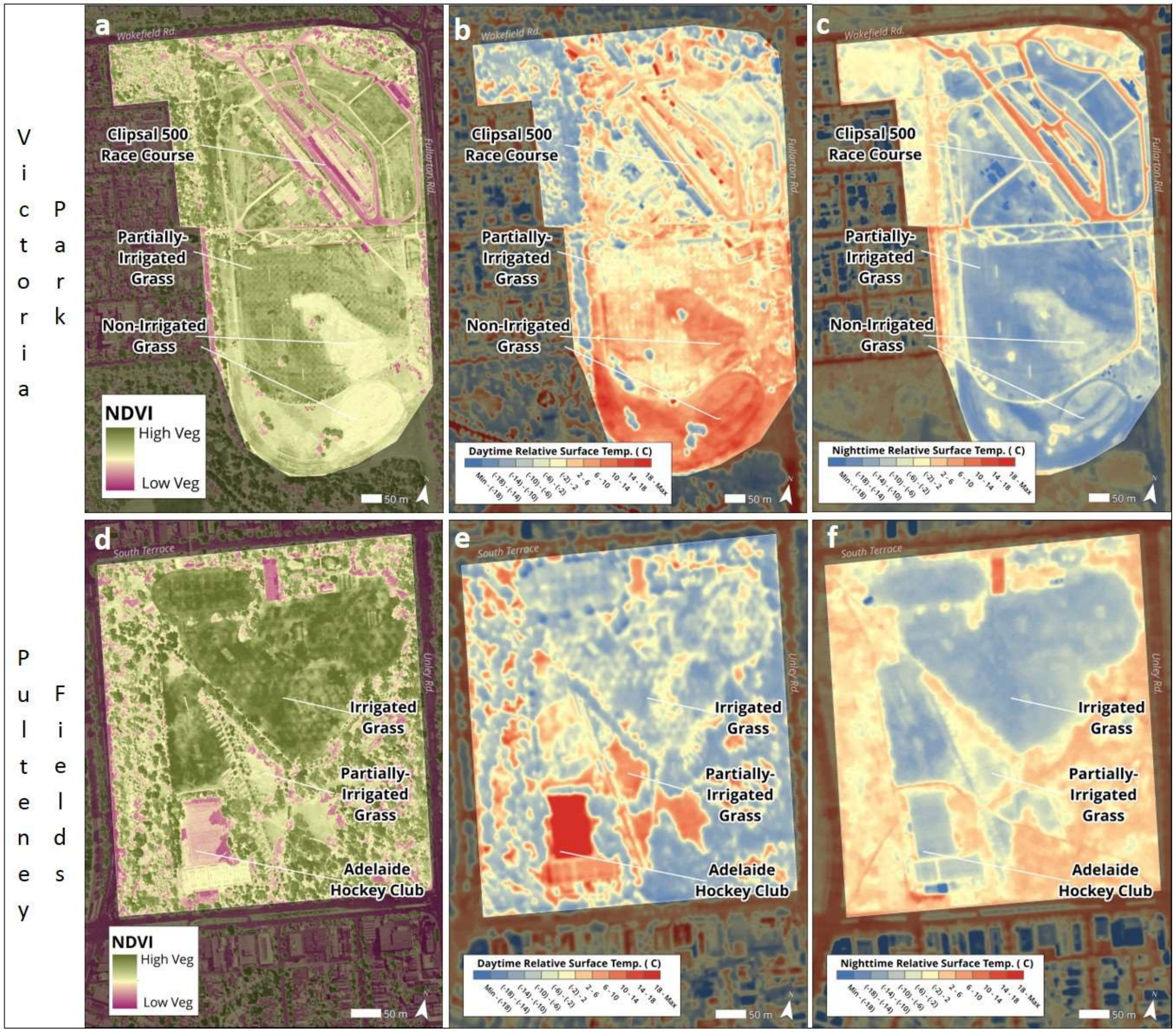

Figure 10. Case Study 2: Comparison of irrigated to non-irrigated landscapes at Victoria Park and Pultney Grammar, respectively. Panels a and d present NDVI data (i.e. vegetation greenness), panels b and e present the daytime surface temperature data, and panels c and f present nighttime surface temperature data for the same areas.

3.2.2.3 Water sensitive urban design (Leader Street, Forestville)

Street level raingardens and other water sensitive urban design (WSUD) features capture and retain surface water in the urban environment. The increased moisture and vegetation in these areas creates local cool spots. Although these features are very small compared to the resolution of the dataset (2 m x 2 m), some signals can be observed. However, because of the small areas and therefore small sample size, results should be further validated with additional on-ground measurements.

The WSUD features along Leader Street in Forestville provide a good case study of their potential impact on the thermal landscape, especially when compared to the barren kerbside of the former Le Cornu site on the northside of the street. The area containing five WSUD features along the southside of Leader Street collectively measured 0.9°C cooler than average during the day while the barren kerbside area across the street measured 2.7°C warmer than average (Figure 11). Because the WSUD features make up only a portion of the area analysed the full difference cannot be attributed to their presence, however, this case study is consistent with findings from the remainder of the study that irrigated grass and trees provide a substantial cooling effect (Figure 8).

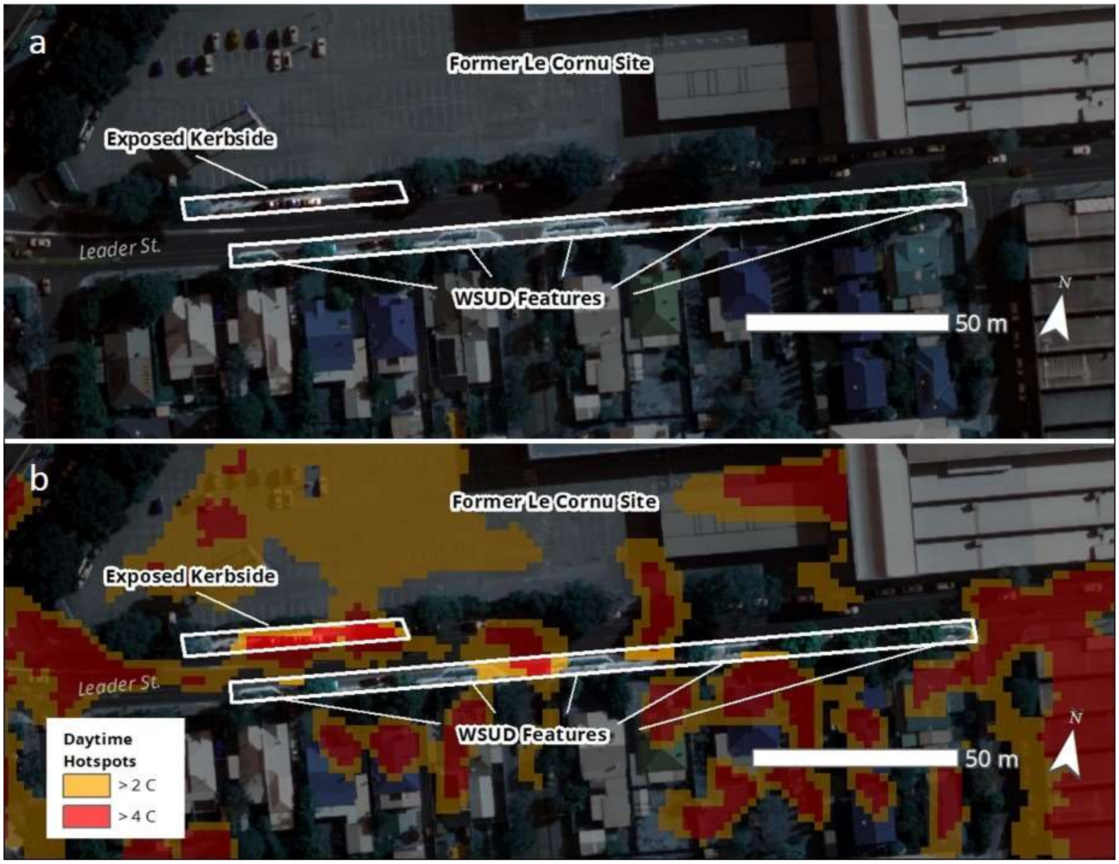

Figure 11. Case Study 3: The impact of Water Sensitive Urban Design features on the surface temperature of Leader Street, Forestville.

3.2.2.4 Bikeways (Frome Street, Adelaide)

The Frome Bikeway, from Halifax Street to North Terrace, averages 1.5°C warmer than the baseline temperature. However, looking just at the bikeway and excluding major intersections, the bikeway is only 0.8°C warmer than average, suggesting that vegetation and shading have reduced the average temperature for most of the rider's path. The most heavily vegetated section of the bikeway, from Halifax Street to Carrington Street was also the coolest, measuring 1.5°C cooler than the baseline, and 3°C cooler than the average for the bikeway (Figure 12).

Hotspots (individual surfaces warmer than 2°C above average) are present along the bikeway as they are among most roads in the urban centre, however, there is an increase in the concentration of hotspots at the intersections of Frome Street with other roads, further supporting the suggestion that the Frome Bikeway is slightly cooler than most other roads.

The new bikeway installations replace bitumen (a 4°C above average surface) with concrete (2°C below average surface during the day) and increase the shade of these areas with additional trees (a 6°C below average surface). If the entire bikeway were to become shaded by closed canopy trees, the net effect could be as large as a 10°C reduction in land surface temperature for those fully shaded areas.

The Frome Street Bikeway is a narrow urban feature that cuts across many different urban landscapes which means it is exposed to a wide range of drivers of heat. Given the small size of the bike path features and the complex shadowing patterns of the Frome Street corridor, more specific information about the benefit of local features are not robust enough to be reported here, but suggests this area would be an ideal location for additional air temperature investigation.

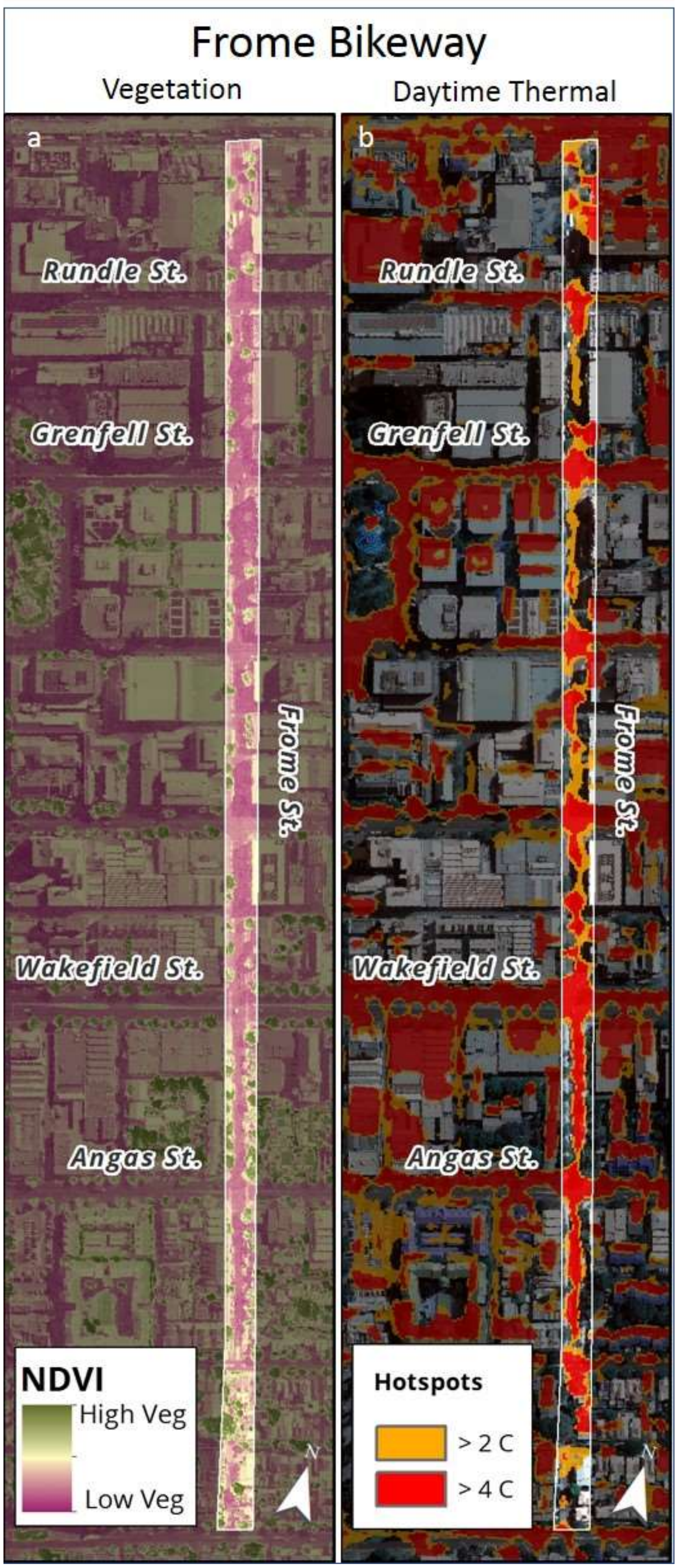

Figure 12. Case Study 4: NDVI (i.e. vegetation greenness) and surface temperatures along the Frome Street Bikeway from North Terrace to Halifax Street.

3.2.2.5 Tree lined streetscape (Rose Park, Norwood, and College Park)

Major streets are one of the most extensive features in the urban landscape and unfortunately, they are also one of the hottest. Bitumen, the predominant street surfacing material, averages 4°C warmer than average during the day, and 3.5°C warmer than average during the night, making it one of the largest contributors to both daytime and nighttime urban heat islands. However, the surrounding streetscape offers the potential to limit streets' contribution to heat islands.

Three streetscapes were analysed to explore the effect of tree-lined streets in reducing the thermal impact of roads. Kensington Road, along the border of Burnside and Norwood Paynehem & St Peters represents a largely exposed road (Figure 13a); Alexandra Avenue in Burnside represents a tree-lined boulevard with an open canopy that blocks a portion of the direct sunlight (Figure 13b); and Fourth Avenue in Norwood Paynehem & St Peters represents a closed canopy street where trees block nearly all of the direct sunlight (Figure 13c).

During the daytime, exposed Kensington Road and surrounding streetscape (highlighted area Figure 13a) measured 3°C above average (slightly cooler than the land scape analysis of bitumen which measured 4°C). In contrast, tree-lined streetscape of Alexandra Avenue recorded 4.5°C below average and the closed canopy of trees lining Fourth Avenue lowered temperatures to 6.5°C below average.

During the nighttime, Kensington Road and its streetscape remained 2.4°C above average, therefore remaining warm long into the nighttime. Fourth Avenue was slightly above average (by 0.6°C) exhibiting the insulating effect of trees. Alexandra Avenue, due to its mix of trees, bitumen, and open grass had no pronounced warming or cooling effect at night.

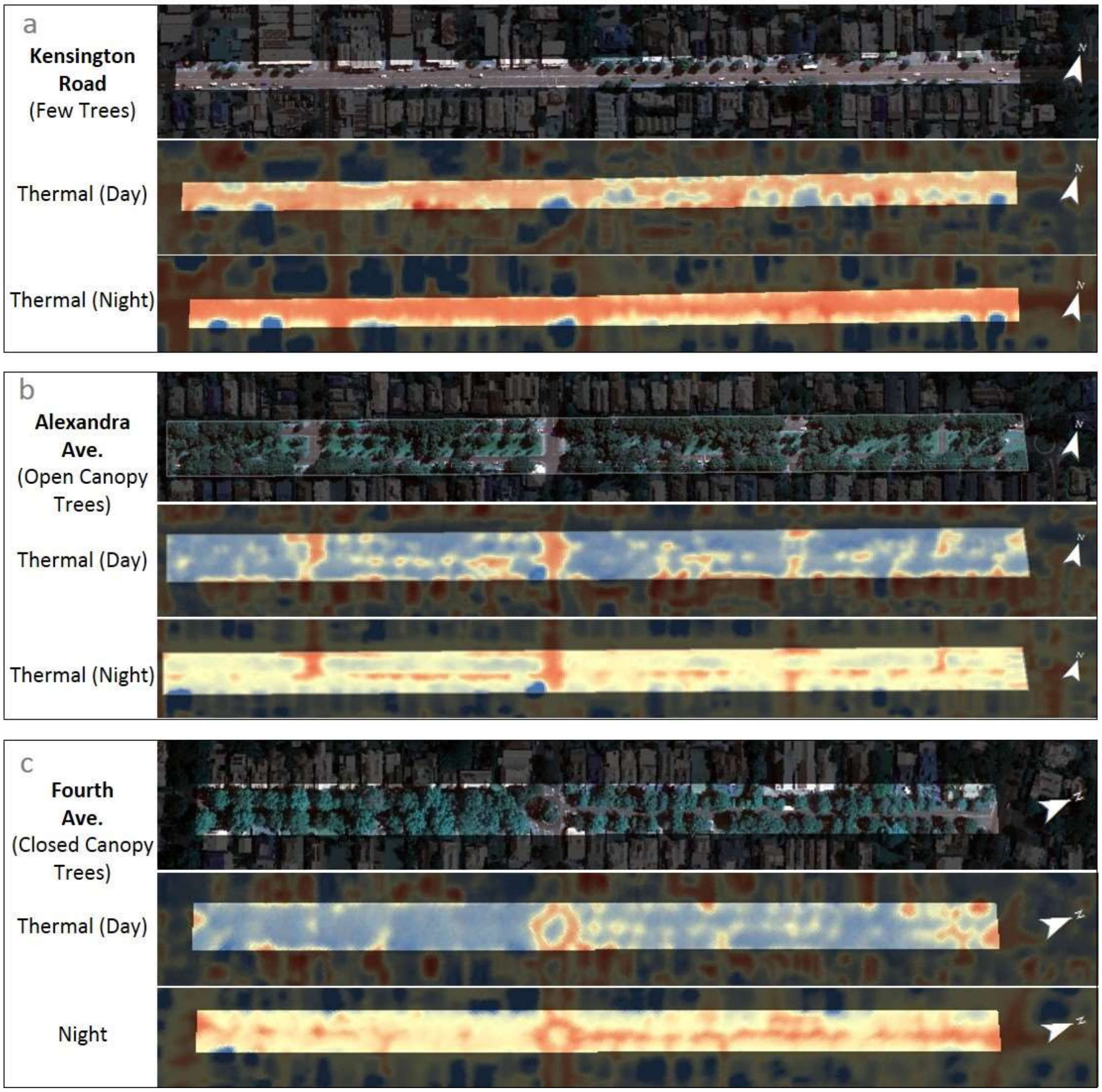

Figure 13. Case Study 5: Surface temperature of streets with and without trees during day and night.

3.2.2.6 Surface materials (Burnside Village Shopping Centre)

Burnside Village Shopping Centre presents a case study for investigating the thermal signal of different surface materials used in parking lots. Hard impervious surfaces are general hotspots in the urban landscape but the two main surface materials, bitumen and concrete, have markedly different thermal responses.

In Burnside Village, the bitumen covered parking areas measured 4.3°C warmer than average during the day, whereas the lighter coloured concrete only measured 0.9°C warmer than average (Figure 14b). No significant temperature difference was found between concrete on the ground level and on top of the parking structure.

Nighttime presented a different pattern with both surfaces delivering a 4°C warming signal (Figure 14c) suggesting that while concrete and light-coloured surfaces may be effective for avoiding daytime heat, the material still retains thermal energy and radiates it back during the nighttime. The parking area at Burnside Village is largely unshaded but the areas with tree shading recorded 5.3°C of cooling during the day and a slight 2°C warming during the night, consistent with the results of the land use analysis.

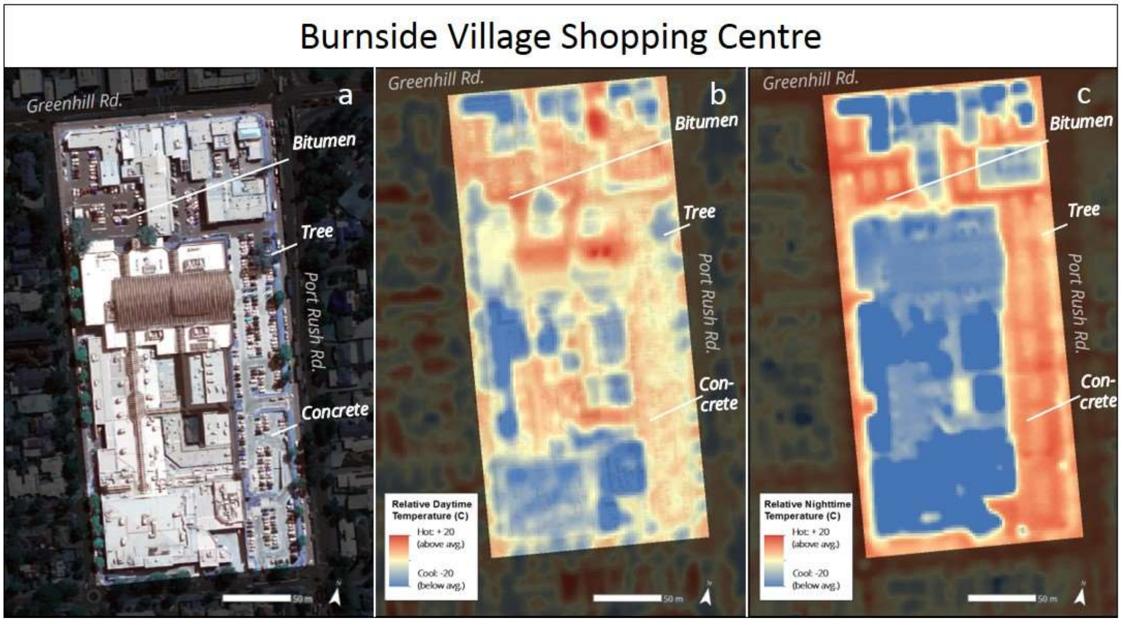

Figure 14. Case Study 6: Impact of different car parking lot construction materials on surface temperature.

3.2.2.7 Density of development (Campbelltown)

The impact of the density of residential housing was explored with three examples of in Campbelltown. The first example shows a high-density development designed with light-coloured roofs and concrete driveways compensating for a lack of vegetation (Figure 15a). These colour choices result in the property's land surface temperature measuring 5°C cooler than average during the day. In contrast, the second example is a medium density, multiple unit dwelling with some vegetation, but a dark roof (Figure 15b). The dark roof of the building measures 3.5°C warmer than average. The vegetation, while cooler than average cannot compensate for the strong warming signal, leading to an average temperature 1.5°C warmer than average during the day for this property. The third example illustrates the impact of a combination of a high-density, dark roofed property with limited vegetation (Figure 15c), which drives a 3.4°C warmer than average temperature, slightly lower than the second example due to a slightly lighter roof colour.

The nighttime temperatures for all of these properties significantly, with the first example measuring 3°C below average, the second example measuring 0.3°C below average, and the third example measuring 0.5°C below average. In contrast, high-intensity hotspots such at bitumen continue to produce a strong warming signal late into the nighttime because the absorptive characteristics and high density of the materials retain a much greater portion of thermal energy. These three examples illustrate how the density of developments contribute to localised heating and how that relationship is influenced by building material choices and colours at the property scale. Further analysis of building materials over larger areas will help identify how effective certain materials are in mitigating heat build-up.

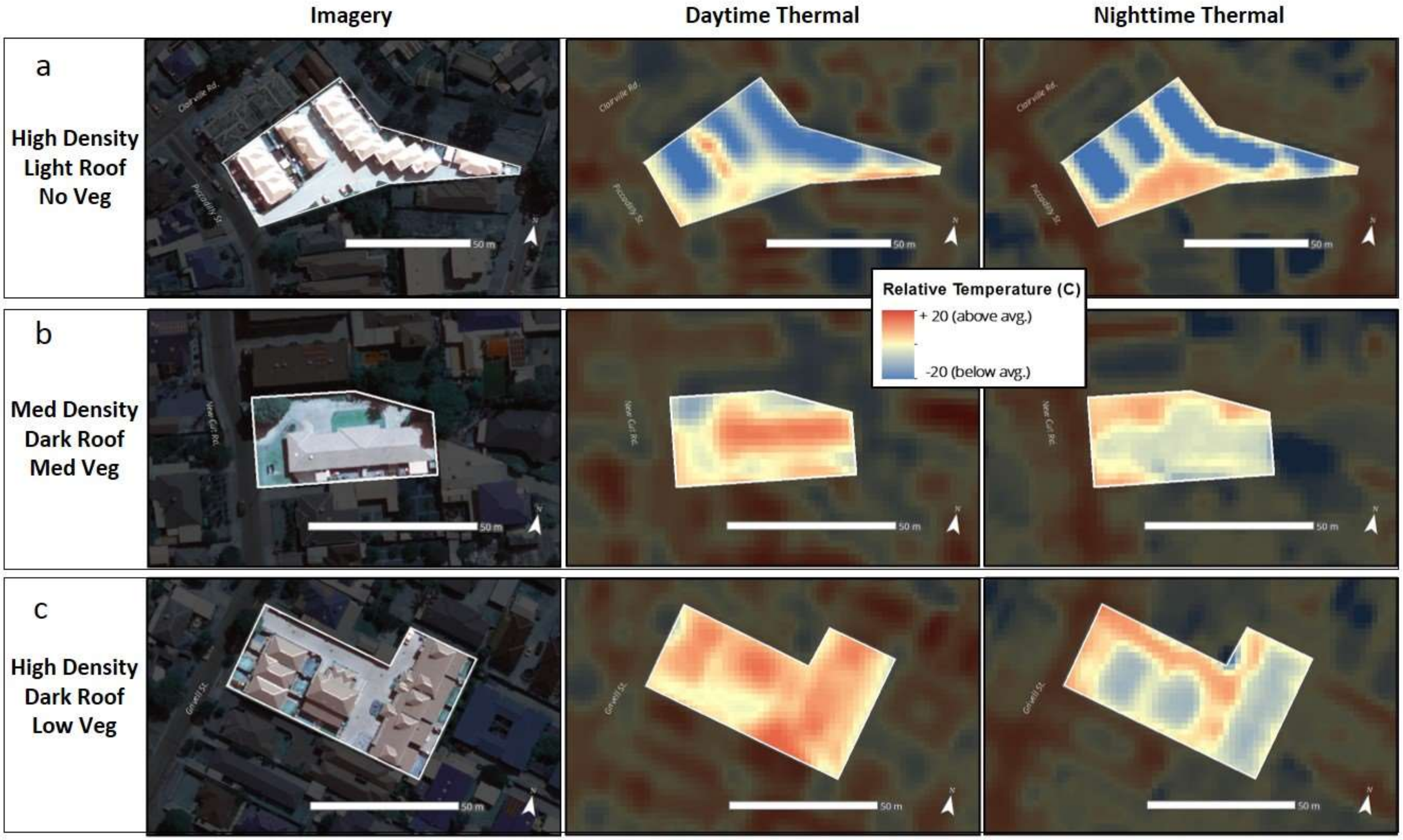

Figure 15. Case Study 7: Impact of the density of development on surface temperature.

3.2.2.8 Integrated development decisions (Lochiel Park, Campbelltown)

While the choice of surface material or land use can impact local scale temperature and liveability, collectively these decisions affect urban heat distribution at a landscape scale. Lochiel park in Campbelltown, less than a kilometre from the examples in Case Study 7, illustrates how local scale land surface types and land use decisions can aggregate into larger thermal patterns.

Three areas of Lochiel Park were assessed, looking at high-density areas with light roofs, medium density areas with mixed roofs, and the broader area including surrounding parklands (Figure 16). While the broader area measured 0.7°C cooler than average, the two areas of development exhibited very different temperatures. The lighter roofed area measured 1.1°C cooler than average even without any interspersed vegetation. In contrast, the medium-density development area with predominately darker roofs, but with some trees and vegetation, measured 0.2°C above average. This medium development area demonstrates how mixed land uses integrating cool features into an otherwise hot landscape can be effective in preventing hotspots accumulating into urban heat islands. The high-density area demonstrates how smart design can allow high density developments to occur with lower impact on urban heat islands.

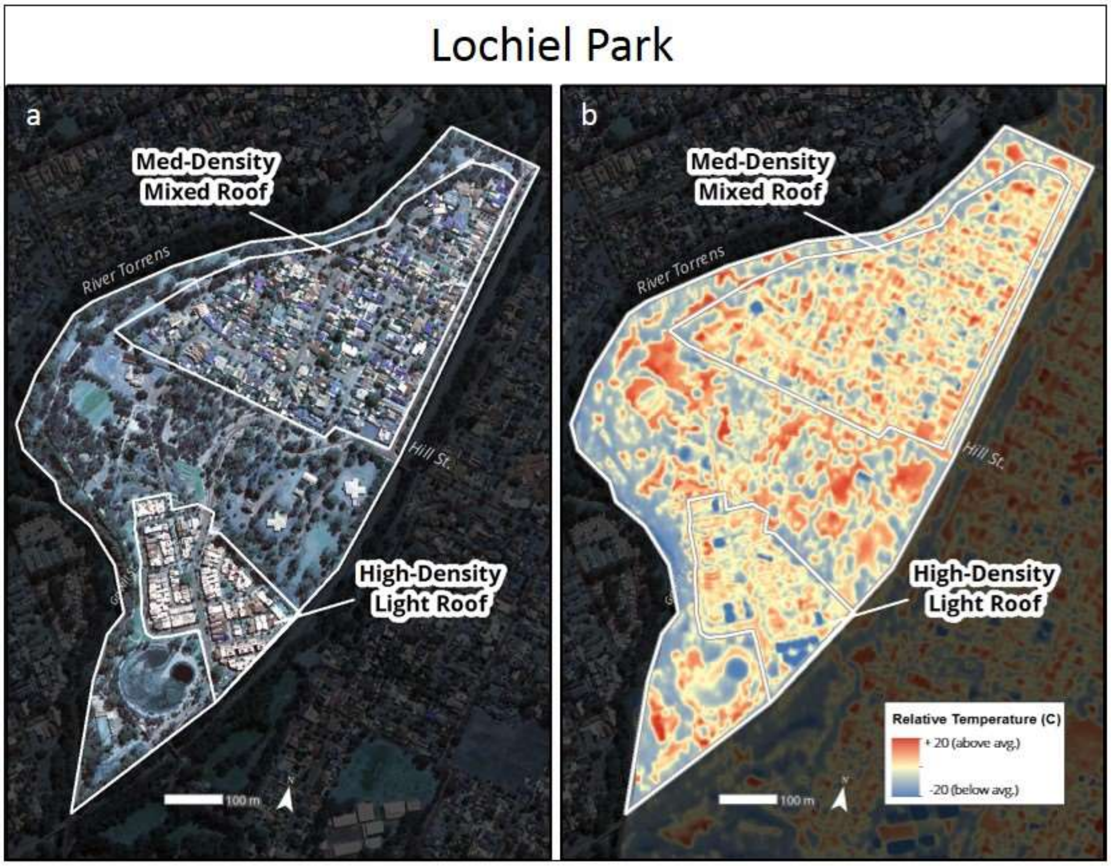

Figure 16. Case Study 8: The impact of landscape scale development decisions on surface temperature.

3.2.2.9 Road surfaces (Mawson Lakes)

Roads represent a major land surface in cities, and as such, the amount of heat they absorb and retain influences overall thermal performance; this is especially true at night when roads are the dominant persistent heat source. The Mawson Lakes area presents a case study of various road surface types and their temperature during day and night (Figure 17), specifically focusing on the residential neighbourhoods directly west of the University of South Australia, Mawson Lakes Campus. This area is characterised as a medium density residential area with predominantly lighter coloured roofs, interspersed with young street trees 3-4 m tall, with grass mainly constrained to park areas. Bitumen roads are the main road type and measure 3.7°C warmer than average in this area. Concrete, which is limited mainly to “The Mall” measures 0.7°C above average during the day (Figure 17b). During the nighttime, concrete maintains the same temperature at 3.7°C above average, whereas bitumen begins releasing its heat and becomes a warming surface at 2°C warmer than average (Figure 17c).

Overall, in this area there is a net cooling effect of 2.6°C during the day and 2.1°C at nighttime due to the prevalence of cool roofs which more than compensate for the number of hot roads. While this exemplifies how material choices contribute to landscape-scale heat, it also highlights the additional cooling that could be obtained by switching to a cooler road covering.

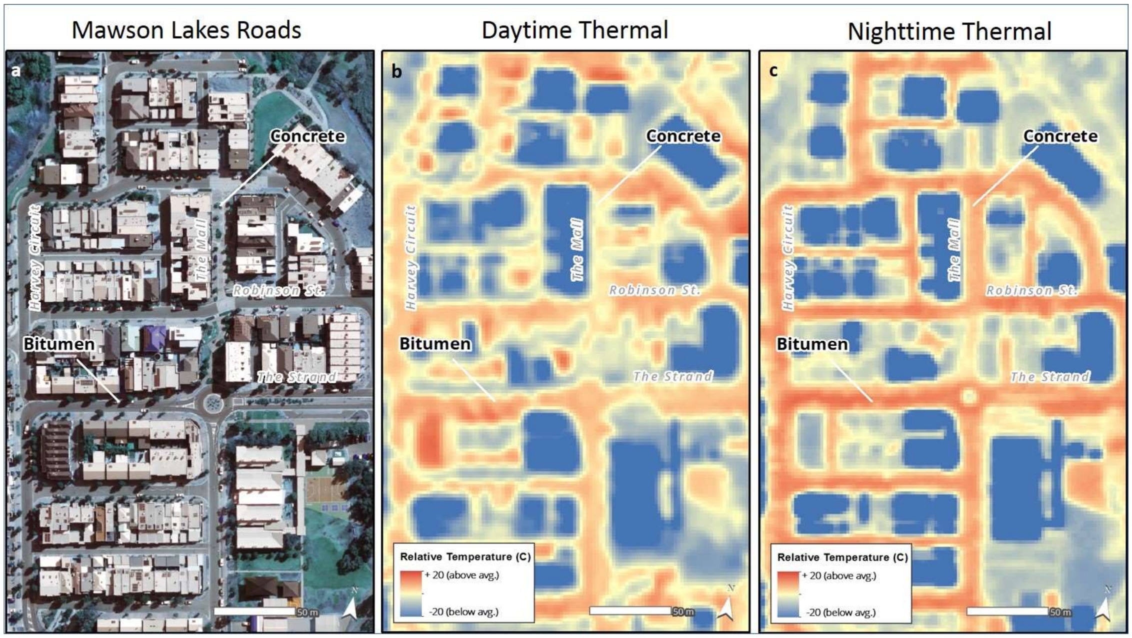

Figure 17. Case Study 9: The impact of road surface type on surface temperature.

3.2.2.10 Artificial turf (Modbury Soccer Club)

The hottest land surface type in the study area is artificial turf. The Modbury Soccer Club, in particular the Smith Partner’s Stadium, illustrates the contrast between artificial and natural turf (Figure 18). The artificial turf field measured 11.4°C warmer than average. In contrast, nearby irrigated grass fields at the same time measured 4.5°C cooler than average.

Local air temperature measurements captured as part of this study (Section 4) showed air temperatures over bitumen to be up to 7°C warmer than in open grass areas. Given that regional air temperature on the day of measurement was 36°C (BOM 2018), and that artificial turf has been shown to be hotter than bitumen, it is likely that players on the field during the hottest portion of the day experienced temperatures in at least the mid 40°Cs.

The artificial turf measured 5°C hotter than local tennis courts and a full 7°C hotter than the nearby parking lot. The broader area surrounding the artificial turf field is mainly covered by grass and trees which was 4°C cooler than average. The extreme heat of the turf field was sufficient to create its own 125 m x 125 m heat island (Figure 18c).

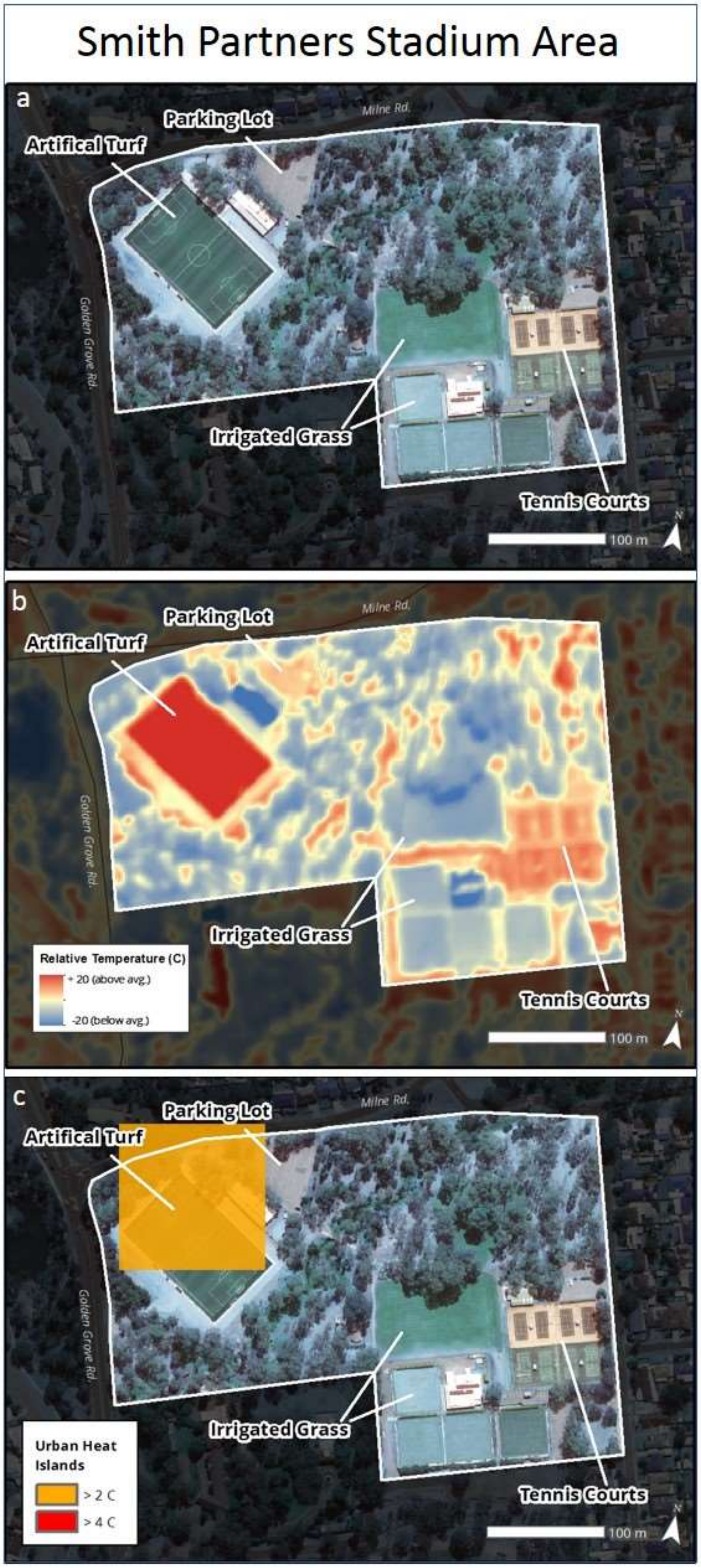

Figure 18. Case Study 10: The impact of artificial turf on surface temperature.

3.3 Social vulnerability

The unequal distribution of urban heat identified in Section 3.1 means that some parts of the community experience disproportionate impacts of hot weather. Social vulnerability analysis explores who is most exposed to urban heat islands by comparing heat island location to a Social Vulnerability Index (SVI) which uses ABS 2016 census data to tabulate the number of youth, elderly, low income earners, culturally and linguistically diverse persons, and persons with disabilities that live within each heat island. Each variable was scored from 0-1 and aggregated to calculate the total SVI score. Over the study region, the average SVI score was 0.5 with a maximum potential score of 5. The average SVI varied from 0.15 in Adelaide to 0.70 in Campbelltown, however, council averages were skewed according to population density with low density tracts reducing the SVI score.

Key statistics on heat islands and their intersection with social vulnerability are presented in Table 5 and Figures 19 and 20. The patterns of heat islands and social vulnerability fall into two categories. The larger swaths of heat island areas, namely industrial areas and open space along the hills face zone, have small populations and generally low social vulnerability. More importantly are the smaller decentralized heat islands that are dispersed across the study area, where heat is concentrated in areas that have very high social vulnerability (dark blue areas in Figure 19). These areas contain people who are the most exposed to urban heat with the most limited means of managing that heat, and as such should be prioritised for heat mitigation actions.

Tea Tree Gully has the largest amount of exposure with over 12 km^2 of socially vulnerable populations within heat islands during the day, and has the second most vulnerable population exposed to nighttime heat. While Salisbury has the largest daytime heat islands, most are concentrated in the large industrial areas, although the non-industrial areas have very high social vulnerability (Figure 19). At night Salisbury cools rapidly seeing a 95% reduction in heat island area, although those areas that remain in a heat island have slightly higher vulnerability.

Campbelltown has 2.2 km^2 of area within daytime urban head islands and 74% of that area is classified as “socially vulnerable”, or having a greater than average SVI score (Table 5). During the nighttime, the area of heat islands increases in Campbelltown to 3.6 km^2 but also shifts to less socially vulnerable areas resulting in a decrease in nighttime heat island exposure for vulnerable populations (Figure 19).

In Adelaide, nighttime heat islands are 40% less in size than Campbelltown but affect a larger number of socially vulnerable people. Burnside heat islands are eight times more prevalent at night, exposing eight times more socially vulnerable people. Norwood Payneham & St Peters, Walkerville, and Prospect all have small heat island areas (<0.25 km^2) with varying degrees of social vulnerability. Unley falls into a similar category except its nighttime heat islands expand to 0.6 km^2 of which approximately half are classified as socially vulnerable.

Social Vulnerability Index					
	SVI Score (Average)	**Daytime UHI Area (km^2)**	**% Socially Vulnerable Daytime UHI**	**Nighttime UHI Area (km^2)**	**% Socially Vulnerable Nighttime UHI**
Study Area	**0.50**	46.97	**44%**	29.67	**36%**
Adelaide	0.14	1.36	2%	0.75	19%
Burnside	0.55	1.22	22%	10.02	25%
Campbelltown	0.70	2.20	74%	3.61	34%
NPSP	0.57	0.27	71%	0.05	0%
Prospect	0.64	0.25	31%	0.13	38%
Salisbury	0.48	20.81	14%	1.11	37%
Tea Tree Gully	0.41	17.66	69%	9.69	23%
Unley	0.57	0.27	35%	0.64	54%
Walkerville	0.61	0.14	78%	0.02	100%

Table 5. Social Vulnerability Index scores for each council and for the urban heat islands within each council.

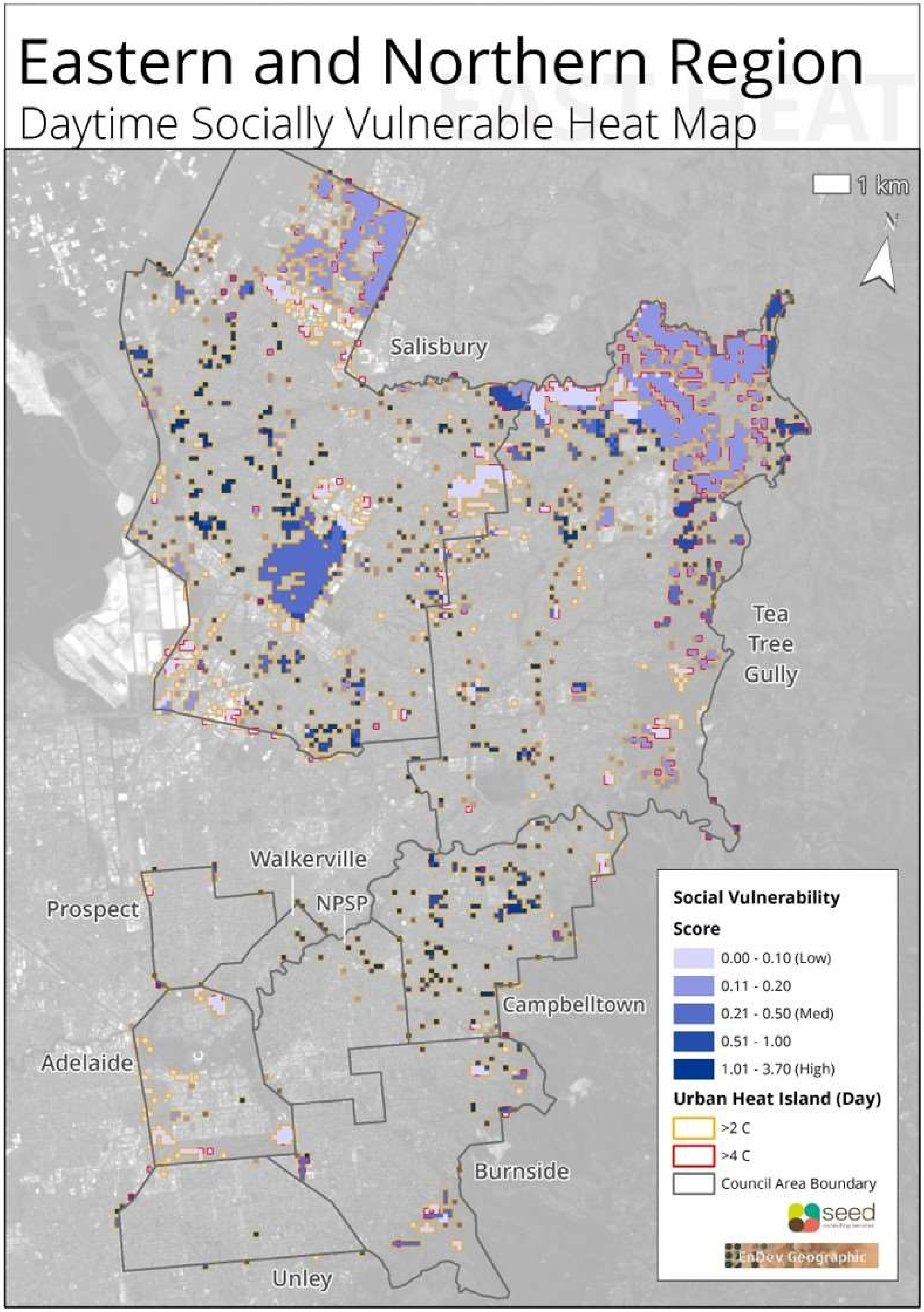

Figure 19. Daytime social vulnerability map.

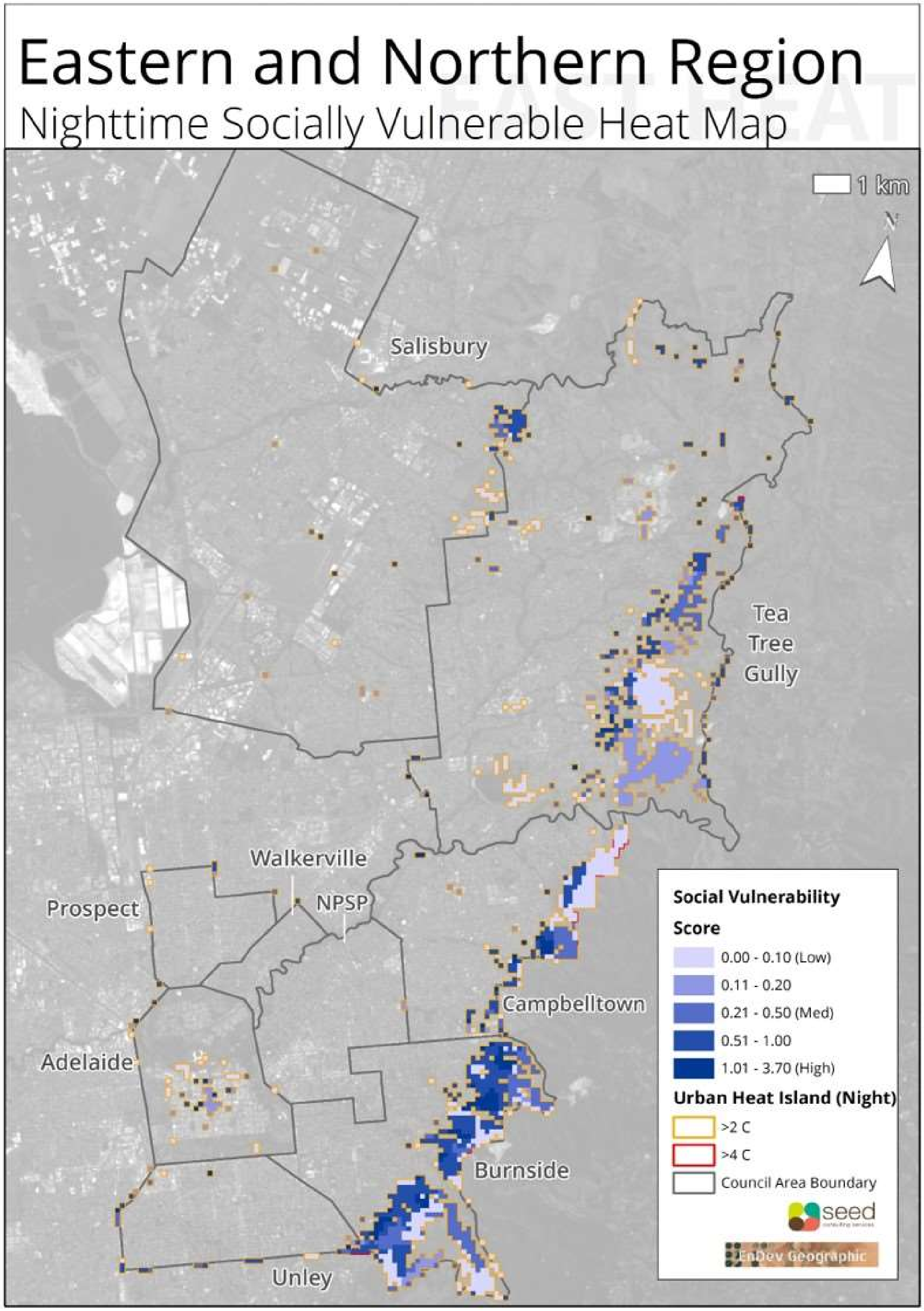

Figure 20. Nighttime social vulnerability map.

4 Factors that influence temperature at a local scale

4.1 Local scale climate

Remote sensing of land surface temperature provides a landscape scale approach to identifying urban heat islands and developing heat reduction strategies. However, the way that people experience extreme heat is better described by thermal comfort, which combines a range of site-specific climate factors such as surface temperature, air temperature, humidity, and wind.

To better understand microclimate, a range of meteorological observations relevant to human thermal comfort were taken on the ground at the City of Tea Tree Gully offices in Modbury. This information was then compared with surface temperature data collected by the aircraft. A detailed technical summary of this analysis is provided in Attachment 6.

The meteorological observations were recorded on the day and subsequent night of the aircraft flyovers (10-11 March 2018) using weather stations called "Kestrels" positioned in three different local microclimatic environments: irrigated grass open area; a sealed carpark; and a heavily tree-shaded grassed environment. The information collected was then used to calculate "human thermal comfort", which describes the way that people experience their local environment. Additional data was also collected on 23 March to further explore the difference in air and surface temperature between the sites.

Manual, handheld measurements of surface temperature were also made at each site every 30 minutes, using a handheld infrared thermometer. Measurements were made from late morning until late nighttime on the day of the flight, capturing surface thermal and human thermal comfort data, including for the specific times of flights.

4.2 Comparison of surface temperature measurements

The surface temperature pattern was the same for both aircraft and the handheld device, which was that bitumen was hotter than grass, which was hotter than trees. This pattern changed somewhat in the night with the surface temperature beneath trees being warmer than grass on account of the grassed areas cooling more quickly Figure 21.

Aircraft collected surface temperature was lower though than the handheld device for open grass and the car park, but greater than the temperature recorded for the tree. At night there was more similarity of aircraft measurements for open grass and tree-shaded areas and a larger underestimation of carpark surface temperature (by 5.6°C).

Air temperatures differed considerably from handheld and aircraft measured surface temperature, which is to be expected given the range of local factors that influence air temperature.

These results confirm that broad surface temperature patterns from aircraft and even satellite remote sensing cannot be directly used to determine microscale surface temperature or air temperatures. There are a number of reasons for differences in surface temperature, one of which is that the relative resolution of the observations differs with aircraft pixel resolution at about 4m^2 compared with hand-held observations that are at a scale of less than 1m^2. Another issue is that the aircraft cannot "see" beneath the tree canopy so is likely overestimating the daytime surface temperature beneath the canopy. There will also be some local microclimatic/topographic variability that the aircraft cannot detect.

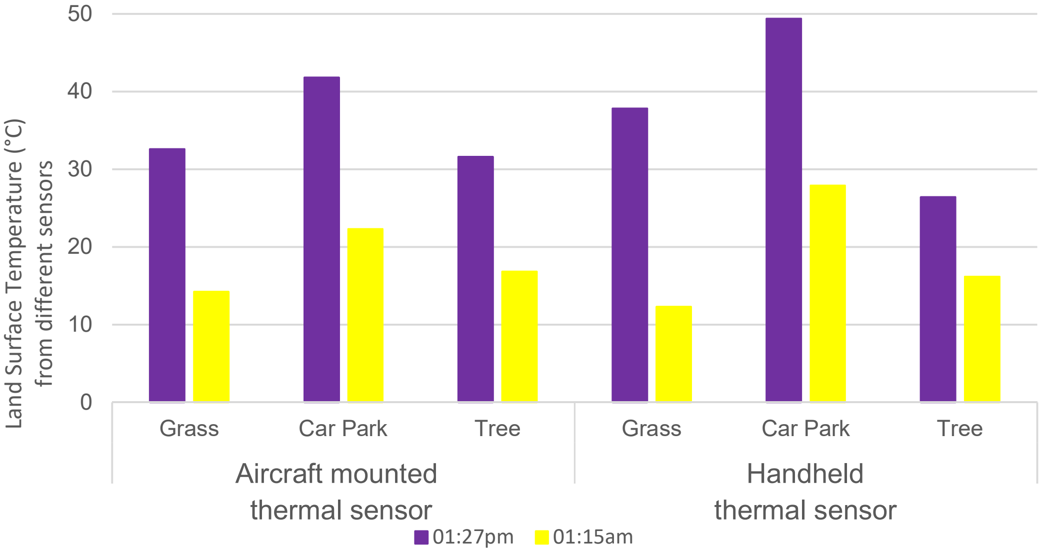

Figure 21. Surface temperature at three sites at Tea Tree Gully Councils offices measured from the flyover (aircraft) and by using a handheld infrared thermometer.

4.3 Local microclimate variation shown by meteorological data

Local differences in surface types, water availability and heat exposure, among other factors, can create differences in microclimate at scales of 10 m to 100 m. This was shown at the Tea Tree Gully Council offices where data collection sites were within 200 m of one another. Relevant data was collected on both 10-11 March and again on 23 March.

On the day of the flyover, air temperature[1] was 3-5°C warmer during most of the afternoon in the carpark compared to under the tree canopy. This reflects the greater amount of energy

---

[1] All air temperature measurements were recorded at 1.2 m above the ground surface.

in the carpark that is heating the air. For the treed site, lower direct sunlight and the moist grass surface results in cooling and moistening of the air over the ground surface.

After sunset, the temperature differences between locations substantially reduced, but the humidity difference remained, showing the importance of continued evaporation from the moist grass surface under the tree canopy.

On 23 March temperatures above the carpark surface were 3-5°C warmer than at the tree-shaded location for much of the late morning and afternoon, reinforcing the temperature pattern observed on the day of the flyover. For much of the day, temperatures above the open grass remained between the shaded and sealed carpark surface, but later in the afternoon the differences disappeared, possibly because of drying of the open grass surface.

4.4 Local thermal comfort

Given the considerable microclimate variations between the different sites at the City of Tea Tree Gully offices, it would be expected that this would be reflected in human thermal comfort. A simple Heat Stress Index (HI), provided as direct output from the weather stations, was calculated from both environmental temperature and humidity. The highest HI was experienced at the carpark site through much of the afternoon on both 10 and 23 March (Figure 22). HI for the open grassed site tended to be intermediate between the carpark and treed sites early in the day, but exceeded that of the carpark by mid-afternoon, until cooling (likely associated with irrigation) dropped the HI at the grassed site in the late afternoon.

Figure 22. The Heat Stress Index (HI) for the treed (shaded), open grassed, and carpark (sealed) sites on 23 March 2018.

There are several other measures of human thermal comfort, including the Universal Thermal Climate Index (UTCI), which accounts for the effects of clothing and the local radiative environment on how people experience hot weather in terms of °C. UTCI temperatures can be classified into various heat stress classes, from Comfortable (no heat stress) to Moderate, Strong, Very Strong and Extreme. As can be seen in Table 6, heat stress at the carpark site during the day on both 10 and 23 March ranged from Strong to Very Strong, and was also Strong at the open grass site on 23 March. However, UTCI in the early hours of the morning on 11 March at both the treed and carpark sites was categorized as being Comfortable, demonstrating these sites equalise as the local environment cools during the night.

	UTCI Category (ºC)		
	Carpark	**Tree**	**Grass**
10 March (2:40 pm)	Very strong (37.7)	Moderate (31.9)	-
11 March (1:15 am)	Comfortable (20.8)	Comfortable (21.0)	-
23 March (11:30 am)	(Strong) 35.7	Moderate (30.6)	Strong (32.5)

Table 6. Universal Thermal Climate Index calculated for various times on March 10, 11 and 23, 2018.

5 Responding to urban heat risks

5.1 Distribution of heat across the region

Hot spots and urban heat islands are widespread across Eastern and Northern Adelaide. Without specific treatment options being developed and applied, their impact can be expected to grow through time. This will in-turn be exacerbated by climate change and infill development if it comes at the expense of green infrastructure.

This analysis provides insights into the most heat-exposed councils and suburbs in Eastern and Northern Adelaide (Table 7). All of the councils displayed a similar proportion of hotspots, ranging from between 26% and 43% of their land areas. What differs though is where those hotspots accumulate into daytime heat islands, with councils ranging from virtually no heat islands (Unley) to heat islands covering almost 1/5 of their land area (Salisbury and Tea Tree Gully).

The data suggests that older suburbs closer to Adelaide such as those in Unley, Burnside, Norwood Payneham & St Peters, Walkerville, and Prospect that have predominately residential areas comprised of more established vegetation, more mature trees, and larger block sizes present cooler land surface temperatures and fewer heat islands. These councils tend to have greater variation in surface coverings with individual properties mixing houses with vegetation, and residential and business areas heavily interspersed with parks. In contrast, the hotter councils have a higher fraction of large homogenous and often tree-less land coverings such as factories and industrial sites, large shopping centres, and Parafield Airport (for Salisbury), all of which contribute to heat islands. This pattern suggests distributing cooling surfaces amongst heat-accumulating surfaces is an effective strategy for mitigating urban heat islands.

At a whole of region scale, the drivers of hot spots and heat islands mainly reflected the expected patterns of impervious surfaces (roads and parking lots) being hot, irrigated green spaces and water bodies being very cool, and buildings presenting a range of responses based on their material composition, especially roof colour.

There was an exceedingly warm response of non-irrigated, non-treed, open space and bare ground; in some areas, with these surfaces registering as hotter than concrete. While non-irrigated open space is usually warmer than irrigated turf, the magnitude of the difference is surprising compared to a previous local study in Western Adelaide (City of West Torrens, 2017), and most likely driven by the extremely hot and dry summer that preceded data collection, making the ground’s colour and hardness closer to that of concrete than grass. As expected these areas cooled quickly in the nighttime meaning that they were no longer heat sources at night.

	Average Daytime Temperature (C°)	**Hotspot Area (>2C)**	**Urban Heat Island Area (>2C)**
Eastern and Northern Region	**37.6**	36.8%	13.6%
Adelaide	**37.2**	31.4%	7.6%
Burnside	**36.5**	28.4%	4.1%
Campbelltown	**37.4**	37.4%	8.4%
Norwood Payneham & St Peters	**37.3**	31.3%	1.6%
Prospect	**37.6**	29.5%	1.3%
Salisbury	**38.9**	42.8%	18.5%
Tea Tree Gully	**36.6**	36.6%	18.5%
Unley	**36.9**	26.4%	0.5%
Walkerville	**37.4**	30.0%	1.6%

Table 7. Council level comparison of the proportion of hotspots versus the proportion of heat islands.

An unexpected finding was the nighttime heat island concentration along the front of the Adelaide Hills. Several causes have been suggested for this pattern, including the presence of a weak nighttime sea breeze which may have cooled the lower lying areas without having the strength to reach and cool the higher elevations, or the westward-facing hills have exposure to the sunlight later in the afternoon allowing them to continue absorbing heat later into the day. Regardless of the driver, awareness of this nighttime pattern is useful in understanding where heat is accumulating in the landscape.

Complementing the broad analysis of the relative temperature of land use types were the case studies, which highlighted specific features of note that can inform future urban design decisions. Based on this analysis, the following key messages can be used to inform future urban design and planning decision making:

- artificial turf creates some of the hottest surfaces during the day and very minor cooling at night;
- bare dirt shows as much hotter during the day but is neutral at night with regard to heating and cooling;
- bikeways can benefit from consideration of different road surface materials and vegetation in close proximity to cyclists;
- bitumen shows as very hot during the day and continues to re- release that absorbed heat overnight;
- concrete surfaces are closer to average temperatures during the day and are cooler overnight, providing a cooler alternative to bitumen as a road or car park surface;
- dry grass shows as hotter during the day, but the heat is quickly lost at nightfall, and such areas then contribute to cooler overnight places;

- incorporation of trees and shade sails into playgrounds can reduce the increased heat caused by surfaces such as rubber softfall, bitumen and concrete;
- surfaces that are evaporating water are cooler, particularly during the day when humidity is lower and evaporation higher (this includes vegetation);
- the difference between light roof surfaces that reflect heat, and dark roof surfaces that absorb heat can be up to 10ºC on average hotter during the day;
- tree lined streets are much cooler during the day and retain some of this heat overnight; and
- WSUD features, in addition to improving the water quality of stormwater runoff, can create localised cool features along roads.

Although surface temperature at a landscape scale provides an appropriate data set to develop and target heat mitigation activities, the way that heat is experienced at a local scale by people is determined by how surface temperature and other factors influence air temperature and hence thermal comfort. This study assessed the local scale microclimate by measuring surface and air temperature in three environments at the City of Tea Tree Gully offices in Modbury: a bitumen carpark, irrigated grass, and tree shade.

The results demonstrated that onground, considerable microclimatic differences can occur across relatively short distances, depending on variables such as exposure, surface materials and water availability. Observations based on surface temperature showed the ability for bitumen to absorb and retain much greater amounts of heat than grass and trees, which inturn had an impact on air temperature. The same measurements also reinforced that there are limitations on the extent to which landscape scale surface temperature measurements can be used to explain local scale microclimate observations.

The microclimatic analysis confirmed the critical benefits of irrigated green infrastructure, and especially of tree shade, in providing human thermal comfort benefits in warm to hot summer conditions.

5.2 Prioritising areas for heat mitigation

While hot spots and heat islands provide a general indication of priority areas for heat mitigation, this can be further refined by identifying where they intersect with areas of social vulnerability and where large numbers of people are active outdoors (i.e. behavioural exposure) (Norton, et al., 2015).

The relationship between social vulnerability and heat islands was assessed by developing a social vulnerability index based on the number of youth, elderly, low income earners, culturally and linguistically diverse persons, and persons with disabilities that live within each heat island.

Overall, 44% of the areas identified as having day time urban heat islands also contained socially vulnerable people (i.e. SVI score above average). The patterns of heat islands and social vulnerability fall into two categories. The first is where heat island areas, mainly influenced by industrial areas, the airport, and dry open space along the hills face zone, have small populations and generally low social vulnerability. The second more important category though are smaller decentralized heat islands that are dispersed across the study area. While each council has urban heat islands that contain socially vulnerable populations, this issue is of greatest significance for Campbelltown, and Tea Tree Gully.

There were a number of specific suburbs that contain urban heat islands and that had a high degree of social vulnerability. In particular, nearly all of the heat islands in Campbelltown coincided with areas of high social vulnerability. However, Salisbury had a higher total number of socially vulnerable people living within heat islands.

Understanding the drivers of social vulnerability (e.g. age versus need for assistance with core activities) across suburbs will be important in designing mitigation strategies for assisting the community to prepare and respond to extreme heat. This may also provide information for councils to work with community service providers to target assistance during periods of extreme heat.

While an explicit analysis of behavioural exposure was not undertaken, the case studies used to identify the impact of surface type and land use characteristics do provide insights. For example, playgrounds with rubber softfall covering where children congregate and sporting fields with artificial turf, used as a low maintenance alternative to grass on lawn bowls greens, present substantially warmer than average surfaces than nearby areas of open space. Furthermore, bikeways and pedestrian thoroughfares with predominantly bitumen surfaces are much warmer than equivalent areas with a combination of hard surfaces and green space.

5.3 Future drivers of heat islands

5.3.1 Climate change

In Eastern and Northern Adelaide, climate change will lead to higher temperatures, reduced rainfall and longer, more severe, and more frequent heat waves. Areas already experiencing the urban heat island effect will bear the brunt of these harsher heat events. Materials identified in this study as absorbing large amounts of heat, such as roads, parking lots, dark coloured roofs, pavements, artificial turf and rubber softfall surfacing, will all absorb even more heat in the future.

Based on the Resilient East Climate Change Adaptation Plan (Resilient East, 2016), climate projections relevant to understanding the urban heat island effect in the region include the following[2]:

---

[2] Further, more detailed information about climate change projections for Eastern Adelaide are contained in the Resilient East Climate Change Adaptation Plan. This includes an explanation of the impact of climate models and emissions scenario choice on projections. Information relevant to the City of Salisbury, which is included in the study area for this project, are contained in the Adapting Northern Adelaide Climate Change Adaptation Plan.

- 1.6°C increase in average annual maximum temperature;
- 1.5-1.6°C increase in average maximum temperature in summer and autumn;
- The frequency of 2 or more days over 35°C will more than double; and
- 7% reduction in average annual rainfall.

Given that urban heat island identification is based on a relative assessment (i.e. surface temperature of a given location compared with the average for the region), it is possible that under climate change the urban heat islands will become hotter, but not necessarily expand. One factor that would lead climate change to alter the pattern of urban heat islands are if changing temperature and rainfall lead to large scale changes in the condition and extent of green space, especially in areas that are not able to be managed by council. Scenario testing and modelling approaches could be used to explore this impact.

Given the magnitude of difference in temperature between some materials (e.g. dark roofs versus light coloured roofs, artificial turf versus irrigated turf), climate change impacts of 2°C on surface temperatures could theoretically be more than offset by materials selection and greater use of green infrastructure in some areas.

5.3.2 Infill development

The 30 Year Plan for Greater Adelaide has clear targets about prioritising new residential development in Adelaide in existing suburbs, with 85% of all new housing in metropolitan Adelaide to be built in established urban areas by 2045. This is already evident across the region with larger house blocks being subdivided to construct multiple dwellings, which occupy a much greater percentage of the available land. If done well, this could lead to larger areas of medium and high-density housing that afford a more environmentally sustainable lifestyle. However, if done poorly, infill could result in the loss of cooler landscape features such as trees and green cover in favour of increased impervious surfaces like bitumen and concrete roads and footpaths, and dark coloured roofs. This would further exacerbate the urban heat island effect as it is currently experienced, and will only add to the additional heating that will be experienced through climate change.

The impact of roof colour and vegetation presence was assessed in a case study as part of this project and suggests that for medium and high density developments, inappropriate roof colour selection and the incorporation of vegetation (or not) can have a significant impacts on the average temperature of new developments. This inturn can increase air temperature which impacts on building cooling loads and energy usage as well as the health and well being of residents. These impacts could be at least as significant as the projected increase in temperature as a result of climate change by 2050. Overall, a clear policy in relation to how land surface type is controlled (or incentivised) in order to mitigate the urban heat island effect is warranted.

5.4 Mitigating urban heat islands

This study has clearly identified where hot spots and urban heat islands exist within Eastern and Northern Adelaide, how they relate to where socially vulnerable people live, and how they can be further exacerbated by climate change and in-fill.

Urban heat islands can be mitigated by understanding the factors that influence temperature at a local scale, such as land use management decisions and building material selection. This is relevant for all councils in the region because despite there being fewer hot spots in councils such as Unley, Prospect and Norwood, Payneham and St Peters, they are also experiencing land use changes that will create an urban environment more susceptible to heat accumulation.

This study re-enforced the findings of other studies that artificial turf, dark surfaces (e.g. roofs) and bitumen roads accumulate significant amounts of heat during the day, with roads being the most significant in retaining this at night. In contrast, trees and irrigated turf help to cool the landscape. However, bare ground can have a significant warming effect, which was seen at sites such as Parafield Airport and non-irrigated parts of the Adelaide Parklands. This suggests that where turf is installed, ensuring access to a long-term sustainable water supply is essential for maintaining the cooling benefits that be achieved from living turf.

Patterns of where heat persists from day into night also provides information useful for planning and decision making. Most importantly, comparing day and night-time thermal data helps to identify *low-intensity* (heat up during the day but cool down during the night) versus *high-intensity* hot spots (heat up during the day and retain heat during the night), and revealed that:

- roads and parking lots with bitumen were the strongest contributor to night-time heat; and
- dark roofs, while hot during the day, quickly dissipated heat after sundown.

Broad strategies for reducing the heat island effect are outlined in Table 8. Based on the findings of this study, similar studies elsewhere in Metropolitan Adelaide (i.e. Western Adelaide and Resilient South), and general strategies for mitigating urban heat islands, it is recommended that:

1. despite the pressure from infill, the amount of green space and tree cover should at least be maintained, and preferably increased to provide cooling benefits;

2. where feasible, areas of dry grass and/or bare ground should be irrigated to reduce their day time warming effect;

3. green infrastructure such as trees, grass and raingardens should be used to shade bitumen covered surfaces such as major and minor roads, bikeways and footpaths. Where feasible, this green infrastructure should be irrigated in order to maximise its cooling effect;

4. where feasible the carriage way for main roads should be narrowed, stormwater treatment devices installed, and road pavement changed to lighter materials or painted with lighter colours;

5. councils maximise the cooling benefit from existing green cover by ensuring sufficient irrigation is provided to urban forests and other green infrastructure networks where

available, such as from recycled stormwater. The benefits of this are evident from the cooling impact of WSUD features as demonstrated in Leader Street;

6. light coloured roofs be encouraged in residential and industrial areas over dark coloured roofs, or where feasible rooftop gardens can be incorporated into the design of multi-story structures such as car parks and apartments;
7. material selection is carefully considered in the design of recreation areas for the young and elderly, with substrates such as artificial turf and rubber softfall covering used only after consideration of how heat absorption can be offset such as through the use of shade sails or nearby irrigated vegetation; and
8. guidelines be developed for the amount of green space and landscaping required and building materials to be used in medium and high density developments, noting their potential to develop into significant heat islands. This should be done in the broader context of the planning and building codes being developed as part of the current planning reform process in South Australia.

Some of the above proposed actions could form the basis of government, private sector or community led initiatives. For example, the New York City Cool Roofs initiative[3] is a community led program to paint reflective coatings onto the roofs of buildings in order to reduce the accumulation of heat. More recently, local government in Los Angeles has launched an initiative to paint roads white, part of action to lower the temperature of the city by 3°C in the next 20 years.

---

[3] https://coolroofs.org/documents/NYC_CoolRoofs_6-14-17_Presentation.pdf

Strategies and technologies	**Description**
Trees and vegetation	Increasing tree and vegetation cover lowers surface and air temperatures by providing shade and cooling through evapotranspiration. Trees and vegetation can also reduce stormwater runoff, improve the quality of stormwater runoff and protect against erosion.
Green roofs	Growing a vegetative layer (plants, shrubs, grasses, and/or trees) on a rooftop reduces temperatures of the roof surface and the surrounding air and improves stormwater management. Green roofs achieve these benefits by providing shade and removing heat from the air through evapotranspiration.
Cool roofs	Installing a cool roof – one made of materials or coatings that significantly reflect sunlight and heat away from a building – reduces roof temperatures, increases the comfort of occupants, and lowers energy demand.
Cool roads	The temperature of roads can be reduced by using construction materials with a lighter colour that absorbs less heat, or applying road surface treatments to change their colour. Roads can also be cooled by planting trees along verges to increase shading on the road surface.
Smart growth	These practices cover a range of development and conservation strategies that help protect the natural environment and at the same time make our communities more attractive, economically stronger, and more livable. Smart Growth principles include: • Mix land uses, such as residential, commercial, and recreational uses; • Take advantage of compact building design; • Create a range of housing opportunities and choices; • Create walkable neighborhoods; • Foster distinctive, attractive communities with a strong sense of place; • Preserve open space, natural beauty, and critical environmental areas; • Make development decisions predictable, fair, and cost effective; and • Encourage community and stakeholder collaboration in development decisions.

Table 8. Broad strategies for reducing the impact of urban heat islands. Adapted from U.S. Environmental Protection Agency (2008).

5.5 Future directions

Cooling benefits project evaluation

All projects undertaken by councils that result in any land cover change will affect the thermal landscape in unseen ways. The high-resolution thermal dataset collected during this project allows for modelling of proposed projects to understand what thermal changes are likely to take place. Using the combined imagery, NDVI, and thermal data, a coupled thermal land-use model would explore the effects of changing from one landscape for another.

This approach would help understand the cooling benefits of all land-use changes including watering non-irrigated grass as a short-term mitigation option. The result would be a quantitative comparison of thermal impacts using location-specific data.

Cooling benefits of various features as mitigation strategies

The analysis presents a first-level investigation into the cooling effectiveness of various landscapes. Deploying a temperature sensor array composed of both surface and air thermometers adjacent to individual land scape features would reveal the magnitude and range of cooling while also exploring the effect on both surface and air temperature. This would result in an explicitly defined relationship of the cooling effect for individual features and would further increase the accuracy of projecting the cooling benefits of individual projects. This approach can also be used to monitor and evaluate the real-time impacts of on-going projects to measure the effectiveness of various mitigation strategies.

Targeting analysis

Thermal data can help prioritise problem areas. Comparing specific land features, such as parks or schools, across the study area or within individual councils will reveal which locations are most exposed to extreme heat. Targeting analysis can identify which locations present the highest degree of risk and should be the primary focus of mitigation efforts. Targeting analysis provides quantitative rationale for where efforts will provide the greatest relief.

Coupling thermal data with social vulnerability data can further guide efforts towards locations that not only exhibit the highest degree of physical exposure, but also the highest degree of exposure for socially vulnerable populations. This is specifically of use in targeting mitigation efforts to help those most in need.

Prioritising green infrastructure to mitigate high temperatures

One central strategy for mitigating urban heat islands is to increase the area of urban green infrastructure. Prioritising green infrastructure to mitigate high temperatures in urban landscapes can be done using a framework developed by Norton et al. (2015), which has the following five steps:

- Step 1 - Identify priority urban neighbourhoods;
- Step 2 - Characterise green infrastructure and grey infrastructure;
- Step 3 - Maximise the cooling benefit from existing green infrastructure;
- Step 4 - Develop a hierarchy of streets for new green infrastructure integration; and

- Step 5 - Select new UGI based on site characteristics and cooling potential.

Step 1 has mostly been competed during this study by the identification of areas of heat exposure and social vulnerability. Step 2 has also been mostly addressed through the provision of NDVI maps identifying the extent of vegetation and its relative condition. In order to complete Step 2, work is required to characterise street width and building height to determine street openness to solar radiation, and self-shading by buildings.

Targeting delivery of community services

The data generated for this study provides insights into where social vulnerability intersects with heat exposure. This information can be used to target the delivery of community services during periods of extreme heat. For example, the Red Cross Telecross service makes daily welfare calls to people who are frail and aged, have a disability, are housebound and/or are recovering from an illness or accident. This includes phone calls during periods of extreme heat. Eastern and Northern Adelaide region councils can work with the Red Cross and other providers to identify suburbs where community services are most required during periods of extreme heat.

References

BOM 2018, historical weather observations and statistics, Australia Bureau of Meteorology. <http://www.bom.gov.au/climate/data-services/station-data.shtml>, accessed 30 March 2018.

City of Port Adelaide Enfield, 2016. *AdaptWest Climate Change Adaptation Plan.* Prepared for the City of Port Adelaide Enfield by URPS in collaboration with Seed Consulting Services and AECOM.

City of West Torrens, 2017. *Western Adelaide Urban Heat Mapping Report.* Prepared by Seed Consulting Services, EnDev Geographic and Airborne Research Australia.

Norton, B. A. et al., 2015. Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning,* Volume 134, pp. 127-138.

Resilient East, 2016. *Resilient East Regional Climate Change Adaptation Plan.* Prepared by URPS as part of the Resilient East consultancy led by URPS, for the Eastern Region in association with the Government of South Australia and the Australian Government..

U.S. Environmental Protection Agency, 2008. *Reducing urban heat islands: Compendium of strategies. Draft.*