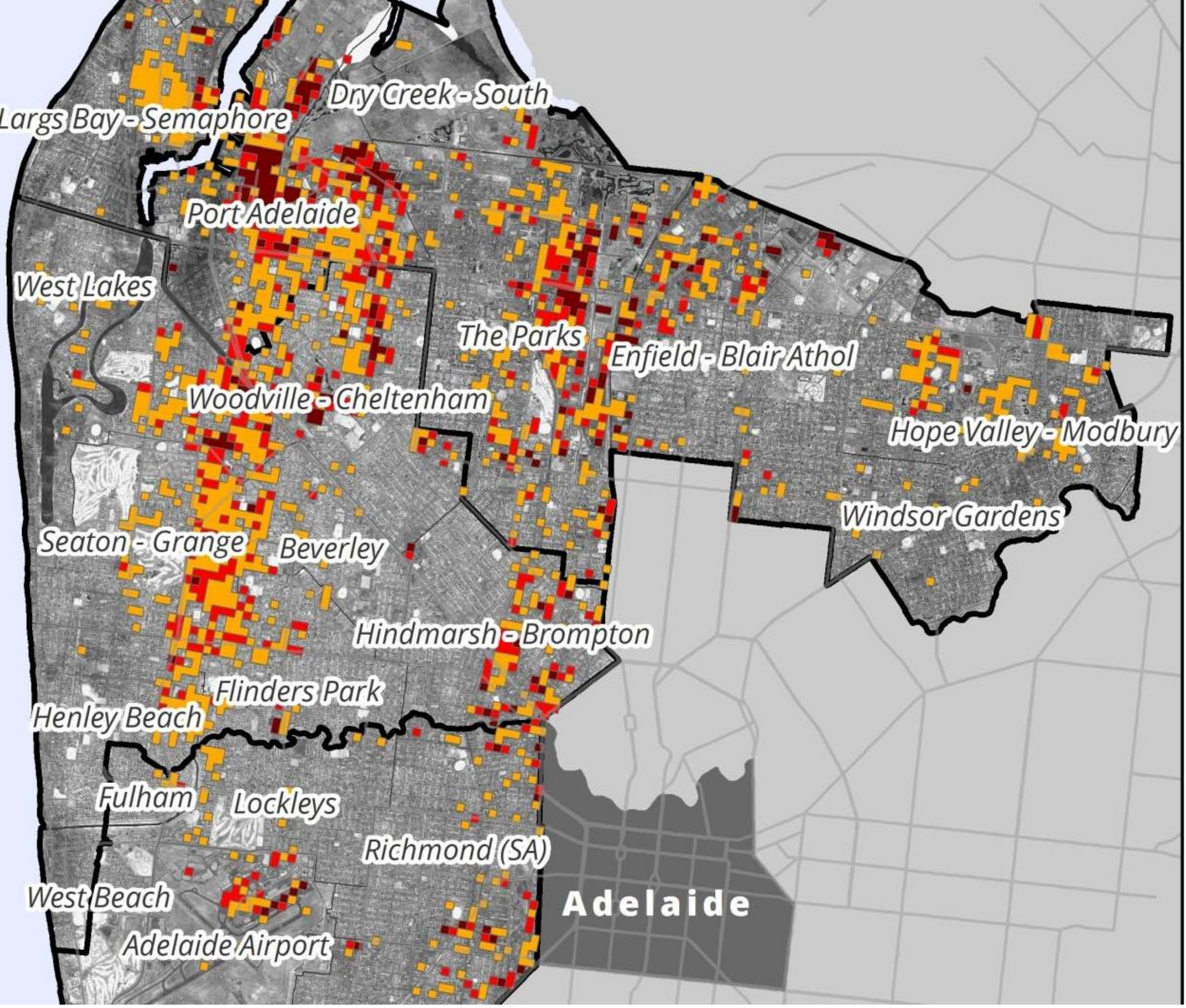

Western Adelaide Urban Heat Mapping Project

Report

August 2017

Western Adelaide
Urban Heat Mapping Project Report

prepared for the Cities of West Torrens, Charles Sturt and Port Adelaide Enfield, and the Adelaide Mount Lofty Ranges Natural Resources Management Board

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Executive summary

Extreme heat impacts the health and wellbeing of the community, the environment, and economic performance. The accumulation of heat in urban areas can result in urban heat islands, which experience temperatures higher than the surrounding landscape. Under climate change, the impact of higher temperatures will become more evident in these areas.

To ensure the Western Adelaide Region can respond positively to the opportunities and challenges of a changing climate, the three Western Adelaide councils are implementing a range of adaptation projects under the AdaptWest Climate Change Adaptation Plan. Given the rising incidence of extreme heat under climate change and projected housing infill trends which could exacerbate the urban heat island effect, the Cities of West Torrens, Charles Sturt and Port Adelaide Enfield, in conjunction with the Adelaide Mount Lofty Ranges Natural Resources Management Board, engaged Seed Consulting Services, EnDev Geographic and Airborne Research Australia to investigate the impact of neighbourhood urban form on its microclimate to enable more effective planning for community health and wellbeing across the region.

To better understand the location of urban heat islands and the factors that influence their occurrence, day and night heat (thermal) data was collected using a specialist remote sensing aircraft across 110 suburbs in Western Adelaide. The data were collected on 9 February 2017, which at 39.2°C was the fourth hottest day and second warmest night (25.2°C) of the 2016/2017 summer. This followed days of 31°C and 42°C, meaning that heat had accumulated in the landscape.

All councils had hot spots present, covering approximately one third of each council area. There were two north-south bands of heat islands, running from Dry Creek South to Henley Beach in the west of the region and from Wingfield to Brompton in the centre of the region. The highest rates of residents living within heat islands occurred in the City of Charles Sturt and City of Port Adelaide Enfield with 20.1% and 17.2% of their population, respectively, compared with only 5.6% of residents in the City of West Torrens.

The warmest suburbs by council area were:

- City of Charles Sturt - Ridleyton, Hindmarsh, Bowden, Brompton, Renown Park;
- City of Port Adelaide Enfield - Walkley Heights, Hillcrest, Enfield, Sefton Park, Northgate; and
- City of West Torrens - Ashford, Keswick, Kurralta Park, Mile End South, Thebarton.

Comparison of low, medium and high density residential developments suggest that the goal of the 30-Year Plan for Greater Adelaide, which is to increase infill across Metropolitan Adelaide, will exacerbate the development of heat islands if sufficient mitigation strategies are not implemented.

A number of suburbs were identified that contain urban heat islands and that also have a high degree of social vulnerability. Heat islands in Fulham Gardens had the highest degree of social vulnerability within the City of Charles Sturt and overall, while heat islands in Oakden and Lockleys had the highest degree of social vulnerability in Port Adelaide Enfield and West Torrens, respectively. Other suburbs that had high social vulnerability and exist within heat islands include parts of Albert Park, Seaton and Findon. Understanding the drivers of social vulnerability (e.g. age versus need for assistance with core activities) will be important in designing mitigation strategies for assisting the community to prepare and respond to extreme heat.

Land use and building materials have a significant impact on surface temperatures. As demonstrated by a series of case studies, land use decisions and material selection in Western Adelaide can cause at least a 7°C difference in surface temperature. For example, major roads averaged 3°C above the surrounding landscape and minor roads and parking lots 1.6°C warmer. Dark roofs were 2.9°C above the region average whereas light roofs were 2.3°C cooler. Temperatures were, on average, 2.8°C lower over green infrastructure, with irrigation creating an additional cooling effect of 1.7°C compared with non-irrigated open space.

The day-night time data comparison revealed that although many residential areas heated up during the day, they also cooled during the evening, with heat islands less evident at night for the region. Despite this, the impact of major roads was still a source of heat during the evening.

The thermal data collected for this study provides a comprehensive illustration of hot spots and urban heat islands and can help guide development and implementation of mitigation strategies. Based on the findings of this study 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. green infrastructure such as trees, grass and raingardens should be used alongside or 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;

3. where feasible the carriage way for main roads should be narrowed, stormwater treatment devices installed, and road pavement changed to lighter coloured materials;

4. 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;

5. light coloured roofs be encouraged in residential and industrial areas rather than using dark coloured roofs;

6. 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 is given to how heat absorption can be offset e.g. through the use of shade sails;

7. 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; and

8. planning, development and infrastructure be supported with a strong focus on design and build quality for dwelling comfort and liveability.

There is a range of additional analyses that can further assist in developing heat mitigation strategies for Western Adelaide, including:

- **targeting analysis,** which integrates numerous variables to identify project-specific priorities that will provide the greatest relief;

- **prioritising green infrastructure to mitigate high temperatures,** which focuses on determining which streets in particular in the region should be the target for greening strategies;

- **targeting delivery of community services,** which would use data generated for this study to target the delivery of community services to suburbs where heat exposure and social vulnerability intersect;

- **further comparison of materials and surface types** across the region to understand how land surface types can differ in their thermal performance (e.g. roof types and colours); and

- **exploring the relationship between surface and air temperature**, focusing on sites with a mix of surface types and materials.

The data collected and analysed during this study has been provided to the councils as spatial layers to inform future decision making for the region. Detailed heat maps are provided as annexes to this report.

1 Introduction

1.1 Context

The Western Adelaide regions lies in the northern western corner of Metropolitan Adelaide, covering the City of Charles Sturt, the City of Port Adelaide Enfield and the City of West Torrens. A common strategic objective for the three councils in the region is to improve the liveability and health and well being of residents. The Western Adelaide Region is characterised by different areas of social vulnerability such as:

- a high proportion of residents who are susceptible to heatwaves (elderly, existing health risk factors);
- a diverse community with English as a second language, complicating the councils' capacity to communicate with people at risk;
- areas of low income experiencing reduced capacity to pay energy bills; and
- corridor development, infill development and proposed higher densities that will further intensify the urban heat effect.

Globally, extreme heat events have led to high rates of mortality and morbidity in cities, having a major impact on the health and well being of the community. They also result in increased electricity consumption which in turn increases the release of greenhouse gases. Heat impacts are greatest in urban heat islands, which are areas where the average temperature is above that of the surrounding urban landscape. Urban heat islands tend to occur where buildings, roads and pavements associated with urban development have largely replaced trees and green space.

Warming associated with urban development will be exacerbated in future years by temperature increases due to climate change (Norton, et al., 2015). This was highlighted by the findings of the recent regional AdaptWest Climate Change Adaptation Plan, which found that the average temperature in Western Adelaide will continue to rise over the century, which will in turn exacerbate the impact of the urban heat island effect.

Without mitigation strategies, the urban heat island effect will be further enhanced by urban in-fill. The 30-Year Plan for Greater Adelaide, which is the strategic land-use plan that guides the long-term growth of Adelaide and its surrounds, has an objective of 85% of new dwellings in the form of infill. This will result in a higher population across Western Adelaide and drive a more compact and dense urban form.

Recent experience has shown that gradual infill across the region is occurring in the form of one into two developments (i.e. one larger single block with a home divided in two blocks with a home on each). This style of development generally results in the loss of tree canopy cover, which has an impact on the State Government's tree canopy targets and the cooling effect which trees have on the local environment and streetscape.

Early identification of areas at high risk from extreme heat due to the urban heat island effect can help to target investment in heat mitigation activities, such as green infrastructure like trees, irrigated open space, green walls and green roofs, and guide the selection of building and construction materials that result in less heat accumulation in the urban environment.

1.2 Objectives

To ensure the Western Adelaide Region can respond positively to the opportunities and challenges of a changing climate, the three Western Adelaide councils are implementing a range of adaptation projects which are driven by the regional AdaptWest Climate Change Adaptation Plan.

Given the rising occurrence of extreme heat under climate change and projected housing infill trends, the Cities of West Torrens, Charles Sturt and Port Adelaide Enfield, in conjunction with the Adelaide Mount Lofty Ranges Natural Resources Management Board, engaged Seed Consulting Services, EnDev Geographic and Airborne Research Australia to investigate the impact of neighbourhood urban form on its microclimate in order to enable more effective planning for community health and wellbeing across the Western Adelaide Region.

The key objectives of the project were to:

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

These objectives were addressed by conducting a flyover in February 2017 to collect data to generate urban heat maps, followed by analysis to identify patterns and relationships to inform decision making. This report provides the results of the analysis and a discussion of mitigation strategies and recommendations. A description of the methodology for conducting the flyover along with additional maps and data are provided in the following annexures:

- Annex 1: Council thermal maps;
- Annex 2: Thermal map profiles;
- Annex 3: Normalized Difference Vegetation Index (NDVI) maps;
- Annex 4: Suburb analysis tables; and
- Annex 5: Instrumentation, data collection and analysis.

2 Responding to urban heat

2.1 Urban heat island and hot spot identification

Heat maps were generated from data collected during a flyover at 3,000 m with a purpose-built aircraft, fitted with a thermal imager and other supporting instrumentation. The trigger for undertaking the flight was two or more consecutive days with the average temperature greater than or equal to 33°C. This occurred on 9 February 2017 and the surveys were flown around solar noon from approximately 11 am to 4 pm, and from approximately 11 pm to 3 am (i.e. 10 February 2017).

Thermal patterns in the urban landscape can be viewed as *heat islands* (areas at least 125 m x 125 m) and localised *hot spots* (areas at least 2 m x 2 m). Heat islands reveal where heat has built up and what features of the urban setting are most severely affected. Hot spots display intricate patterns of heat and allow for exploration of how different surfaces contribute to heat build-up.

For this project, the processes of identifying and analysing urban heat islands and hot spots were applied to both day and night time thermal data, resulting in day and night urban heat island and hot spot maps. Different thermal patterns emerge in the day and night time thermal maps. A spatial comparative analysis was applied to assess where and why these patterns vary. Comparing warm areas that persist into the night with those that cool rapidly identifies *high intensity* and *low intensity* heat islands each of which require different strategies for remediation and have different implications for planning.

2.2 Understanding urban heat in Western Adelaide

The data collected describes the land surface temperature of the study area which directly influences air temperature. Air temperature, however, is also influenced by local wind patterns, proximity to water, and other local weather conditions that affect the interaction between land surfaces and air. For instance, wind increases circulation which limits the time that any individual column of air is in contact with a hot surface thus weakening the influence of surface heat on air temperature; on calm days surface heat translates more directly into warmer air temperature. This report discusses impacts of land use on land surface temperature and methods for reducing the disproportionate build-up of surface heat.

The varying influence of surface heat on air temperature is governed by local conditions known as micro-climates. In addition to surface heat, many local factors affect air temperature including building shadows, urban wind-tunnelling, and fountains which have a cooling effect, and air conditioners, traffic exhaust, and other sources of waste heat which have a warming effect.

Surface temperature is the main influence on general air temperature, but understanding the balance between these additional, local factors requires a detailed micro-climate model.

While land surface temperature and air temperature are clearly different, mitigating high surface temperatures in cities is an appropriate target, as these reflect locations where both 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). Therefore, and notwithstanding that micro-climate modelling has not been undertaken, for the purposes of this study, surface temperature provides an appropriate and sufficiently reliable indicator on which to base conclusions and recommendations.

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 structure the presentation of results for this analysis. 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 neighbourhoods.

This study provides quantitative data to inform identification of areas of heat exposure and social vulnerability, and their overlap. In contrast, behavioural exposure is considered qualitatively by describing areas of outdoor activity in the land use management and building material selection section e.g. playgrounds, bikeways, sporting fields, pedestrian thoroughfares.

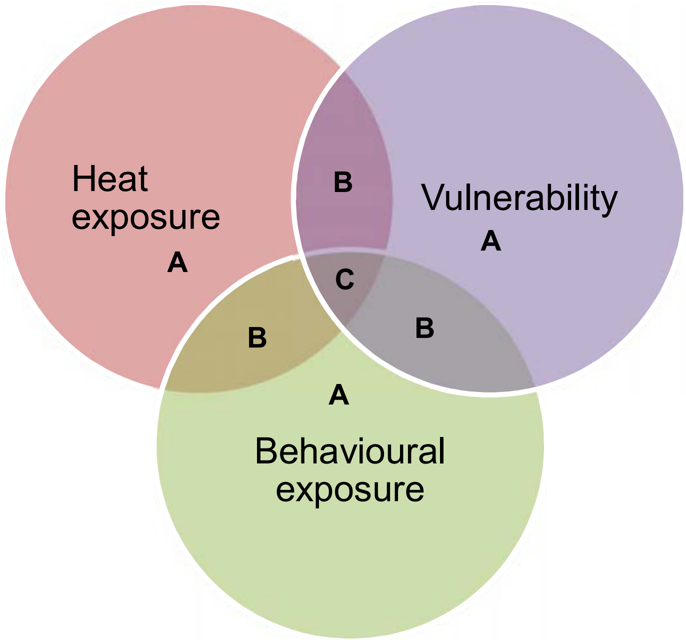

Figure 1. Framework to identify priority neighbourhoods for heat mitigation activities. Factors required to of high (C), medium (B) and moderate (A) priority for Urban Green Infrastructure (UGI) implementation for surface temperature heat mitigation. The key factors are high daytime surface temperatures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

3 Identifying priority areas

NB. While not referred to specifically through the text in this section, the analysis presented is also supported by a range of additional maps (A3) and data provided in Annexes 1-4.

3.1 Heat exposure

3.1.1 Temperature during flyover

On 9 February 2017, temperatures at the Adelaide Airport weather station reached 39.2°C, making it the fourth hottest day of the 2016/2017 summer. Of the three councils analysed, the City of Port Adelaide Enfield was the warmest with a mean surface temperature of 38.9°C, more than 1.3°C warmer than the mean temperature of the City of West Torrens. During the evening of 9 February 2017, night time temperatures at the Adelaide Airport reached a minimum of 25.2°C, the second warmest night of the 2016/2017 summer.

3.1.2 Hot spots and thermal analysis

The thermal data collected for this project reveals that 34.9% (63.7km2) of Western Adelaide classifies as a daytime hotspot, measuring warmer than 2°C above average temperature (Figure 2). Day time temperatures ranged from 10°C to 80°C, with 95% of the landscape measuring between 31°C and 42°C. Extreme temperatures over 65°C were driven by highly localised manufacturing processes, with the maximum temperature of 80°C occurring at Adelaide Brighton Cement.

The City of Charles Sturt received the highest percentage of hot spots of the three councils within the study region with hotspots covering 36.8% (20.1 km^2) of its land, mainly in the areas between Tapleys Hill and Findon Roads, and east of South Road, concentrated within the suburbs of Hendon, Woodville, Brompton, Bowden, and Hindmarsh (Table 1). The coolest areas within the council were found near West Lakes, around the golf courses in Grange and Seaton, and generally along the coast.

The City of Port Adelaide Enfield had 35.1% (32.1 km^2) of its land classified as a hotspot, mainly concentrated in the heavily industrialized areas in the north and central areas within the city. The largest and most intense hot spots occur within the suburbs of Port Adelaide, Dry Creek, and Gepps Cross, however, none of these rank in the ten warmest City of Port Adelaide Enfield suburbs as these industrial suburbs also contain substantial wetlands which lower the overall average temperature of the suburb (Table 2).

The City of West Torrens had the fewest hot spots with 31.2% (11.5 km^2) of its land meeting the hot spot criteria, mainly east of the airport in Netley, as well as along the eastern edge of the council in Keswick, Ashford, Mile End South, and Thebarton.

Council	Rank	Suburb	Mean Day Surface Temp (C°)
Charles Sturt	1	Ridleyton	40.97
	2	Hindmarsh	40.63
	3	Bowden	40.46
	4	Brompton	40.35
	5	Renown Park	40.34
	6	Albert Park	40.15
	7	Ovingham	40.12
	8	Pennington	39.54
	9	Hendon	39.47
	10	Cheltenham	39.45

Table 1. Ten hottest suburbs for the City of Charles Sturt.

Council	Rank	Suburb	Mean Day Surface Temp (C°)
Port Adelaide Enfield	1	Walkley Heights	42.95
	2	Hillcrest	41.02
	3	Enfield	40.88
	4	Sefton Park	40.88
	5	Northgate	40.84
	6	Gilles Plains	40.80
	7	Hampstead Gardens	40.79
	8	Kilburn	40.62
	9	Broadview	40.59
	10	Greenacres	40.47

Table 2. Ten hottest suburbs for the City of Port Adelaide Enfield.

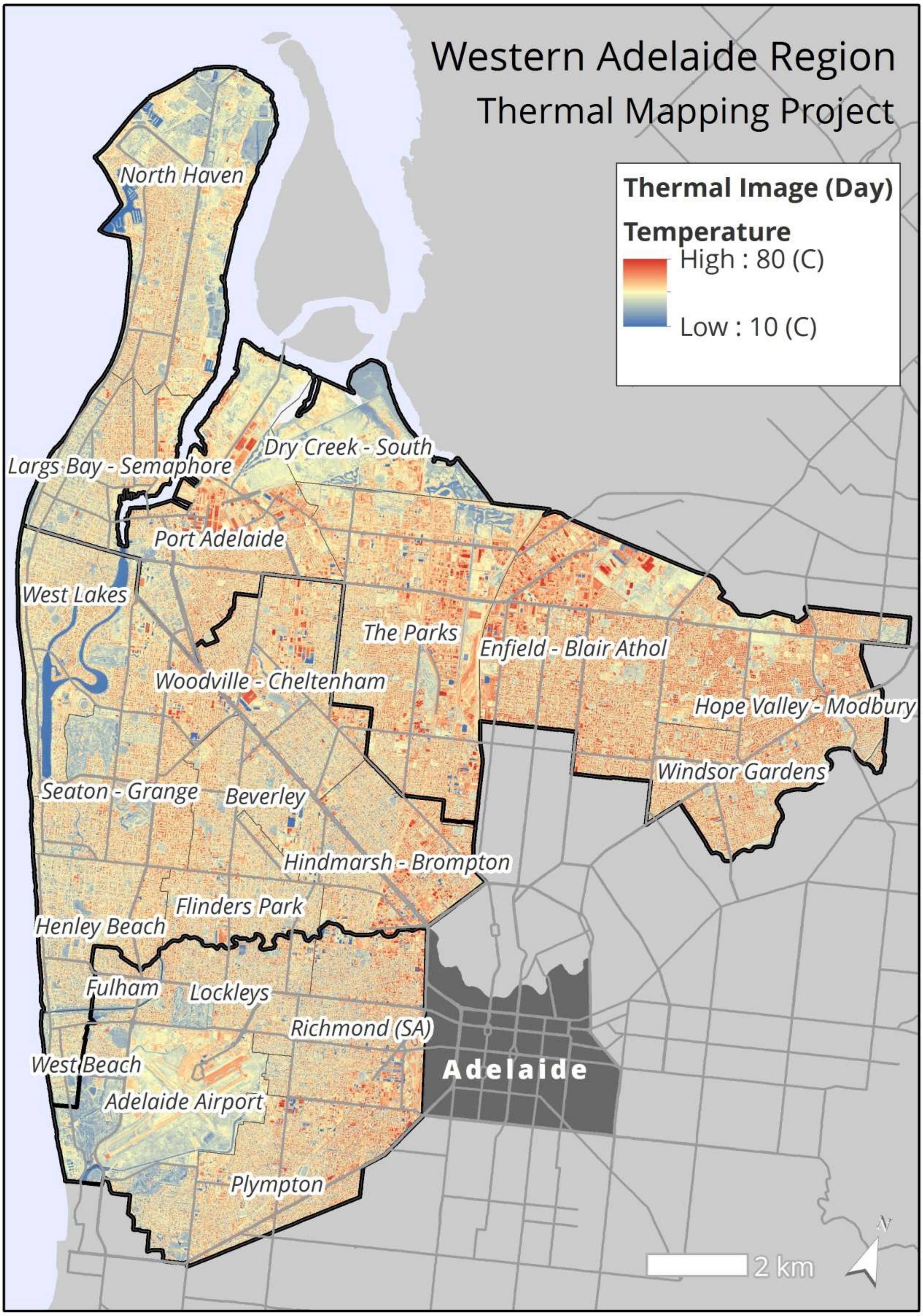

Figure 2. Day time thermal map showing the surface temperature for different features in the landscape at 2 m x 2 m resolution.

The Adelaide Airport provides a day time cooling effect, ranking this area as the third coolest (compared to surrounding suburbs) within the City of West Torrens. The City of West Torrens has a large portion of residential areas that encompass a wide variety of land uses. The mixed land covers within residential areas result in a more moderate thermal signal.

These results change significantly when considering night time thermal data (Figure 3). Night time temperatures range from 5°C to 70°C with 95% of values measuring between 21°C to 29°C. The highest temperatures are driven by heat-intensive manufacturing processes, with the maximum temperature recorded at I-O Glass Manufacturing within the City of Charles Sturt. In the evening, the overall hotspot percentage drops to 18.8% (34.4 km^2), and the order reverses with the City of West Torrens having the highest percentage of evening hotspots with 19.98% (7.4 km^2), and the City of Port Adelaide Enfield dropping to 17.9% (16.3 km^2).

Council	Rank	Suburb	Mean Day Surface Temp (C°)
West Torrens	1	Ashford	40.18
	2	Keswick	39.98
	3	Kurralta Park	39.80
	4	Mile End South	39.77
	5	Thebarton	39.64
	6	Glandore	39.26
	7	Marleston	39.23
	8	Richmond	38.94
	9	Mile End	38.91
	10	North Plympton	38.67

Table 3. Ten hottest suburbs for the City of West Torrens.

The ranking reversal of councils between day and night time is highly illustrative of the different sources of day and night heat. As shown in Section 3.2, during the day, buildings and bitumen are the dominant drivers of urban hot spots. In the evening, buildings cool rapidly compared to bitumen, leaving paved, hard surfaces as the dominant contributor of night time heat. The City of Port Adelaide Enfield has a high number of buildings particularly along Perkins Drive that are hot during the day but that cool during the evening, whereas the City of West Torrens has a higher proportion of bitumen (due in large part to the airport) which takes longer to cool.

Buildings can be seen as *low-intensity* hot spots (warm during the day but cool down during the night) whereas bitumen can be considered a *high-intensity* hot spot (warm during the day and retain heat during the night) as the higher heat capacity of paved surfaces means they continue to emit heat longer after sundown.

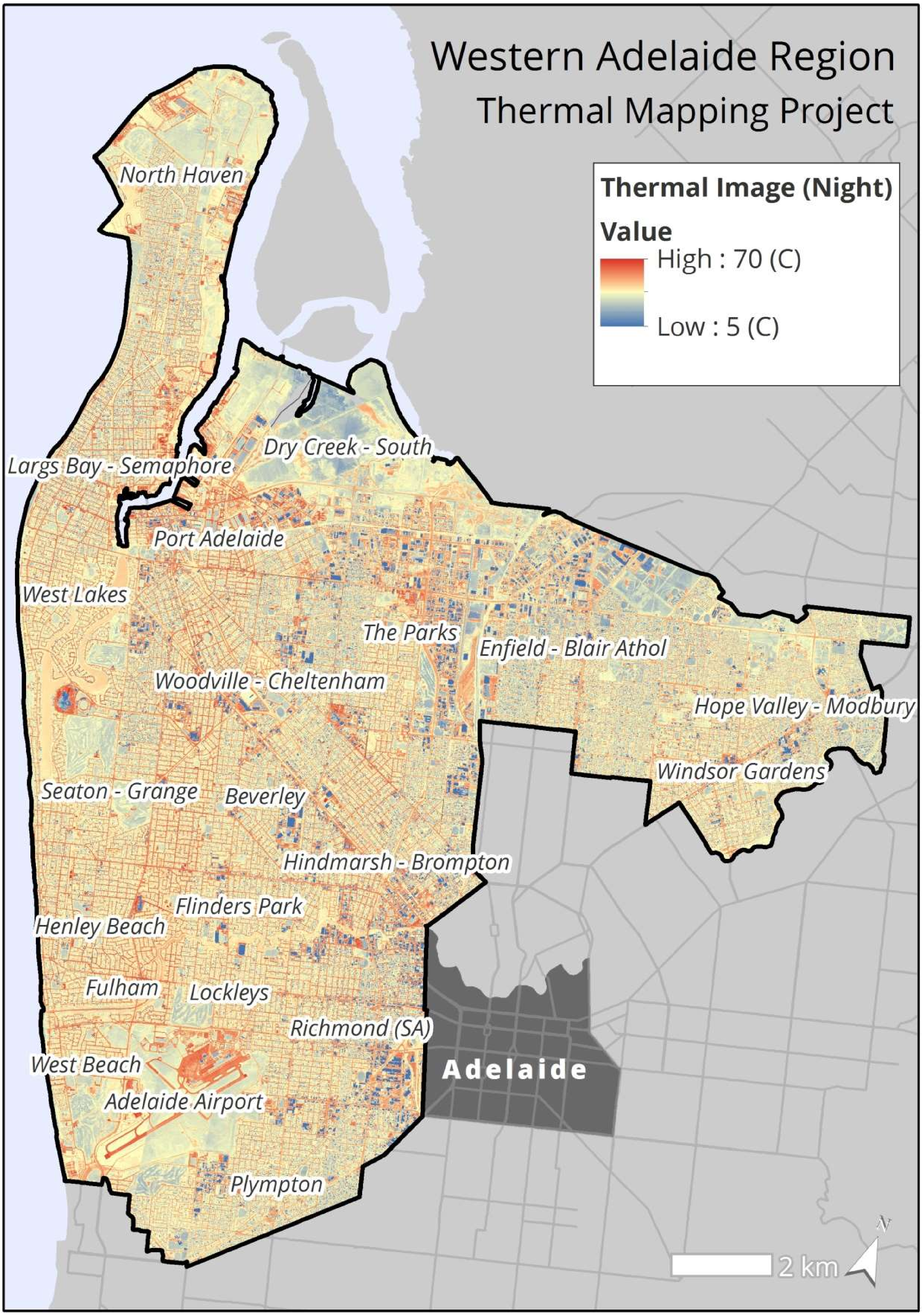

Figure 3. Night time thermal map showing the surface temperature for different features in the landscape at 2 m resolution for the Western Adelaide Region.

3.1.3 Urban heat island analysis

Excess urban heat becomes most problematic when it concentrates into larger urban heat islands. Thermal data aggregated to 125 m^2 resolution for the urban heat island analysis found that 15.9% (26.9 km^2) of the Western Adelaide Region falls within an urban heat island, 1.9% of which falls within a severe heat island (>4°C above the average surface temperature on the day of the flyover) (Figure 4).

The City of Port Adelaide Enfield has the highest proportion of urban heat islands with 19.9% (16.6 km^2) of its land falling into this category, of which 2.7% is classified as a severe heat island. The largest and most severe heat island falls within the suburb of Port Adelaide. This major industrial zone contains large areas of severe heat, and although very few people reside in this area it contains many businesses that operate during the daytime. Regency Park also has a concentration of medium and severe heat islands due to the rail infrastructure and associated industry. There also exists small (125 to 250 m^2), localised heat islands scattered throughout North Haven and Outer Harbor driven by interspersed industry and impervious surfaces.

The City of Charles Sturt has the second highest level of urban heat islands encompassing 13.6% (7.0 km^2) of its land with the highest concentration lying immediately east of Tapleys Hill Road in Hendon, Seaton and Albert Park. A second concentration of urban heat islands occurs in the eastern areas of the council, namely within Ridleyton, Brompton, Bowden, Hindmarsh, and Thebarton. The most severe of these urban heat islands are in Brompton, Hindmarsh, Albert Park, and Hendon.

The City of West Torrens has 9.6% (3.3 km^2) of its land covered by heat islands, much of which are centred on the terminal of the Adelaide Airport. This low proportion of heat islands is likely to be a product of large residential areas with mixed land uses, as well as extensive green space and proximity to the sea.

Night-time urban heat island distribution reveals a starkly different pattern, which with the exception of the Adelaide Airport, mainly consists of a few, small (< 1 km^2) heat islands (Figure 5). There are several drivers of this pattern. First, night-time heat is caused primarily by paved roads which are relatively narrow features compared to the 125 m^2 resolution of the urban heat island analysis; roads are too narrow to be picked up by this analysis. Second, evening temperatures tend to have a narrower range and therefore less area meets the 2°C threshold for an urban heat island.

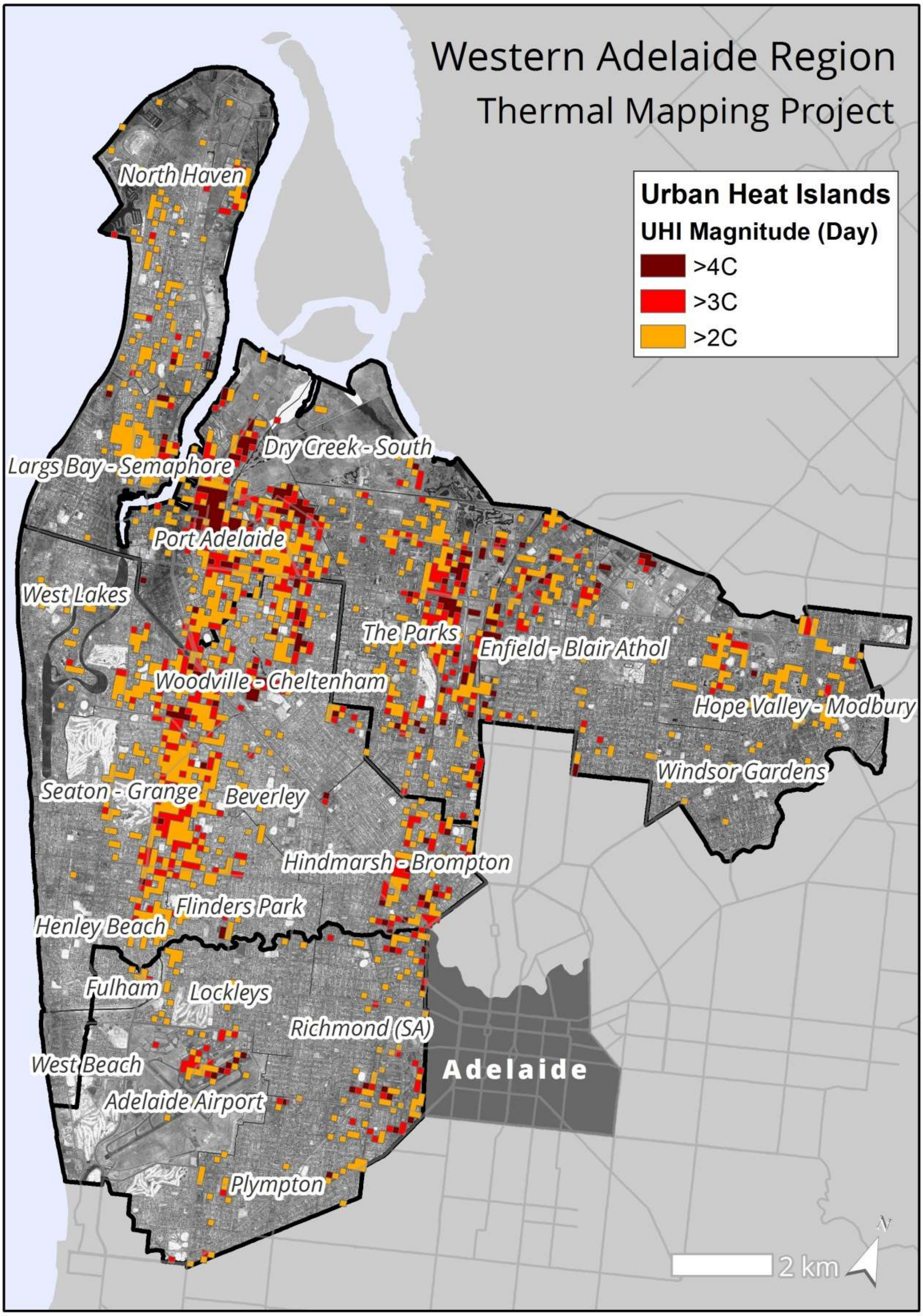

Figure 4. Daytime urban heat islands present in the Western Adelaide Region on 9 February 2017. Areas of built-up heat were identified as exhibiting a temperature greater than 2°C, 3°C or 4°C above the local mean temperature at the time of measurement.

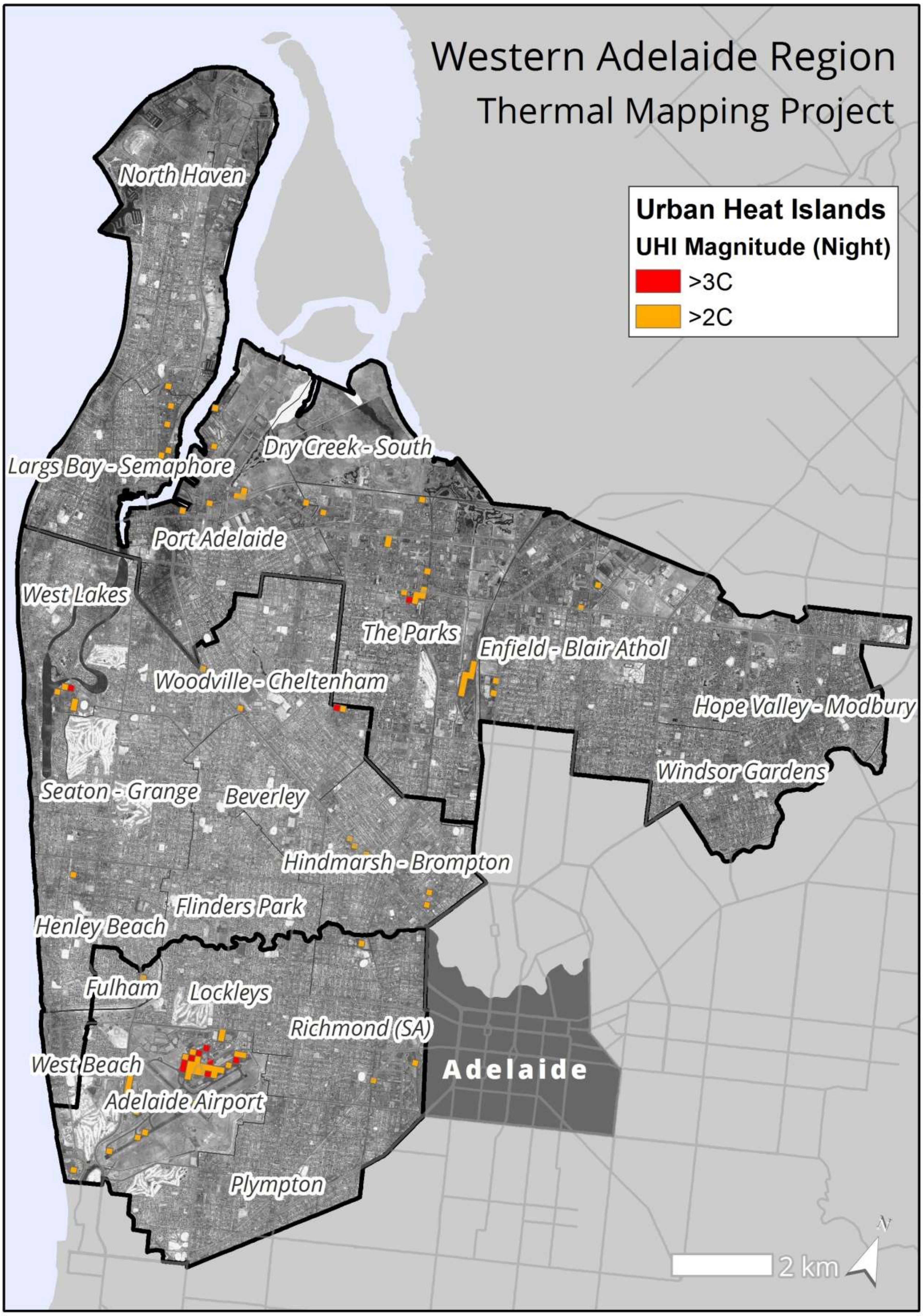

Figure 5. Night-time Urban Heat Islands present in the Western Adelaide Region on 9 February 2017. Areas of built-up heat were identified as exhibiting a temperature greater than 2°C or 3°C above the local mean temperature at the time of measurement.

3.2 Vulnerability analysis

The vulnerability analysis focused on identifying where urban heat islands intersect with areas in which vulnerable members of the community live. In Western Adelaide, 17.1% of residents (43,442) live within a day time urban heat island (Table 4). The highest rates of residents living within heat islands occurs in the City of Charles Sturt and City of Port Adelaide Enfield with 20.1% (20,908) and 17.2% (19,470), respectively. Only 5.6% of residents (3,065) live in heat islands in the City of West Torrens.

For people over 75, 22.3% of City of Charles Sturt elderly population lives within an urban heat island, well above the regional average of 14.5%. The City of Charles Sturt heat islands also contain the highest rate and number of people in need of assistance due to disabilities and people who speak English as a second language, giving the City of Charles Sturt the highest rate of vulnerability across three of the five metrics assessed. The City of West Torrens has the highest Socio Economic Index For Areas (SEIFA) score indicating higher levels of economic disadvantage, but higher median rent for areas within heat islands.

Across the three councils, five indicators of social vulnerability were investigated and only weak correlations were found between temperature and social vulnerability with the greatest correlation being English as a second language and people needing assistance due to disabilities (Table 5). These weak correlations suggest that heat islands are distributed across areas with differing levels of social vulnerability. Figure 6 shows the social vulnerability index for each day time heat island within Western Adelaide. More detailed displays of the location and magnitude of heat islands in relation to social vulnerability are provided in Annex 1.

Within the City of Port Adelaide Enfield, the Peterhead and Alberton urban heat islands have a high degree of social vulnerability, whereas the more severe urban heat islands in the suburb of Port Adelaide have relatively low residential densities and therefore less social vulnerability. The City of Charles Sturt has several large urban heat islands with high social vulnerability.

The largest urban heat island in the City of West Torrens is at the Adelaide Airport. While there are no residents and therefore no social vulnerability, there a large number of ground crew who work outdoors at the airport for whom heat mitigation should be considered. Most other heat islands in the City of West Torrens have moderate social vulnerability.

Social Vulnerability Within UHIs	Port Adelaide Enfield	Charles Sturt	West Torrens	Western Adelaide Region
Population	19,470 (17.1%)	20,908 (20.1%)	3,065 (5.5%)	43,442 (15.1%)
Number of Households	8,472 (19.0%)	9,509 (22.7%)	1,503 (6.4%)	19,484 (16.0%)
Age (Median)	39.7 (38.4)	41.1 (40.8)	36.9 (17.8)	39.9 (39.0)
Rent (Median)	242 (227)	227 (239)	256 (241)	237 (236)
SEIFA Score	921 (922)	945 (947)	994 (967)	941 (945)
Ederly Population (>75)	1,368 (15.4%)	2,322 (22.3%)	328 (5.8%)	4,019 (14.5%)
Population in Need of Assistance	1,220 (16.5%)	1,592 (23.9%)	170 (5.3%)	2,983 (15.2%)
Population who speak English as a Second Language	940 (16.6%)	1,159 (24.9%)	112 (5.0%)	2,211 (15.5%)

Table 4. Social vulnerability analysis showing the statistics of who lives within urban heat islands for each council compared with council averages provided in brackets. For population comparisons, the percentage of that group that lives in an urban heat island is given. For all others, median council values are provided.

Variable Relationship	Correlation Coefficient
ESL-Temperature	0.25
Needs Assist-Temp.	0.20
Elderly-Temperature	0.17
Rent-Temperature	0.15
SIEFA-Temperature	0.11

Table 5. Coefficients showing relationship between social vulnerability indicators and temperature.

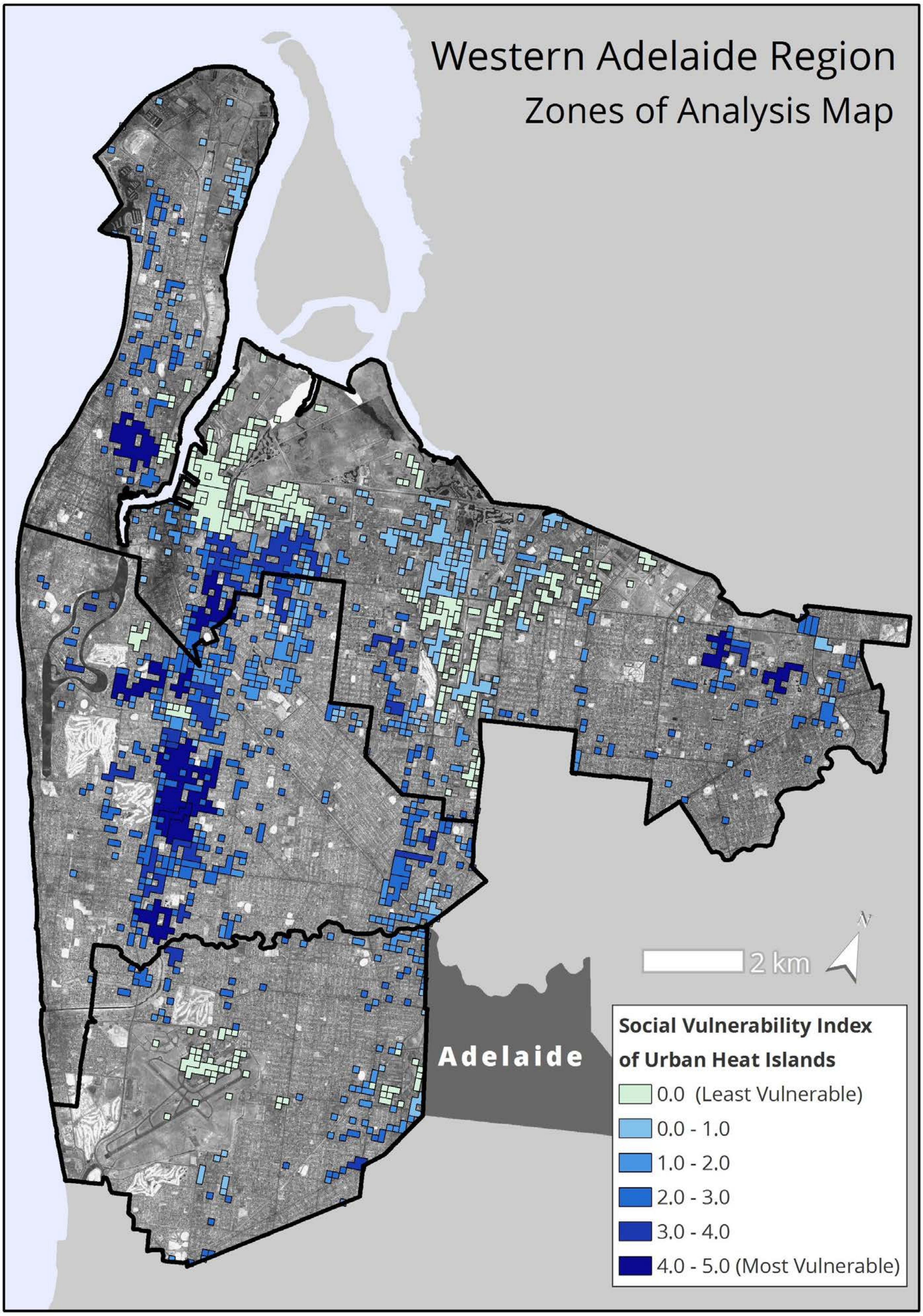

Figure 6. Social vulnerability index score calculated for each day time heat island within the Western Adelaide.

3.3 Factors that influence temperature at a local scale

This project used land use analysis to show how surface temperatures vary between areas where people are active outdoors and how management of urban areas and material selection for built assets can influence surface temperatures. The results of this analysis are discussed first from the perspective of general relationships, and second through the use of case studies, which have been designed to demonstrate key features of interest in Western Adelaide.

3.3.1 General relationships

There are clear relationships between surface temperature and material type and urban form in Western Adelaide (Figure 7). This demonstrates that management of these factors can impact the development of hotspots and urban heat islands and hence the impact of extreme heat on residents.

During the day, paved surfaces experienced the largest warming with major roads measuring 3.0°C above average surface temperatures. Minor roads and parking lots had a less pronounced warming of 1.6°C, likely due to lighter coloured concrete used in some parking lots.

Green infrastructure produced a large cooling signal, lowering temperatures by 2.8°C compared with the average. Irrigated open space had the largest impact, cooling land surfaces by 4.0°C. While all green infrastructure was shown to have a large cooling effect, irrigation cooled areas by an additional 1.7°C.

The effect of green infrastructure on temperature was further analysed through the use of Normalized Difference Vegetation Index (NDVI) data. NDVI identifies the amount of healthy vegetation present at any given location. NDVI maps for each council are provided in Annex 3. Comparing NDVI values with temperature data at the land-use analysis points[1] revealed a correlation coefficient of 0.88, indicating a very strong relationship between vegetation and cooling. This supports the case for using green infrastructure as a means for combating urban heat islands.

The thermal impact of buildings varied widely with dark roofs creating a warming of 2.9°C and light roofs creating a cooling of 2.3°C. Therefore, roofing choices have a major impact on surface temperatures, alter the temperature by 5.2°C.

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[1] See Annex 5 for description of the land-use analysis points methodology.

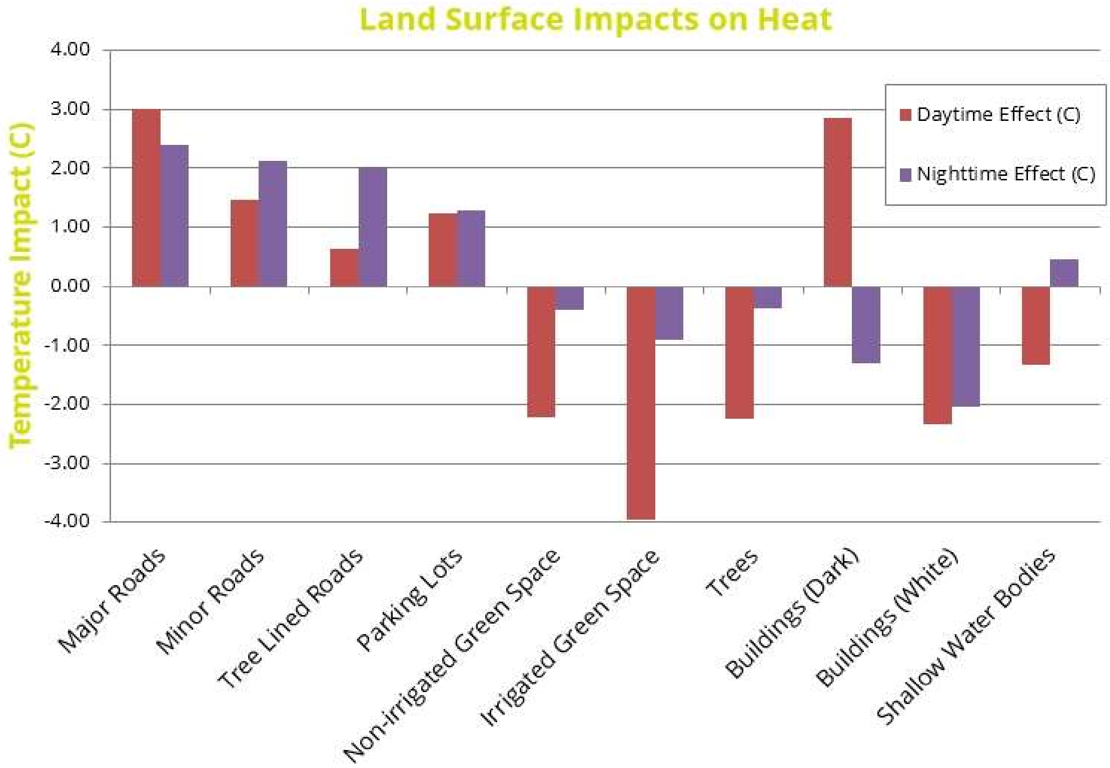


Figure 7. Heat effect of different land surfaces during the day and night.

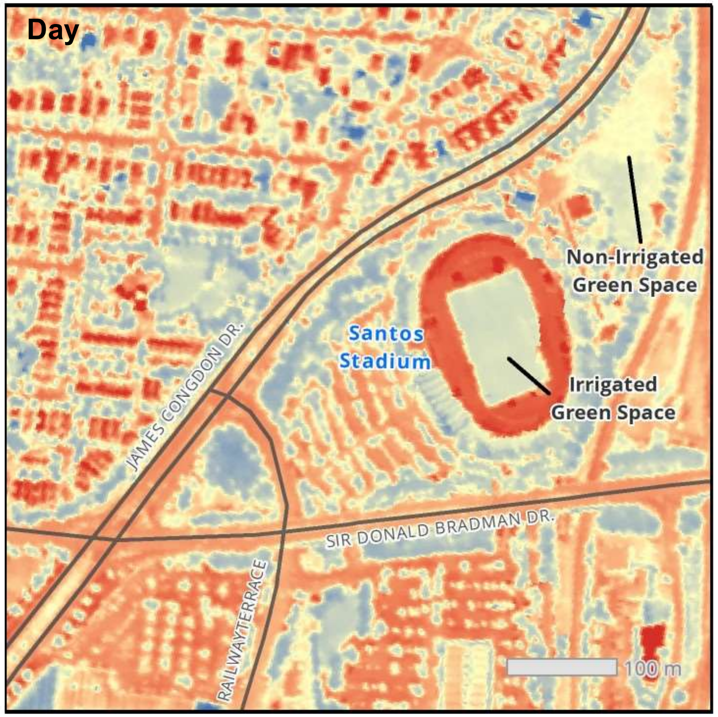
3.3.2 Case studies

The case studies presented below are as follows:

- Case study 1 – Irrigated vs non-irrigated open space;
- Case study 2 – Impact of artificial turf;
- Case study 3 – Water sensitive urban design along a roadside;
- Case study 4 – Playgrounds;
- Case study 5 – Tree lined streets vs non-tree lined streets;
- Case study 6 – Major versus minor road;
- Case study 7 – Parking surface materials;
- Case study 8 – Roof colour;
- Case study 9 – Combination of roof colour and green space;
- Case study 10 – Bikeways; and
- Case study 11 – Water bodies.

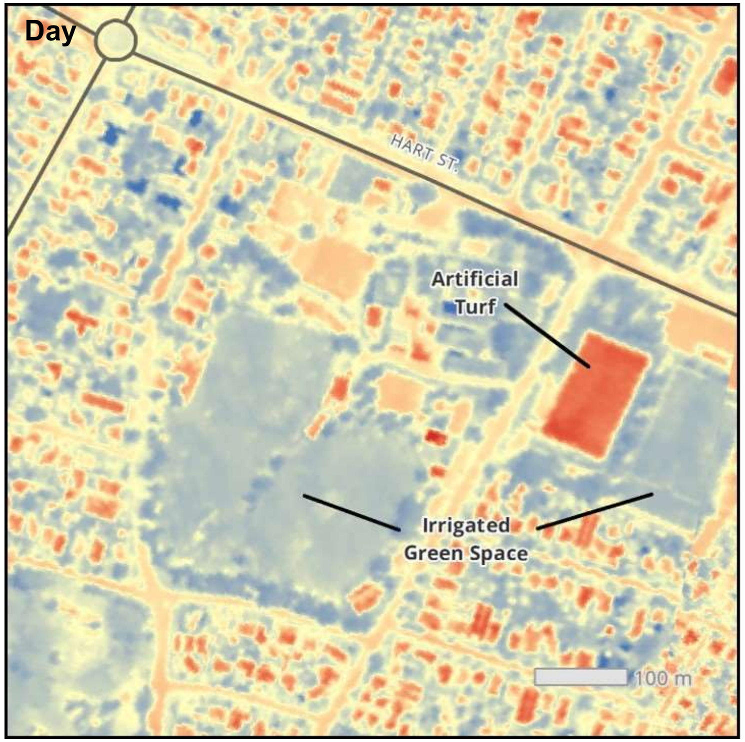
Case study 1 - Irrigated vs non-irrigated open space

- Santos Stadium in Mile End South highlights the thermal differences between irrigated and non-irrigated green space.
- The irrigated sports field inside the stadium displays a cooler, medium blue colour whereas the non-irrigated green space to the north east of the stadium displays a warmer light blue-yellow. Notably, some of the non-irrigated open space areas in the far right of the image (to the east of the Stadium) show as much warmer yellow to red.
- Both surfaces, irrigated and non-irrigated green space, produce cooler than average temperatures across the whole of the study area with non-irrigated areas having a cooling effect of 2.2°C and irrigated areas showing 4.0°C of cooling.



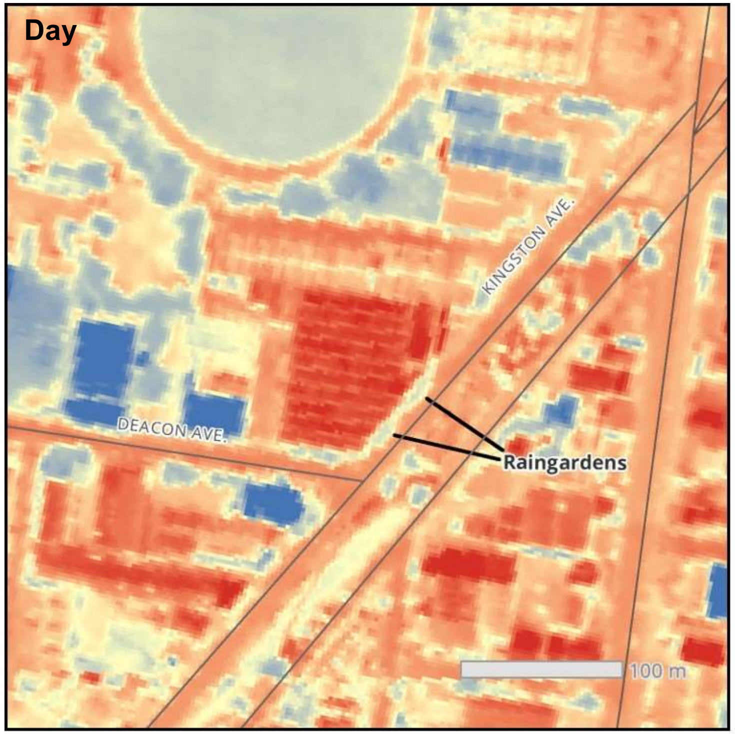
Case study 2 – Impact of artificial turf

- Artificial versus natural turf sporting field surfaces show a large difference in temperature.
- The Port Adelaide Hockey Club in Ethelton provides a clear example of this pattern with the artificial turf surface measured at 8.1°C warmer than average surface temperature across the region. Conversely, the surrounding irrigated natural turf surfaces measured 14°C cooler than the artificial turf at the time of data collection.
- Overall, analysis of four large artificial turf surfaces across the study area revealed an average warming of 5.5°C above the average surface temperature.



Case study 3 – Water sensitive urban design along a roadside

- Water sensitive urban design features such as raingardens are an important landscaping tool with the dual benefits of allowing rainwater to percolate into the soil while expanding green space along the road corridor. One of several examples that exist across the study area lies along Kingston Avenue, Richmond.
- The impact of the two raingardens is visible in the thermal imagery showing two semi-circle shaped cool areas jutting into Kingston Avenue matching the geometry and location of raingardens. Temperatures within these two raingardens measured 36.2°C, while neighbouring kerb areas without raingardens measured on average 42.3°C, suggesting that raingardens may have up to a 6°C cooling effect.
- Further investigations can help to verify the exact magnitude of the cooling effect from water sensitive urban design features.



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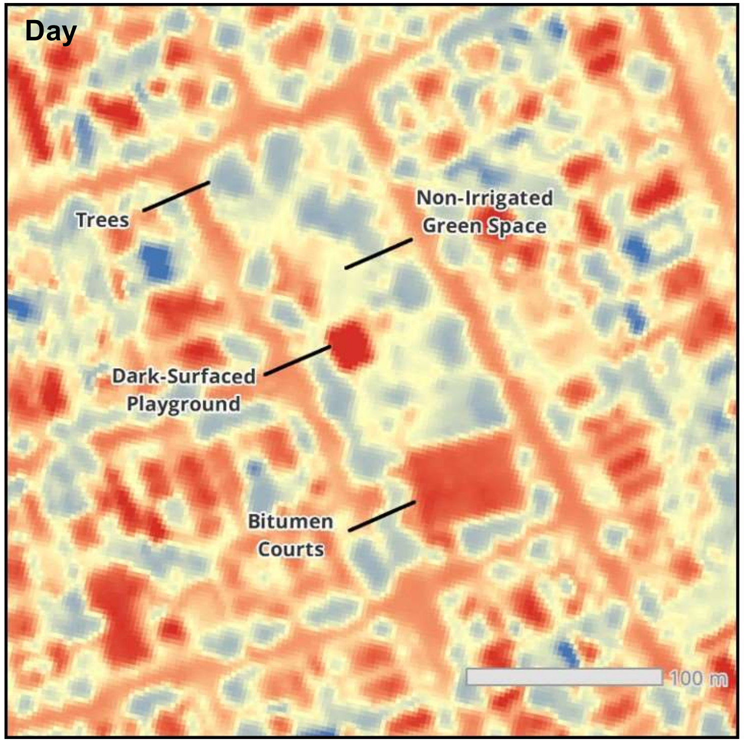
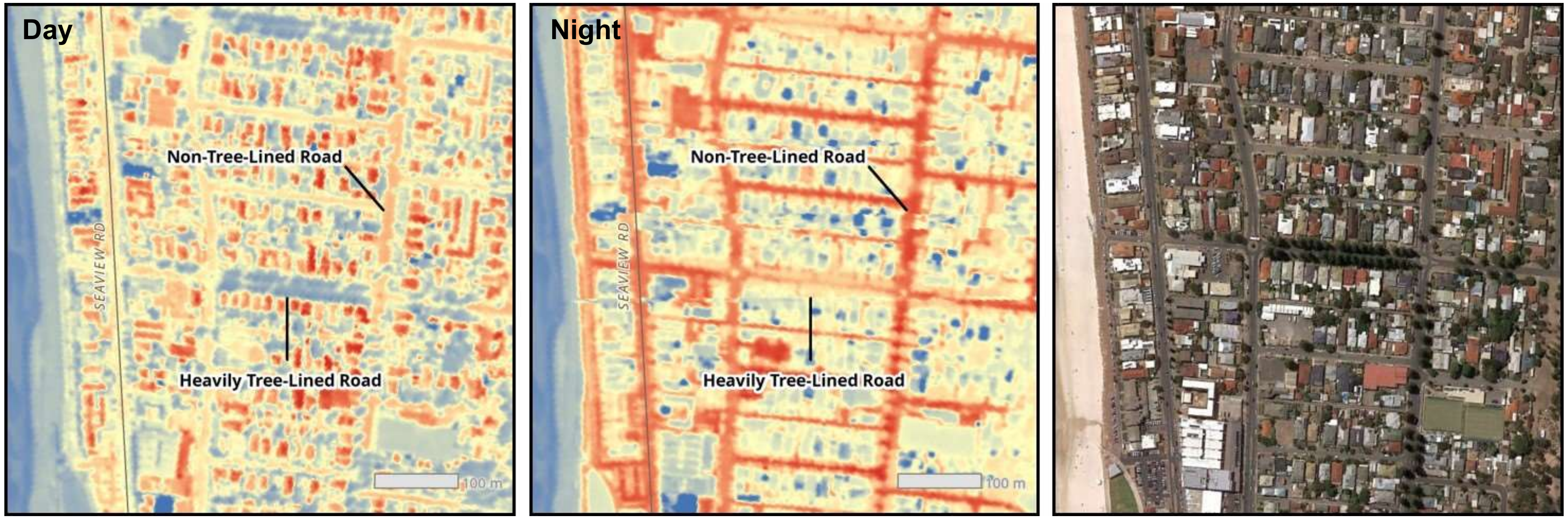
Case study 4 – Playgrounds

- Failing to account for heat can expose vulnerable members of the community such as young children to significant danger.
- Company Square Reserve in Alberton consists of a mixture of open space, playground and tennis/netball courts. The dark-surfaced playground area is covered in rubber softfall surfacing and registered over 52°C, more than 4°C hotter than the nearby bitumen tennis/netball courts, and more than 15°C hotter than the surrounding non-irrigated open space.
- This case study demonstrates that construction material choices affect comfort and safety.



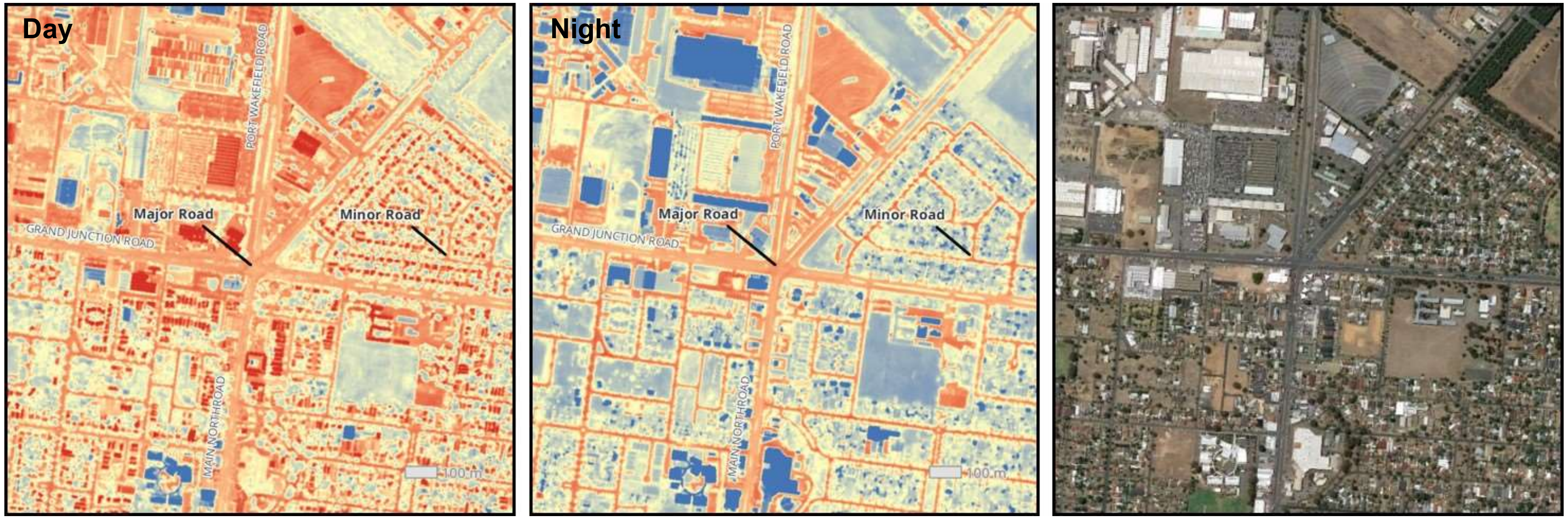
Case study 5 - Tree lined streets vs non-tree lined streets

- Large, exposed tracts of bitumen are one of the warmest urban surfaces absorbing heat during the day and holding that heat well into the night. However, tree-lined streets present a powerful mitigation approach.
- North Street in Henley Beach is one of the most heavily tree-lined streets in the study area. Its measured day time temperatures were 34°C while neighbouring exposed streets measured upwards of 42°C.
- Shading during the day means there is less heat to re-emit at night leading to cooler temperatures both day and night.



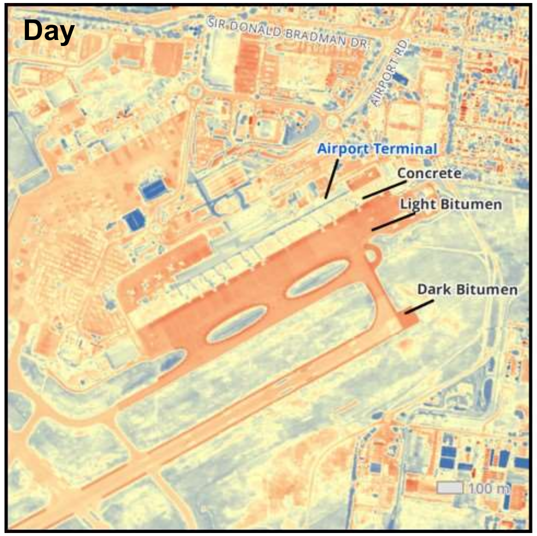
Case study 6 - Major versus minor road

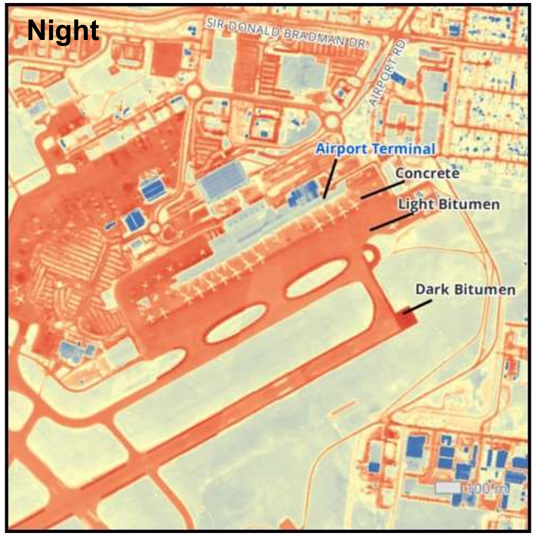
- Gepps Cross, one of the largest intersections in the study area, illustrates the warming caused by large tracts of exposed bitumen.
- Across the whole of the study area, major roads averaged over 3°C above mean temperature while minor roads were typically 1.5°C warmer than average.
- Roads are major drivers of not only day time hotspots but also night time hot spots as their high heat capacity means they emit a strong warming signal well into the night.



Case study 7 – Parking surface materials

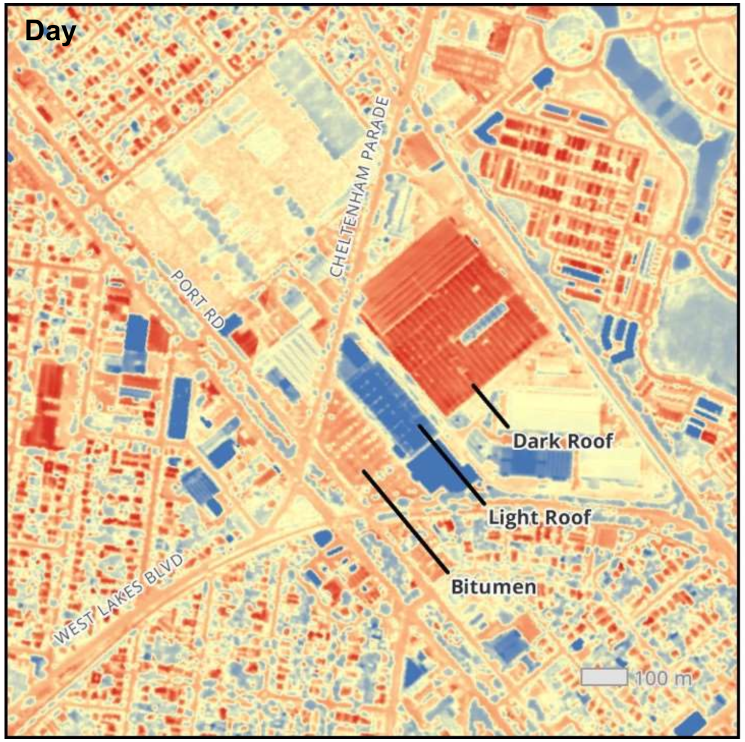
- The choice of materials for constructing roads and car parks can have a major effect on landscape heat.
- The Adelaide Airport has many types of hard surfaces creating a natural case study for exploring their impacts on heat absorption during the day and re-emission during the night.
- Surface temperatures varied by up to 3°C between dark coloured bitumen and light coloured bitumen, and by up to 7°C between dark coloured bitumen and concrete.





Case study 8 – Roof colour

- Building roofs represent one of the most dynamic surface classes as measured by the range of measured temperatures.
- Buildings at the intersection of Port and Cheltenham Roads, Woodville West, illustrate this by showing the very cool (blue) light roof of a large retail hardware store contrasted with the very dark roofs of surrounding industries.
- Across the study area, dark roofs were 2.8°C above the average surface temperature while light roofs were 2.3°C cooler, equating to substantially less heat absorbed. This demonstrates that material choices can drastically effect thermal impacts.



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Case study 9 – Combination of roof colour and green space

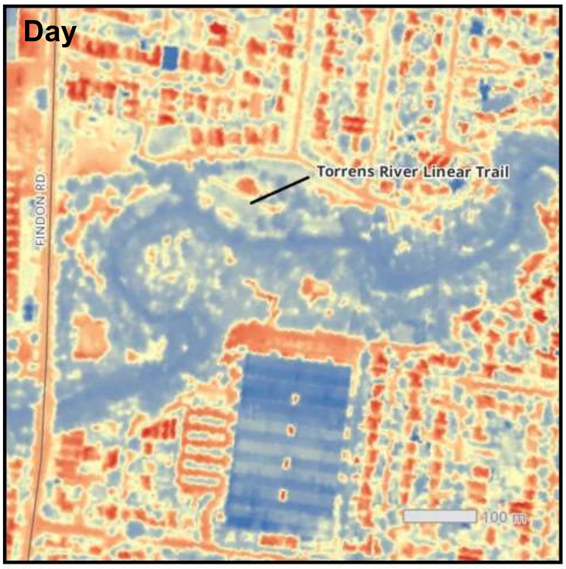
- Not all areas in Western Adelaide were hot, with some cool areas providing useful lessons on how to mitigate heat.
- Dark roofs are one of the largest contributors to hotspots and heat islands. Communities that choose lighter coloured roofing materials, such as this area in Seaton, are exercising a simple choice that can dramatically affect liveability.
- The area with predominately white roofs form a cool island exhibiting consistently below-average temperatures while surrounded by a heat island - an area consistently more than 2°C above average.

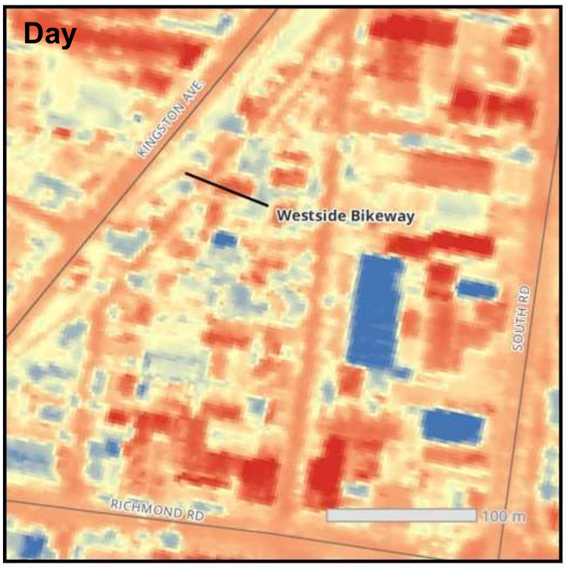
Case study 10 - Transport corridor

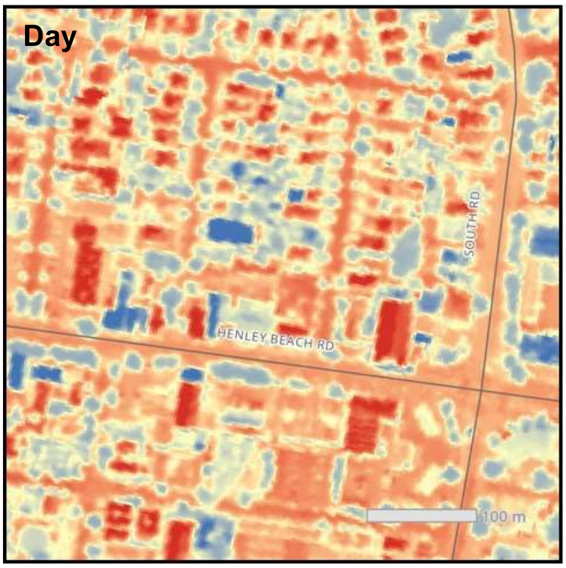
- Cool space, open space, and roads all exhibit significantly different temperature impacts meaning that human thermal comfort can differ significantly depending on the surrounding urban form. One implication of this is that bike route location can influence how many days may be bikeable.

- The River Torrens Linear Trail was as much as 5°C cooler on the day of the flyover compared with average surface temperatures. Road corridors, in addition to being crowded and noisy, are hot, with bike lanes on Henley Beach Road being more than 3°C above average. Open spaces with limited shading, such as the Westside Bikeway, provide some relief compared to exposed roads but are still about 1°C above average surface temperatures.

- A more detailed investigation covering the full length of these and other bike routes would provide more detailed information to help planners and cyclists choose the paths that are safer and more comfortable to use during periods of extreme heat.


Day
Torrens River Linear Trail
FINDON RD
100 m


Day
KINGSTON AVE
Westside Bikeway
SOUTH RD
RICHMOND RD
100 m

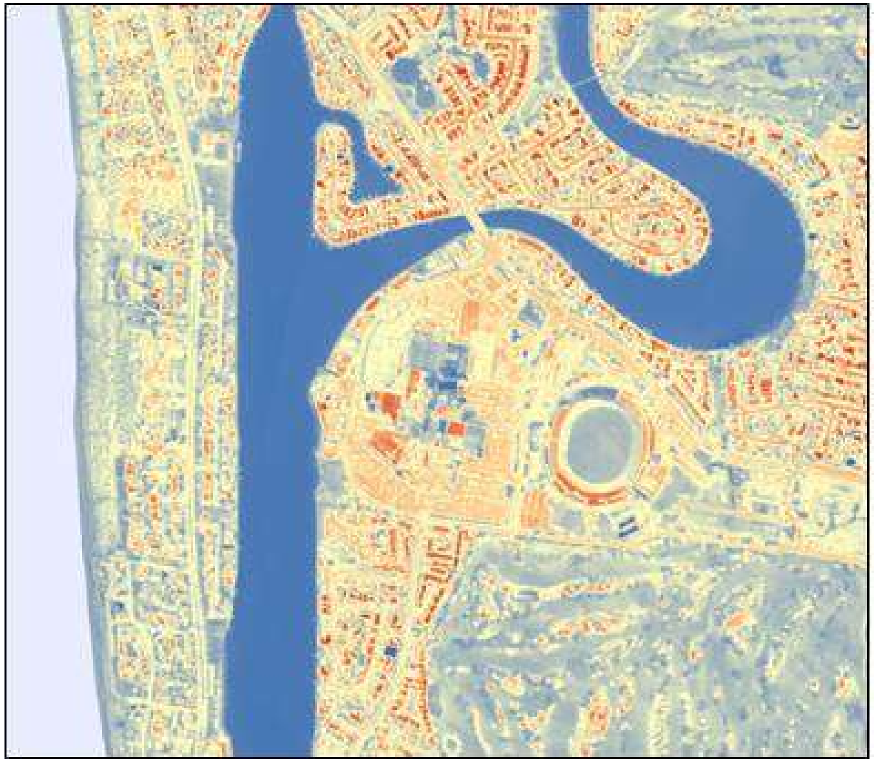

Day
SOUTH RD
HENLEY BEACH RD
100 m

Case study 11 – Water bodies

- Water exhibited some unexpected temperature patterns between day and night. During the day, water provided a strong cooling effect due to its high heat capacity. However, as high heat capacity means it is slow to warm, water was also slow to cool, causing it to shift to warmer colours on the night time thermal map.

- This is most important for shallow bodies of water as prolonged warm periods may cause them to warm significantly above the baseline temperature and become a contributor to evening heat islands.

- The West Lakes region provided a clear example of this process. The extent to which the regular flushing of the lake reduces this effect may require additional investigation.



4 Drivers of future heat impacts

4.1 Potential impact from climate change

In Western Adelaide, climate change will lead to higher temperatures, reduced rainfall and longer, more severe, and more frequent heat waves. Urban areas already suffering from the 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 AdaptWest Climate Change Adaptation Plan (City of Port Adelaide Enfield, 2016), specific climate change impacts relevant to heat accumulation and the condition of green cover include the following[2]:

- Average temperature (Summer – Autumn) - An increase in average annual temperatures of up to 2°C is projected in summer-autumn across the region by 2070;

- Average rainfall (Winter-Spring) - Average winter rainfall is predicted to decrease by up to 20% and spring rainfall by up to 20% below 1990 levels by 2070; and

- Extreme heat - Sequences of three or more consecutive days with average temperatures of at least 32°C are projected to increase from 1 in 20 years to one in every 3-5 years under a low emissions scenario in 2070 and every year under a high emissions scenario by 2070.

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.

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[2] Further, more detailed information about climate change projections for Western Adelaide are contained in the AdaptWest Climate Change Adaptation Plan. This includes an explanation of the impact of climate models and emissions scenario choice on projections.

4.2 Density of development

A target of the South Australian Government's 30 Year Plan for Greater Adelaide is "Containing our urban footprint and protecting our resources". This in part will be achieved through infill by ensuring that 85% of all new housing in metropolitan Adelaide is built in established urban areas by 2045.

Infill will result in transition of low density developments toward middle and high density developments. A consequence of the current approach to infill is a more compact urban form, increasing area of impervious surfaces and loss of green space and tree canopy.

Future potential impacts of infill can be assessed using the current heat mapping data by comparing surface temperatures in low, medium and high density residential zones (Figure 8). Areas with a low density of dwellings, such as Fulham, have more room for green space which can offset the warming impact of impervious driveways, roads, and dark roofs. Medium density residential areas, such as West Croydon, have less room and fewer options for mitigation but still preserve some landscape for open space providing some relief from heat. High density residential areas, such as areas within Northgate, have limited open space and few options for heat mitigation.

Comparing temperatures across different density development zones, high density areas of Northgate were found to be 2.9°C warmer than the low density areas of Fulham. The high density and predominately dark roofs create a heat island for the residents in this area of Northgate raising their temperatures more than 2°C above average, whereas the low and medium density areas of Fulham and West Croydon exhibit a slight cooling effect of 0.3°C and 0.9°C, respectively.

At a suburb a scale, these findings suggest that the density of development can have at least as great an effect on temperature as climate change. In order to reduce this impact, careful consideration needs to be given to material selection in higher density developments and how to encourage green space, such as through green roofs and green walls.

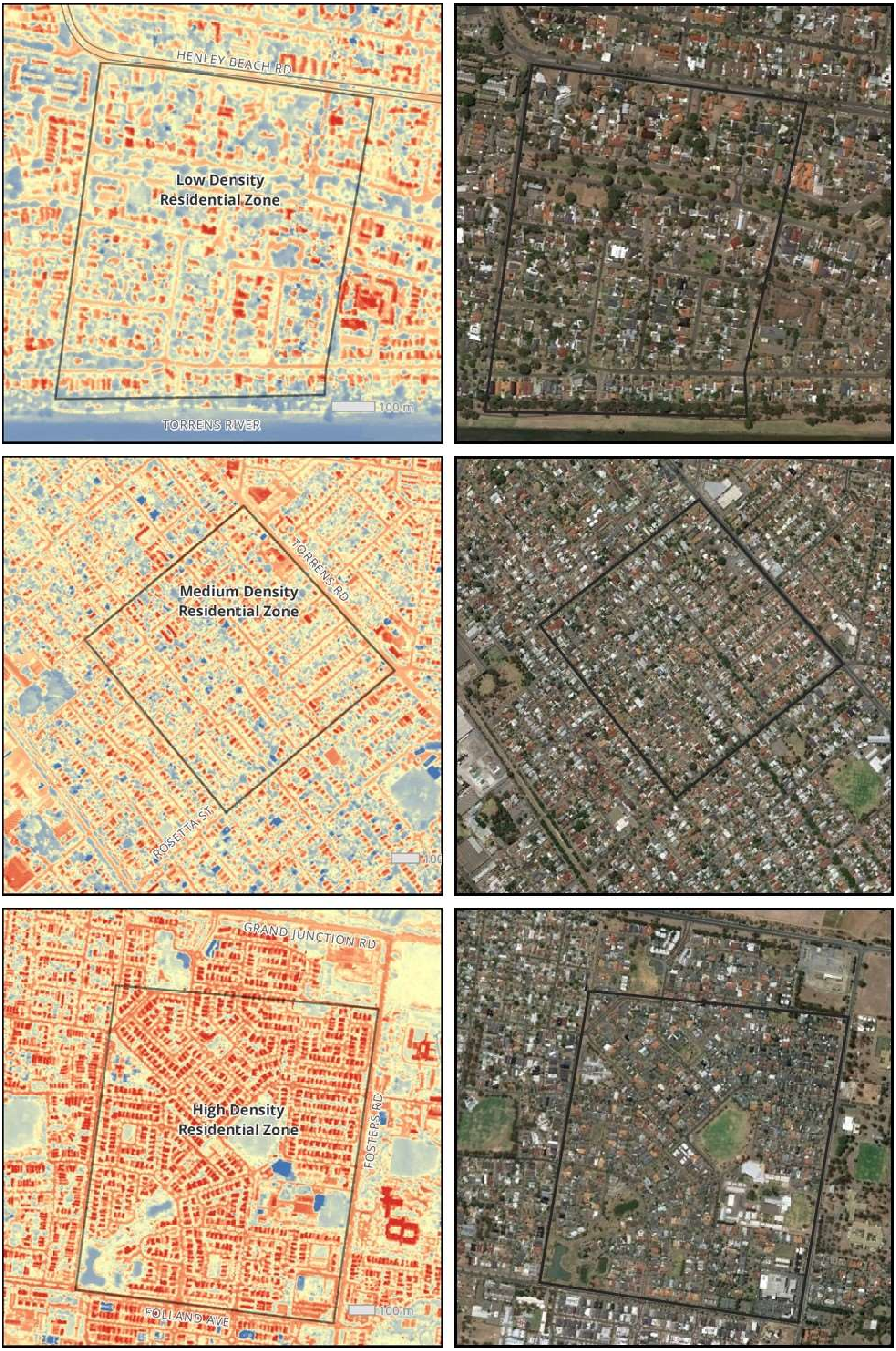


Figure 8. Surface temperatures in low (Fullham), medium (West Croydon) and high (Northgate) density residential zones.

5 Responding to urban heat risks

5.1 Priority areas for heat mitigation

Hot spots and urban heat islands are widespread across Western Adelaide. Without due consideration of planning, design, material selection and provision of green space, urban infill as forecast in the 30-Year Plan for Greater Adelaide will lead to an expansion in urban heat islands over the next 20 years due to increases in higher density living and loss of green cover. Urban areas already suffering from the heat island effect will bear the brunt of more frequent and intense extreme heat events under climate change.

While the City of Charles Sturt had the highest percentage of hot spots of the three councils at 36.8% (20.1 km^2) of its land area, the percentage of land covered by hotspots is broadly similar (31 to 37%). In contrast, 20% of the City of Port Adelaide Enfield falls within an urban heat island compared to 16% for the City of Charles Sturt and 10% for the City of West Torrens.

The results of the analysis clearly identified suburbs located within heat islands that can provide a focus for future management activities. There were also two north south bands of heat islands, running from Dry Creek South to Henley Beach in the west of the region and from Wingfield to Brompton in the centre of the region. The extent to which this is due to warm air moving south from hotter industrialised areas in the region requires further investigation.

Most of the heat islands evident during the day were found to diminish during the evening, with concentrations of heat less noticeable at night. While there were still concentrations of heat during the evening in surfaces such as roads, these were largely road and pavement surfaces and were not evident at the spatial scale of a heat island (i.e. 125 m x 125 m).

While hot spots and heat islands provide 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 (Norton, et al., 2015).

At a whole of region scale, 15% of people live within an urban heat island, which includes 4,019 people aged over 75 years and nearly 3,000 who require assistance for day to day activities, both being key indicators of social vulnerability.

There are a number of specific suburbs that contain urban heat islands and that have a high degree of social vulnerability. For example, heat islands in Fulham Gardens had the highest degree of social vulnerability within the City of Charles Sturt and overall, while heat islands in Oakden and Lockleys had the highest degree of social vulnerability in Port Adelaide Enfield and West Torrens, respectively. Other suburbs that had high social vulnerability and exist within heat islands include parts of Albert Park, Seaton and Findon.

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.

5.2 Mitigating urban heat islands

Urban heat islands can be mitigated by understanding the factors that influence temperatures at a local scale, such as land use management decisions and building material selection.

This study reveals that land use decisions and material selection in Western Adelaide can cause at least a 7°C difference in surface temperature, as illustrated by the case studies presented in Section 3 and 4. Key features to note for the region are that:

- during the day, major roads had the largest warming impact (3.0°C) followed by minor roads and parking lots (1.6°C above average). Both surfaces retain more heat during the evening than most other surface materials in the region;
- green infrastructure leads to cooler temperatures in general, ranging from 2.2 to 4.0°C below the average depending on the extent of irrigation;
- roof colour has a major impact on surface temperature, with a 5.2°C difference between light and dark roofs.

These temperature differentials provide a strong case for using green infrastructure and encouraging light coloured roofing materials as a means for combating urban heat islands. The tangible benefits of tree for example are demonstrated by Case study 5, which showed a difference of 8°C between a street with and without trees in Henley Beach. The combination of roof colour and green space is also demonstrated by Case study 9, which shows an area in Seaton with light coloured roofs and green space which is noticeably cooler than surrounding streets and suburbs. Both case studies indicate that greening and irrigation type treatments at the street level are very likely to make a difference to street level thermal comfort.

Patterns of where heat persisted from day into night also provide 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) vs. *high-intensity* hot spots (heat up during the day and retain heat during the night), and revealed several key patterns:

- roads and paved surfaces were the strongest contributor to night-time heat;
- dark roofs, while hot during the day, quickly dissipated heat after sundown; and
- shallow/closed bodies of water, which provided cooling during the day, emerged as warm-spots at night. This is due to the high heat capacity of water.

The observations from this study into the land use types and materials that influence cooler surface temperatures align well with general strategies for heat island cooling (Table xxx). Based on the findings of this study 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. 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;

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

4. 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;

5. light coloured roofs be encouraged in residential and industrial areas over dark coloured roofs;

6. 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 e.g. through the use of shade sails;

7. 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; and

8. planning, development and infrastructure be supported with a strong focus on design and build quality for dwelling comfort and liveability.

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 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. Also called “rooftop gardens” or “eco-roofs,” 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.
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, farmland, natural beauty, and critical environmental areas; • Strengthen and direct development towards existing communities; • Provide a variety of transportation choices; • Make development decisions predictable, fair, and cost effective; and • Encourage community and stakeholder collaboration in development decisions.

Table 6. Broad strategies for reducing the impact of urban heat islands. Adapted from (U.S. Environmental Protection Agency, 2008).

5.3 Decision mapping

The collection and analysis of data to inform the development of heat maps generates significant quantities of spatial information. While this data can generate a broad range of mapping outputs, without tailoring the maps or conducting further analysis and modelling, the data is unlikely to directly inform decision making.

To help guide the ongoing use of the data generated for this project a decision map is provided in Figure 9. This recognises that initially the objective of generating heat mapping information is to build capacity amongst decision makers. This is followed by identifying specific areas of risk and finally, implementing projects that reduce a specific risk.

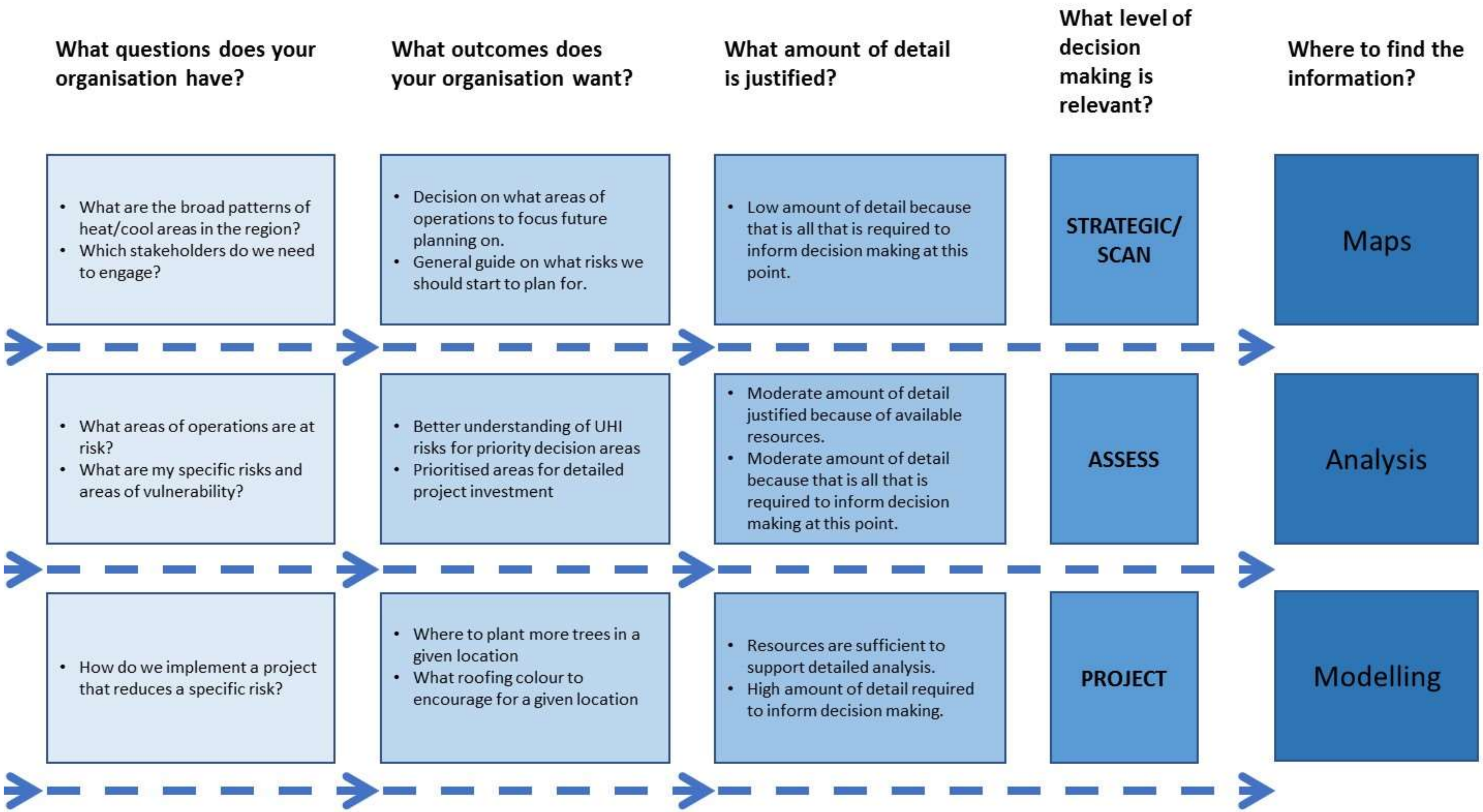
It is recommended that the decision map is used before any additional analysis or use of the data occur, and that consideration be given to the following four questions:

- What questions does your organisation have?
- What outcomes does your organisation want?
- What amount of detail is justified?
- What level of decision making is relevant?

Depending on the responses to the questions, decision makers may choose to:

- refer to the maps provided in the annexes of this report;
- consider the results of the analysis presented, such as the relationship between land surface types and materials and temperatures; and
- conduct modelling to estimate the impact of different heat mitigation strategies for a given location.

Figure 9. Decision map to assist with determining what heat mapping information is required to inform decision making. Working left to right, the decision map can be used to determine which series of responses to the four questions are most relevant to your current key area for decision making and therefore whether you require maps, analysis or modelling information.



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5.4 Future directions

5.4.1 Targeting analysis

Thermal data can help prioritise problem areas. For instance, investigating the parklands within the suburbs of Alberton and Rosewater reveals that two local parks are warmer than average, and of those two, one is particularly hot. If a council looks to develop its parks as a reprieve from summer heat, prioritised Parks 1 and 2 (Figure 10) should be targeted for mitigation, with Park 1 taking priority for first actions as its mean temperature is the highest of the five. Targeting analyses can integrate numerous variables to identify project-specific priorities. Targeting analysis provides quantitative rationale for where efforts will provide the greatest relief.

Figure 10. Examples of parks prioritised for heat mitigation strategies based on their current surface temperature.

5.4.2 Prescriptive analysis

With priority targets identified, the impacts of specific mitigation options can be evaluated using prescriptive analyses. For example, within Priority Park 1, maximum temperatures of 56°C occur over the dark-surfaced playground area which makes up a small portion (200 m^2, <2%) of the park's total land surface (10,500 m^2) but substantially alters the park's thermal landscape, specifically within a high-use area for children (Figure 11). Prescriptive analysis demonstrates that resurfacing the playground with a lighter-coloured material or a sunshade of average surface temperature would reduce the playground temperature by 18°C at the hottest places and lower the park's overall mean temperature by 1.5°C, making the park a local cool spot offering relief to residents.

Figure 11. Results of prescriptive analysis for a playground where dark-surface covering is replaced in the thermal data set with a proposed sunshade.

5.4.3 Prioritising green infrastructure to mitigate high temperatures

One central strategy for mitigating urban heat islands is to increase the area of urban green infrastructure (UGI). 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.

5.4.4 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 period of extreme heat. Western 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.

5.4.5 Further comparison of materials and surface types across the region

This study provides broad comparisons of the surface temperature of different material types e.g. irrigated versus non-irrigated sporting fields and green space, dark versus light coloured roofs. Further comparison should be conducted to determine how materials and design features generate different heat profiles for the same elements across the region. This would require on ground verification of the difference in material types, for example whether a roof is made from shingles, tin, asbestos sheeting, or different shades of colour.

5.4.6 Relationship between surface and air temperature

The thermal data collected and the analyses performed are based on surface temperature, which directly influences but is not the only control of ambient air temperature. While airborne remote sensing measurements remain the best method for capturing city-scale temperature, minor local variations potentially driven by local wind patterns and other factors, may be missed.

Establishing the relationship between air temperature and surface types in the region requires further investigation. This should focus on the air temperature at sites with a mix of surface materials with contrasting surface temperatures e.g. retail precincts with light coloured roofs alongside large areas of open bitumen, major roads fringed by trees and raingardens.

References

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.

Matzarakis, A., Rutz, F. & Mayer, H., 2007. Modelling radiation fluxes in simple and complex environments - Application of the RayMan model. *International Journal of Biometeorology,* 51(4), pp. 323-334.

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.

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

Annex 1: Council thermal maps

This Annex provides day and night heat maps for each Council. It should be noted that these are a clipped map from the whole of region heat maps.

The six maps are organised in the following order:

1. City of Charles Sturt (Figure A1.1)
2. City of Charles Sturt (Figure A1.2)
3. City of Port Adelaide Enfield Day (Figure A1.3)
4. City of Port Adelaide Enfield Night (Figure A1.4)
5. City of West Torrens (Figure A1.5)
6. City of West Torrens (Figure A1.6)

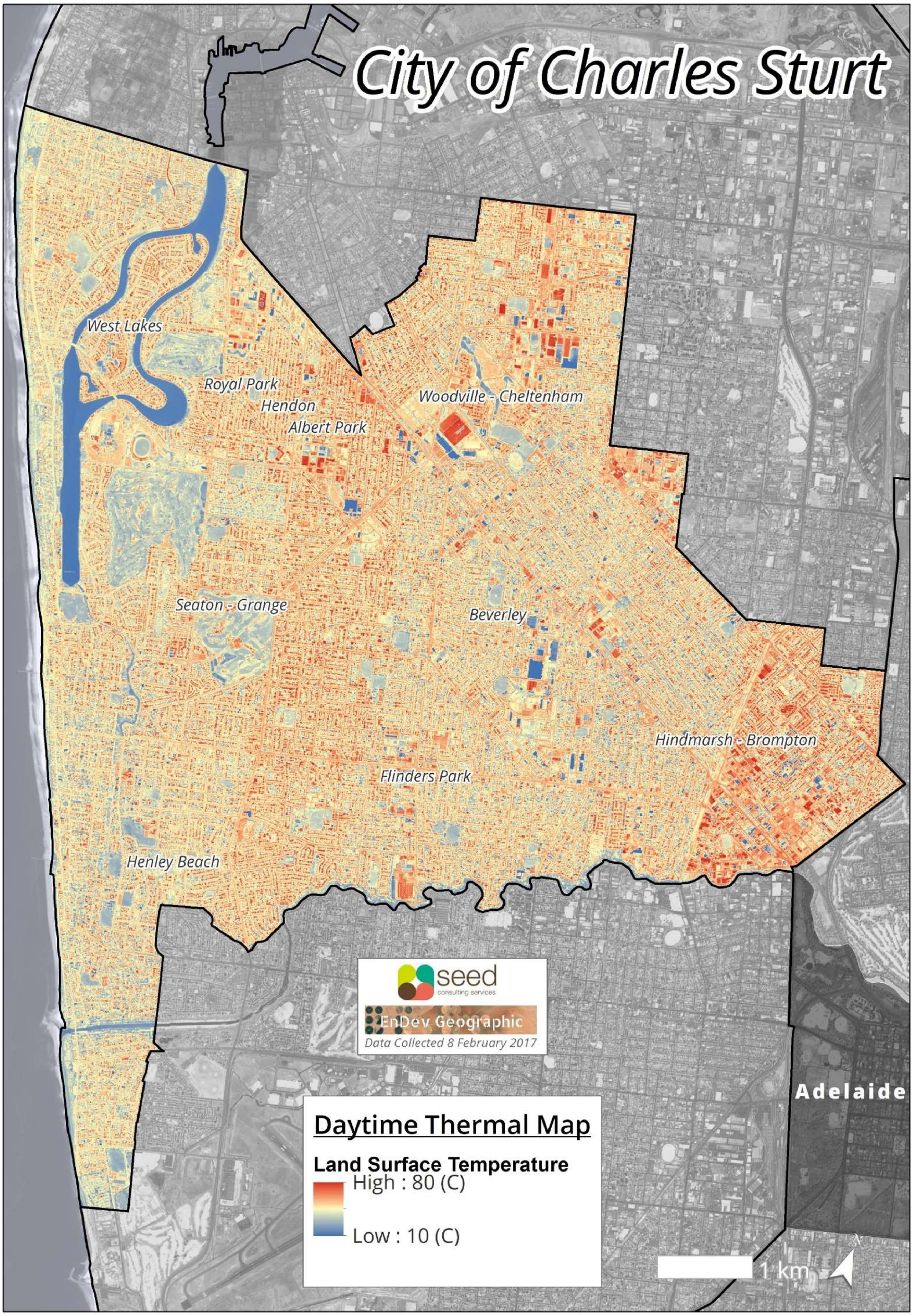

Figure A1.1. Day time thermal map for the City of Charles Sturt.

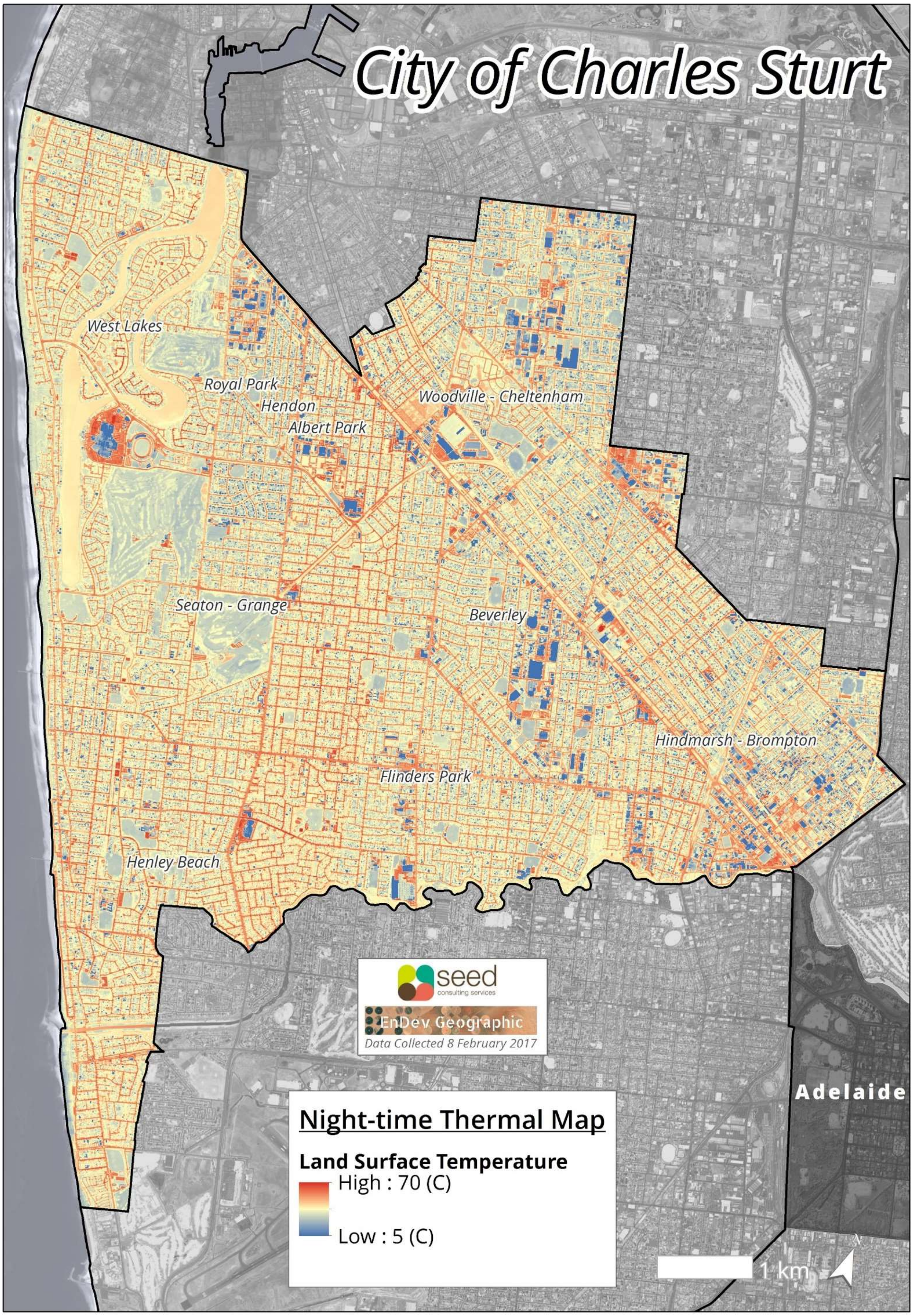

Figure A1.2. Night time thermal map for the City of Charles Sturt.

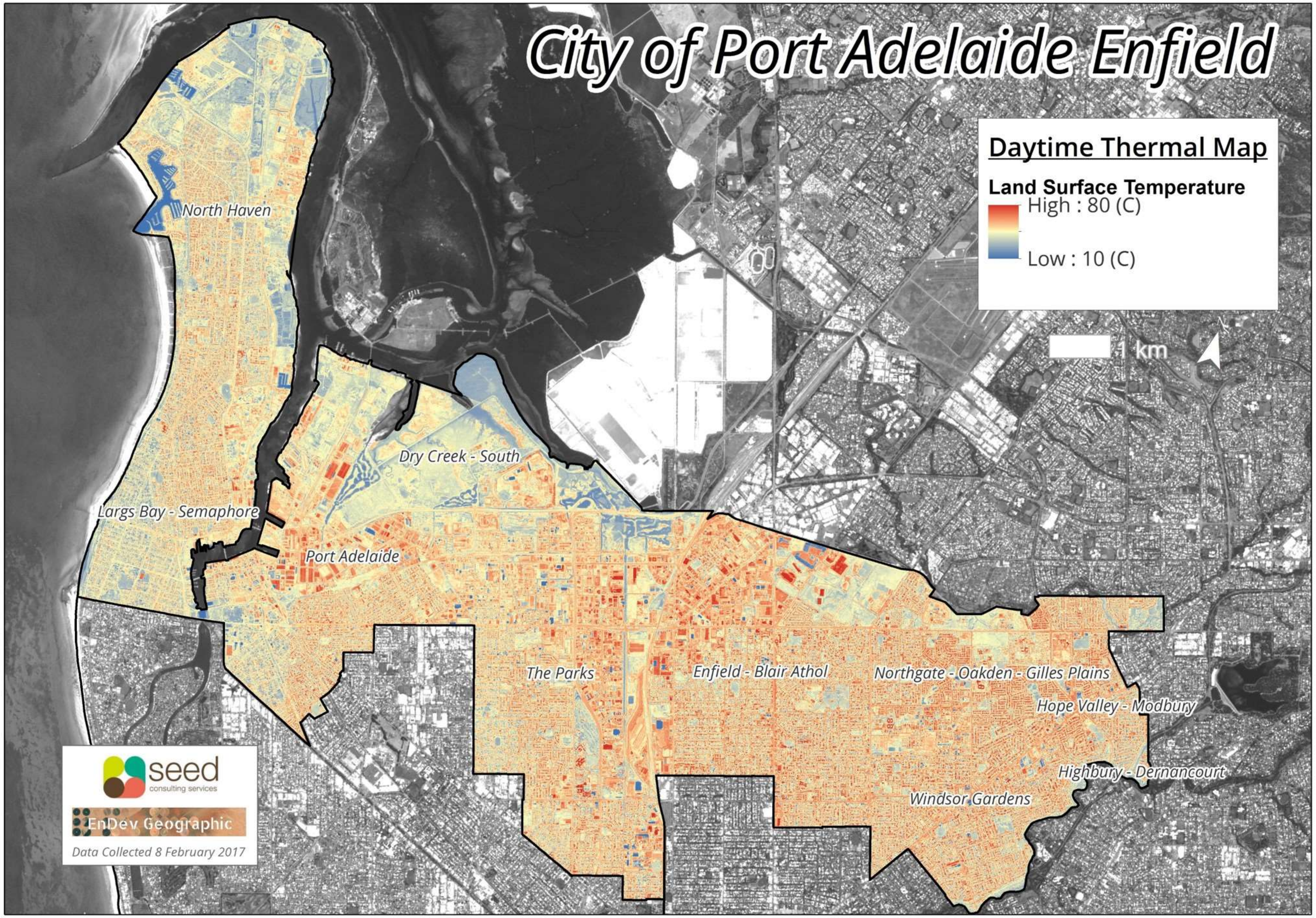

Figure A1.3. Day time thermal map for the City of Port Adelaide Enfield.

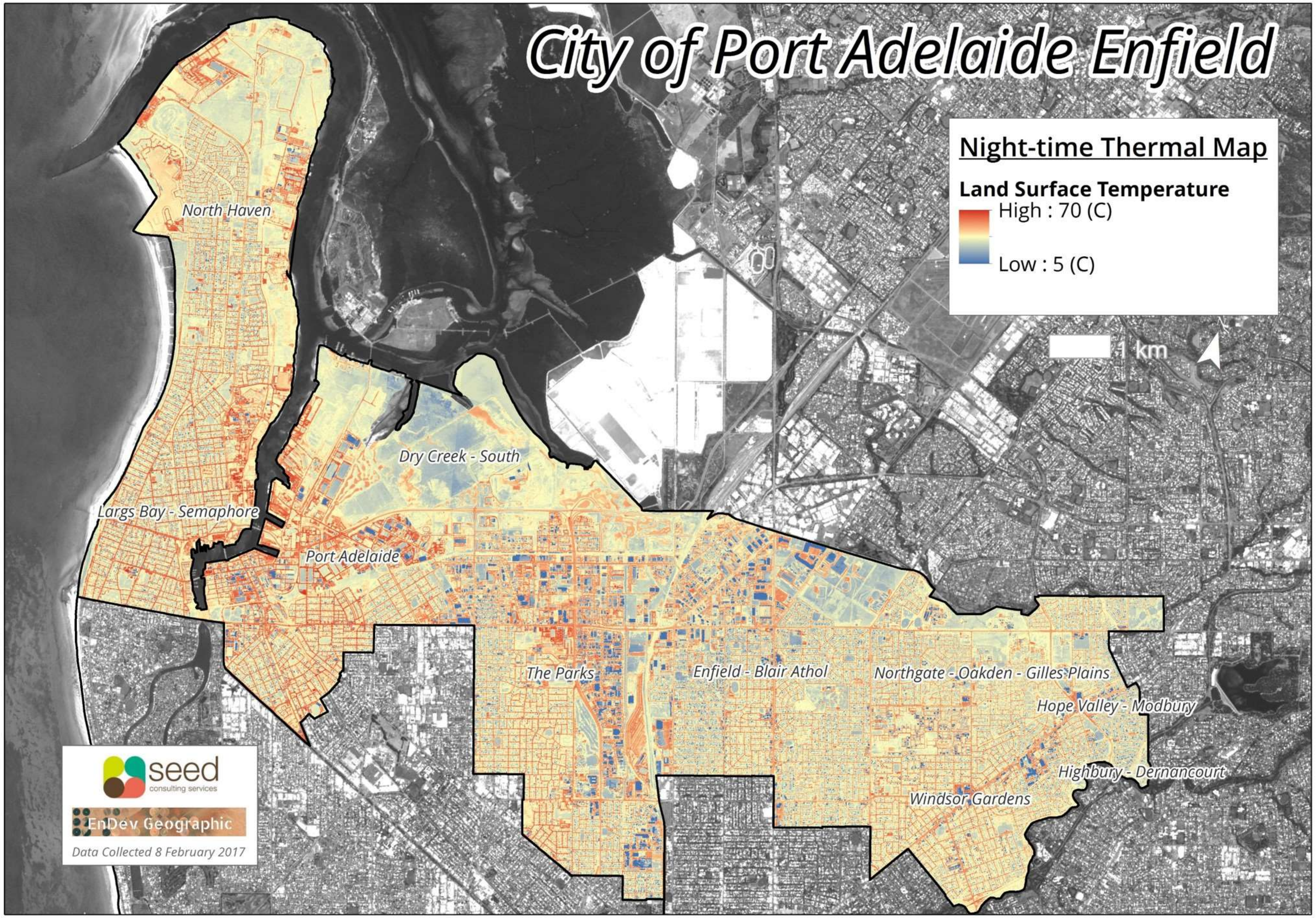

Figure A1.4. Night time thermal map for the City of Port Adelaide Enfield.

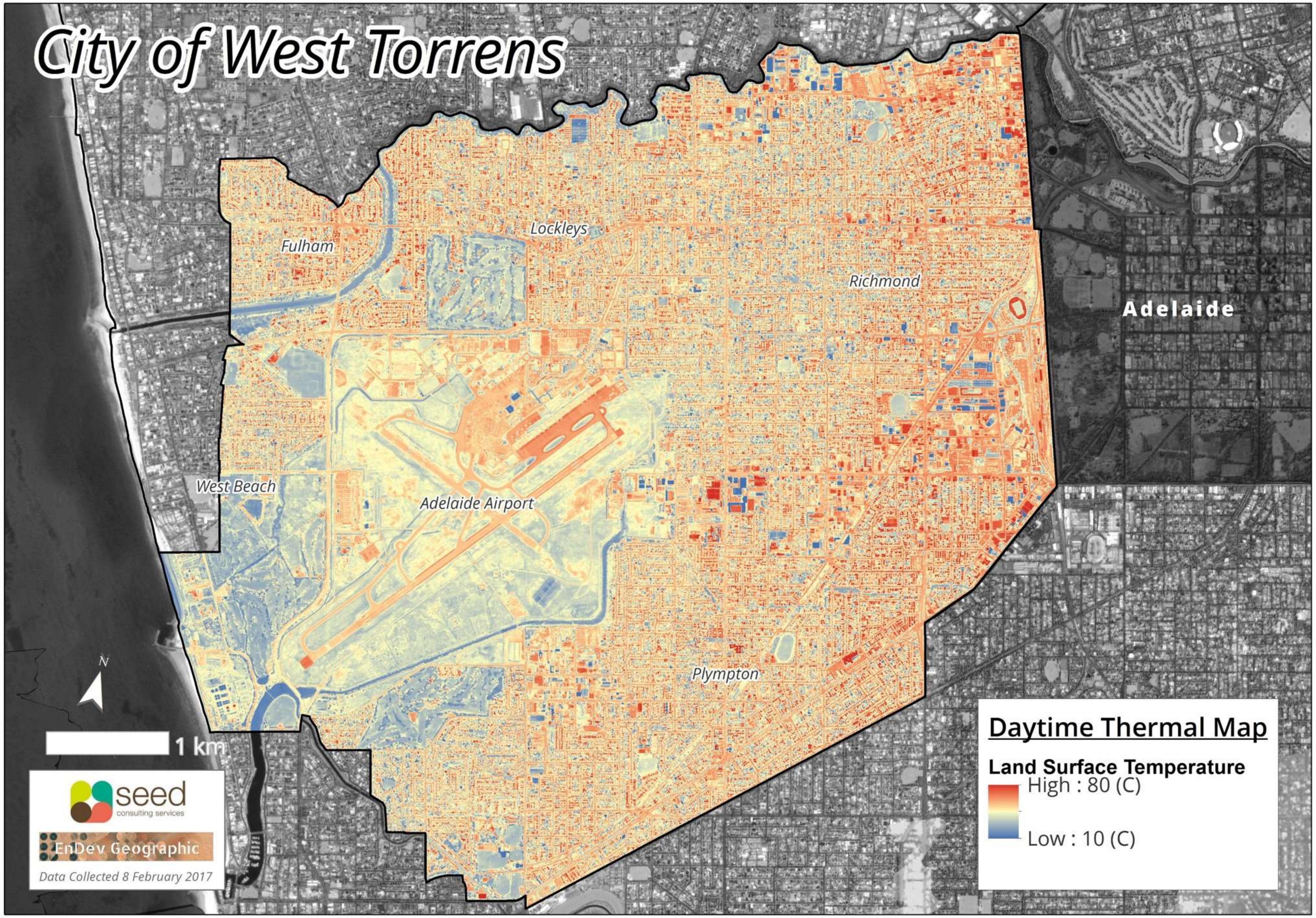

Figure A1.5. Day time thermal map for the City of West Torrens.

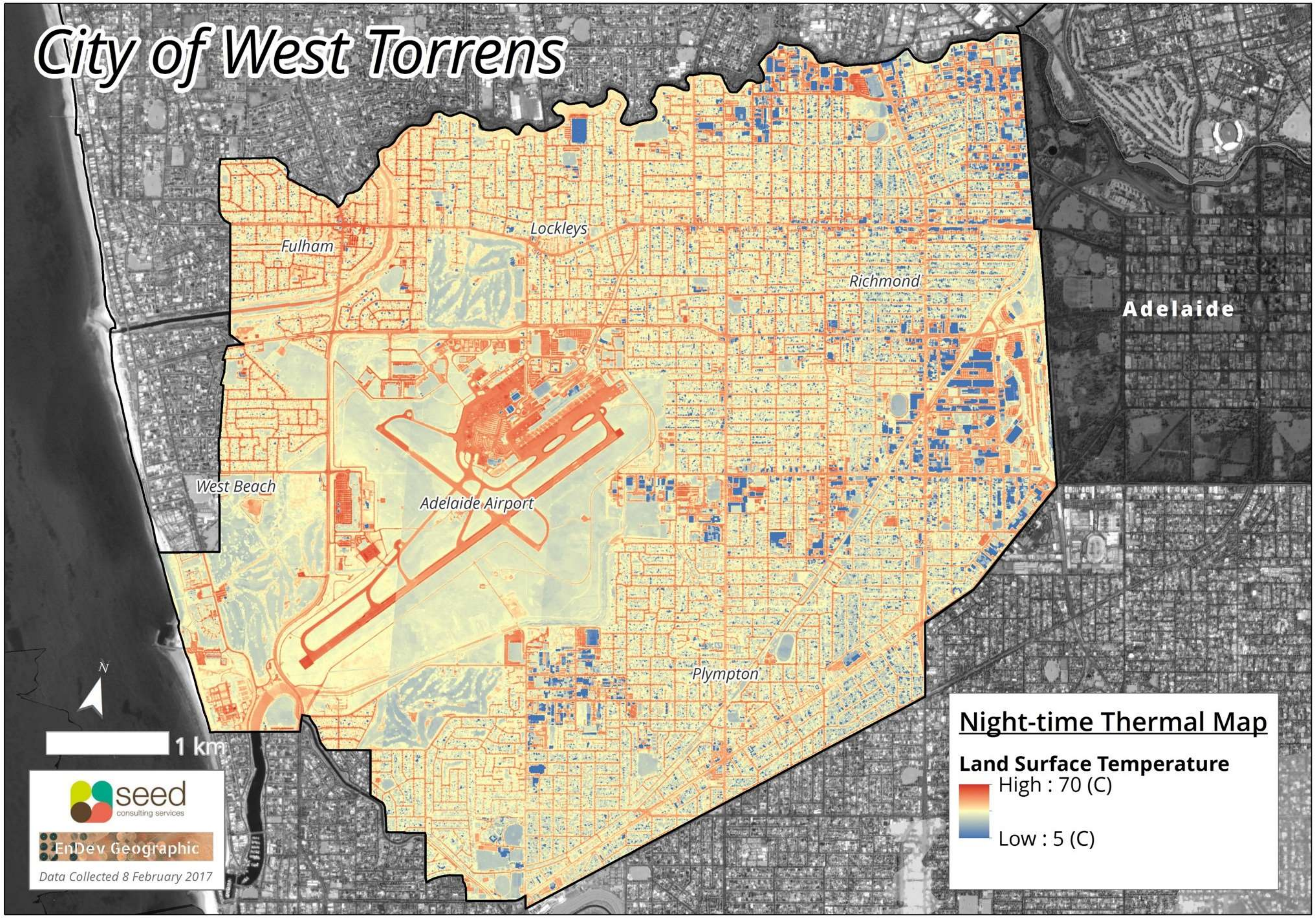

Figure A1.6. Night time thermal map for the City of West Torrens.

Annex 2: Thermal map profiles

Due to the detail of the data and complexity of the analysis, additional results are presented in an indexed series of eight map panels. The following index map (Figure A2.1) shows the location of each map within the study area. Each map panel contains:

- Day-Time Thermal Map (top left)
- Night-Time Thermal Map (top right)
- Day-Time UHI and Social Vulnerability Map (bottom left)
- Night-Time UHI and Social Vulnerability Map (bottom right)

The eights maps are organised in the following order:

1. Port Adelaide Enfield North (Figure A2.1)
2. Port Adelaide Enfield South (Figure A2.2)
3. Port Adelaide Enfield Central (Figure A2.3)
4. Port Adelaide Enfield East (Figure A2.4)
5. Charles Sturt West (Figure A2.5)
6. Charles Sturt East (Figure A2.6)
7. West Torrens East (Figure A2.7)
8. West Torrens West (Figure A2.8)

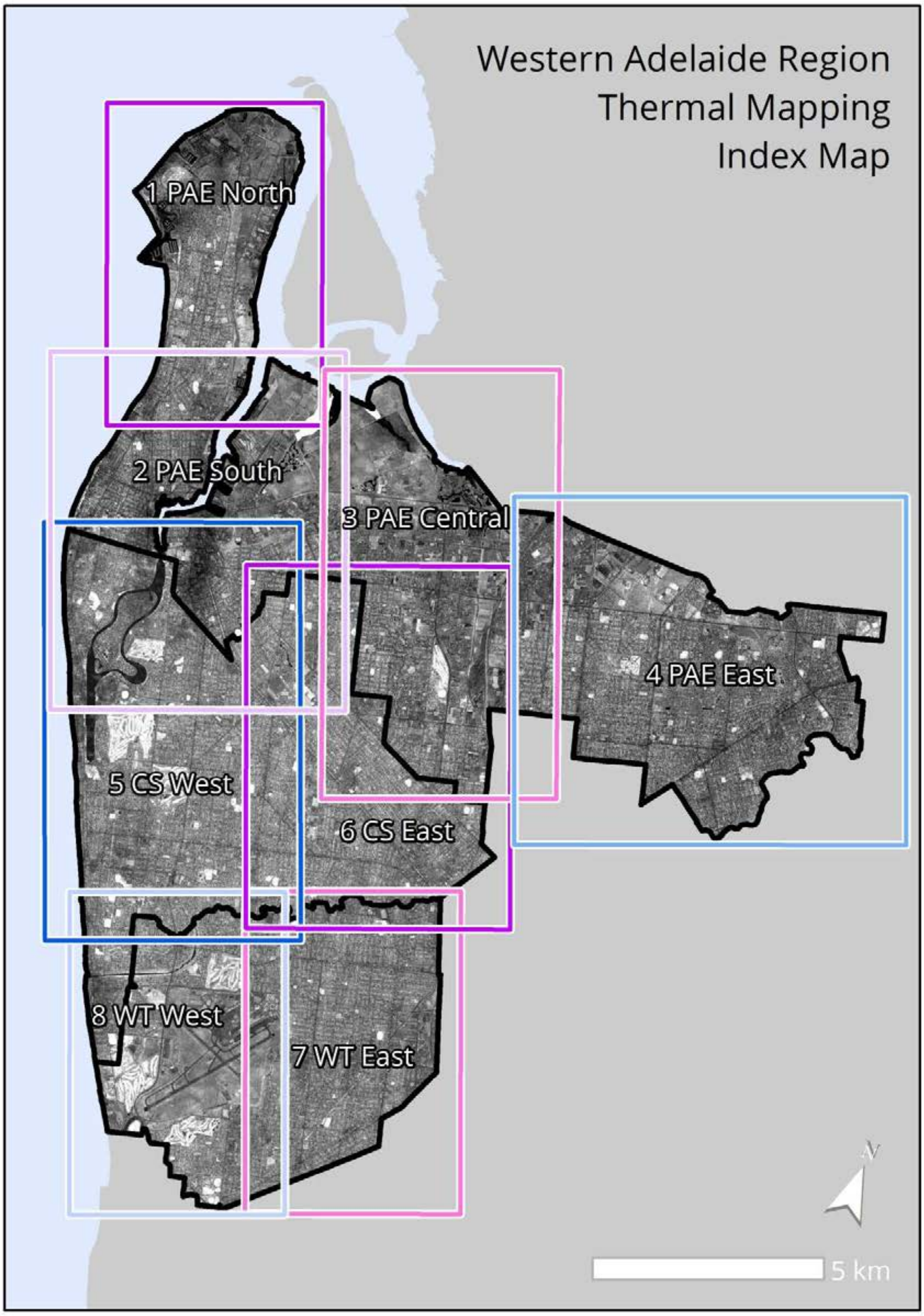

Figure A2.1. Index map

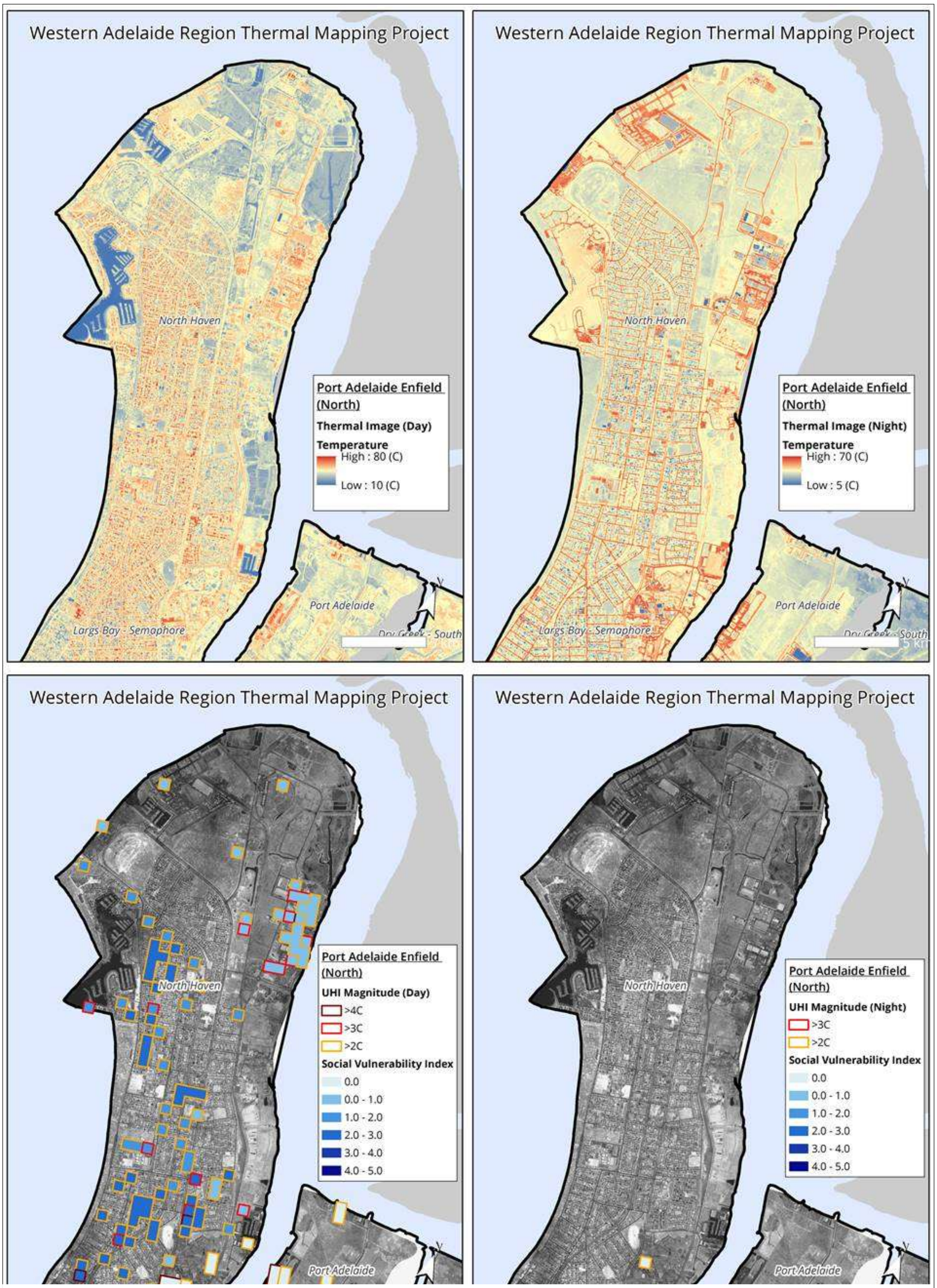

Figure A2.2. Port Adelaide Enfield North Thermal Map Series

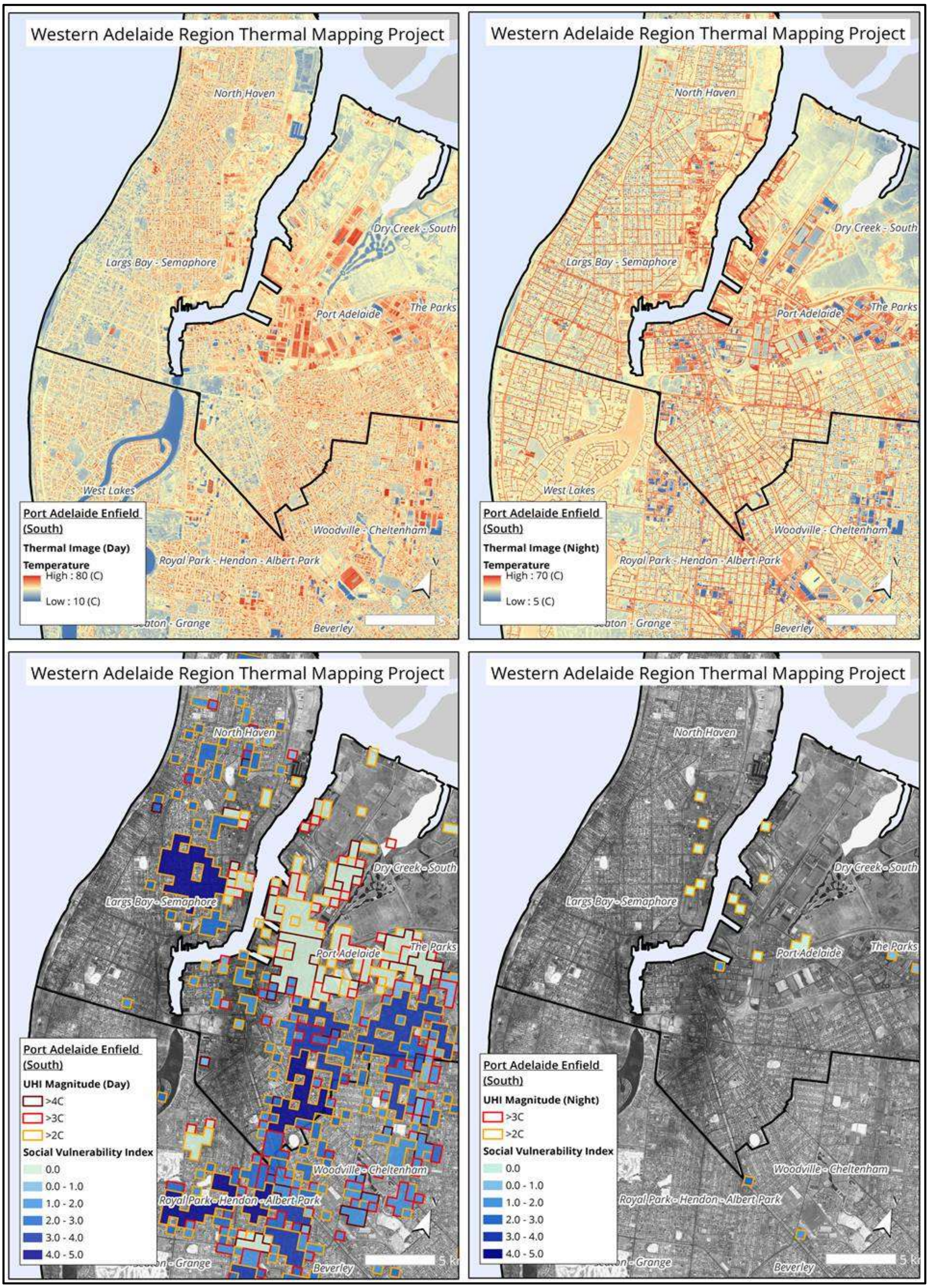

Figure A2.3. Port Adelaide Enfield South Thermal Map Series.

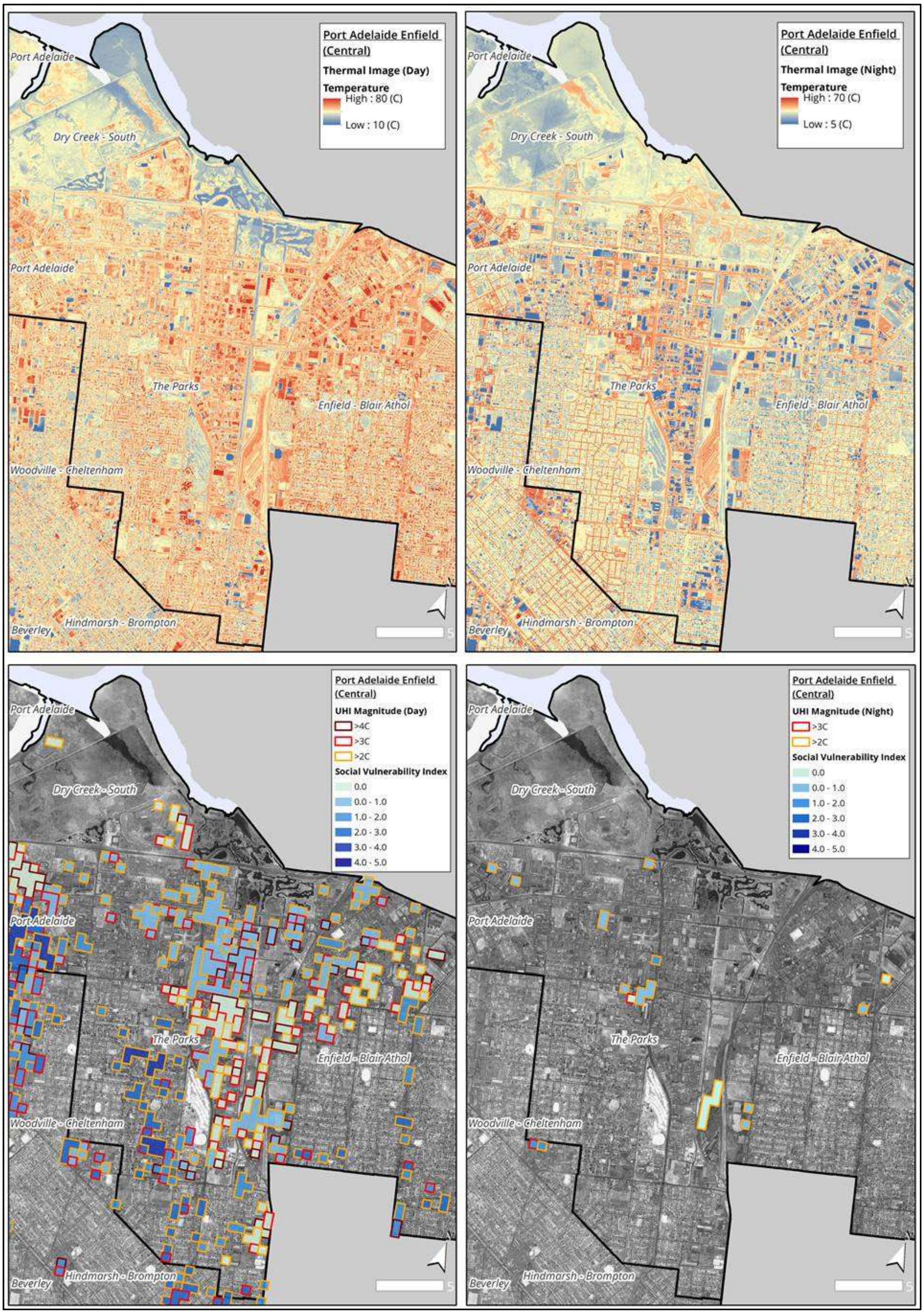

Figure A2.4. Port Adelaide Enfield Central Thermal Map Series.

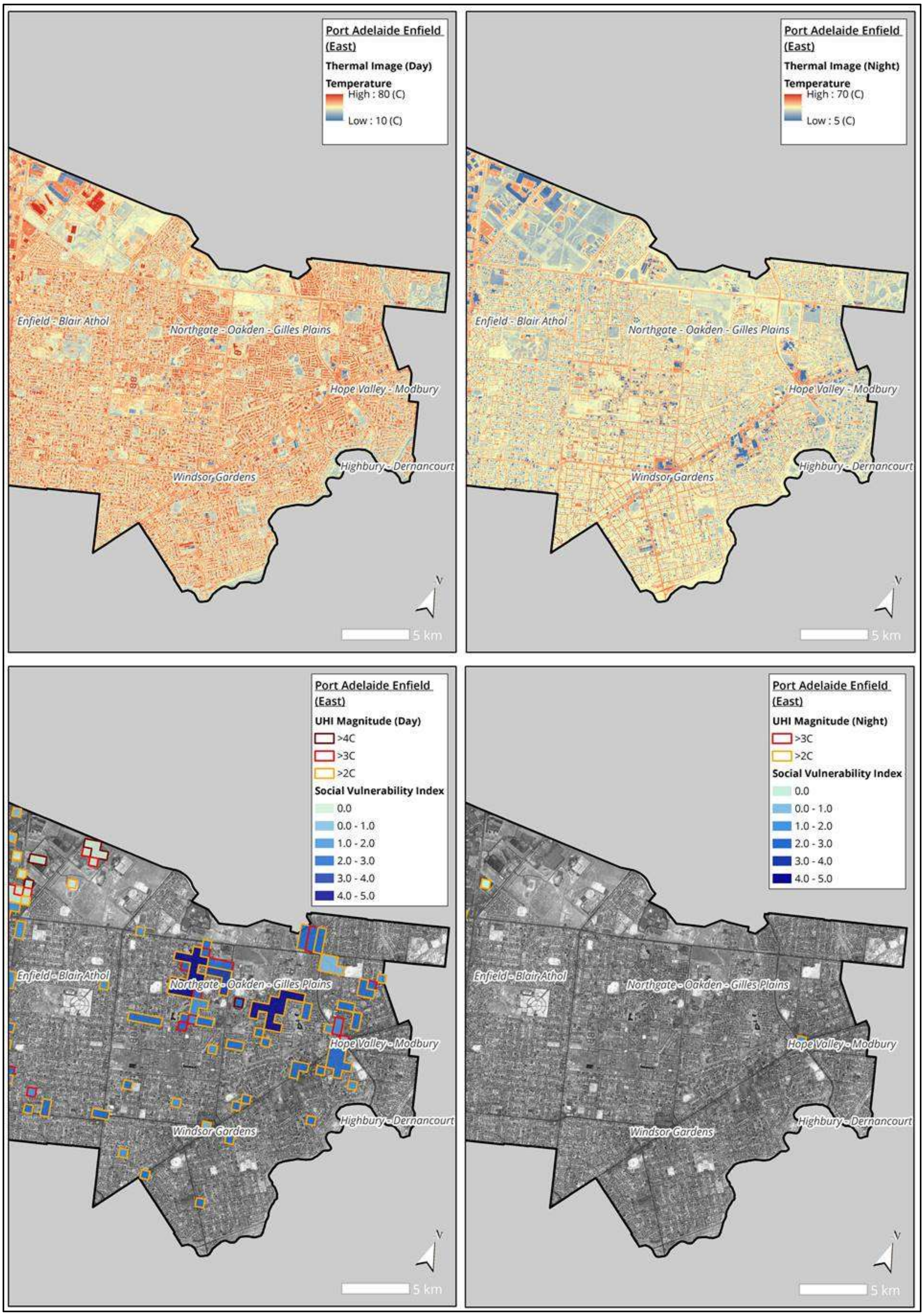

Figure A2.5. Port Adelaide Enfield East Thermal Map Series.

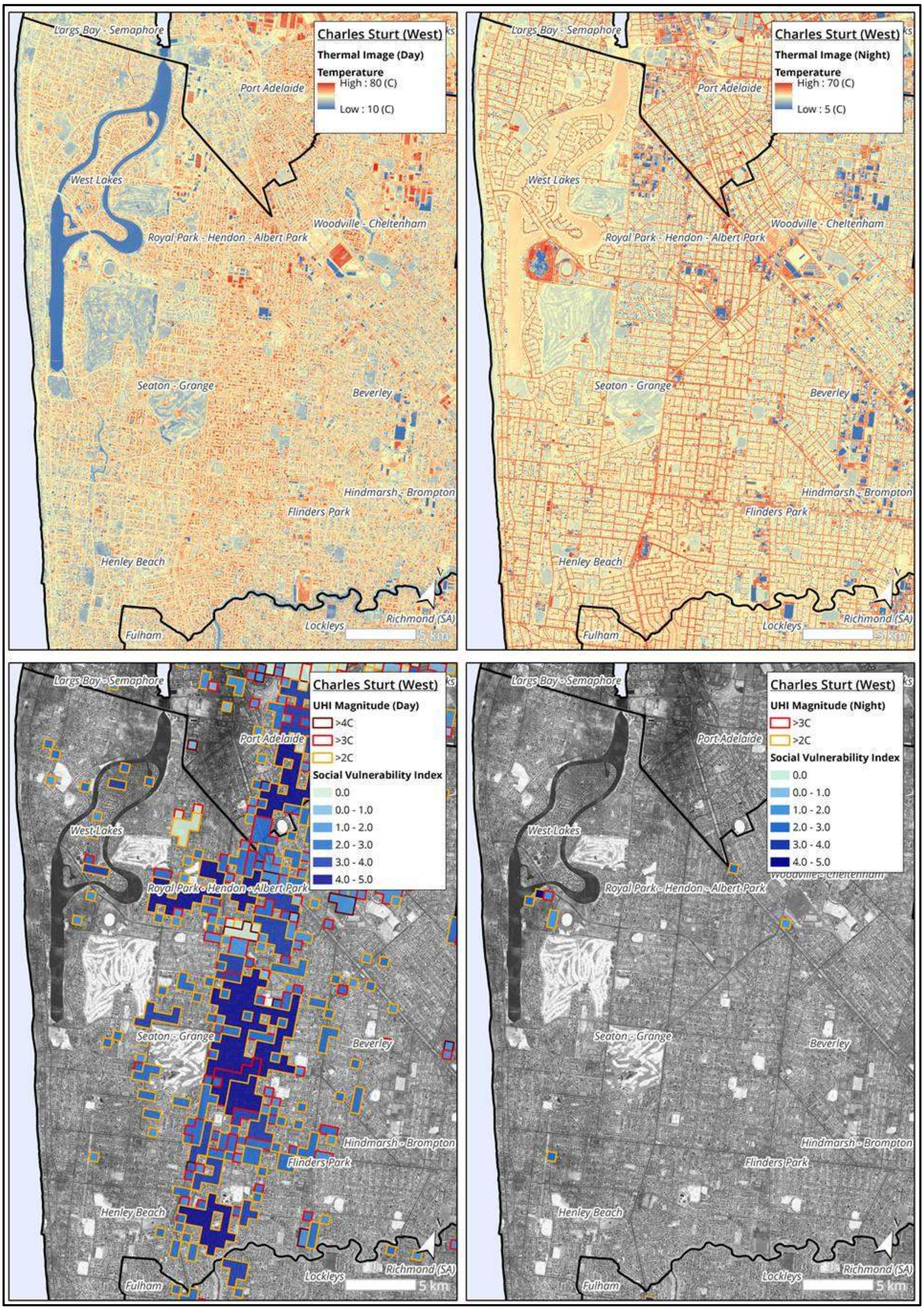

Figure A2.6. Charles Sturt West Thermal Map Series.

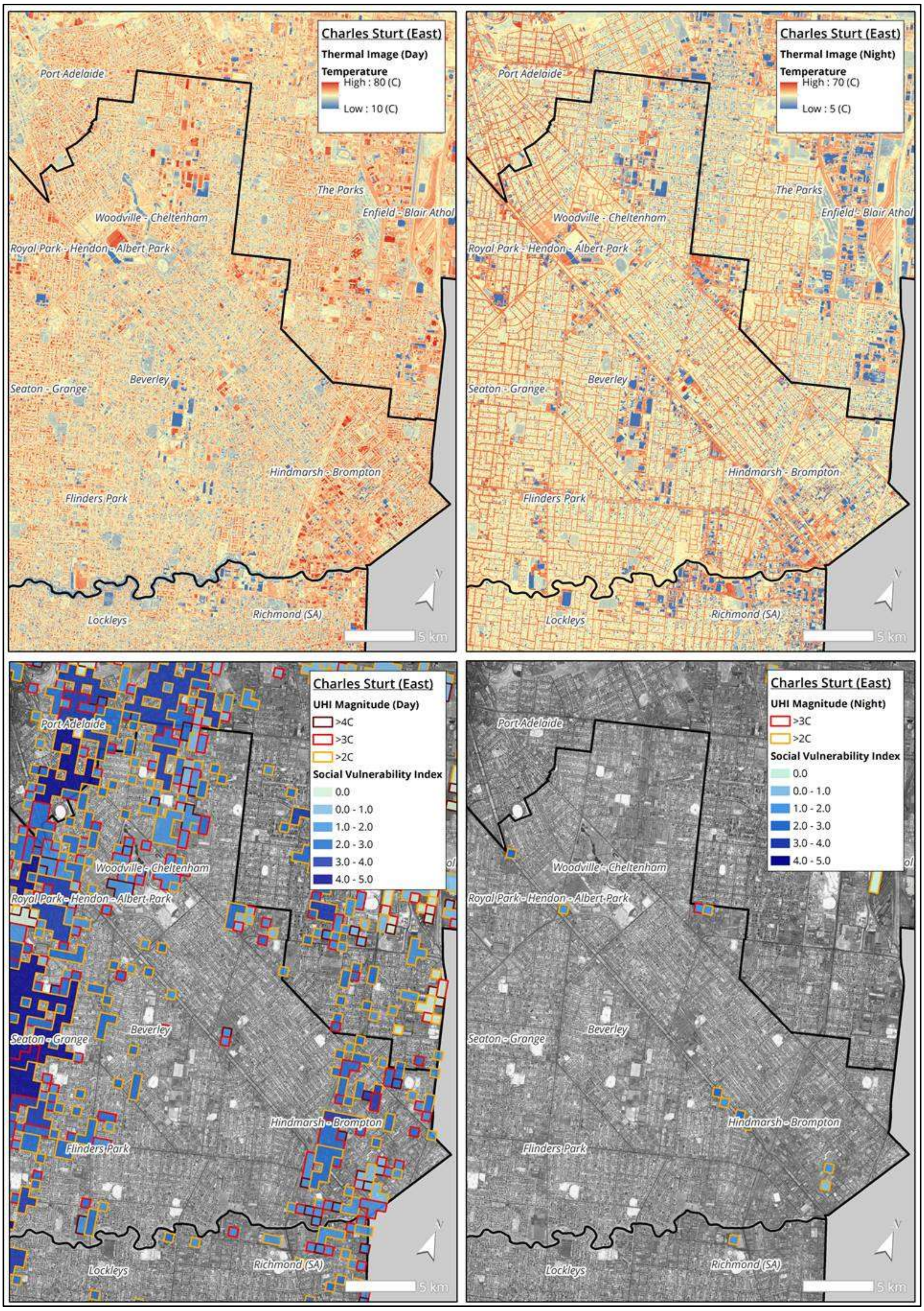

Figure A2.7. Charles Sturt East Thermal Map Series.

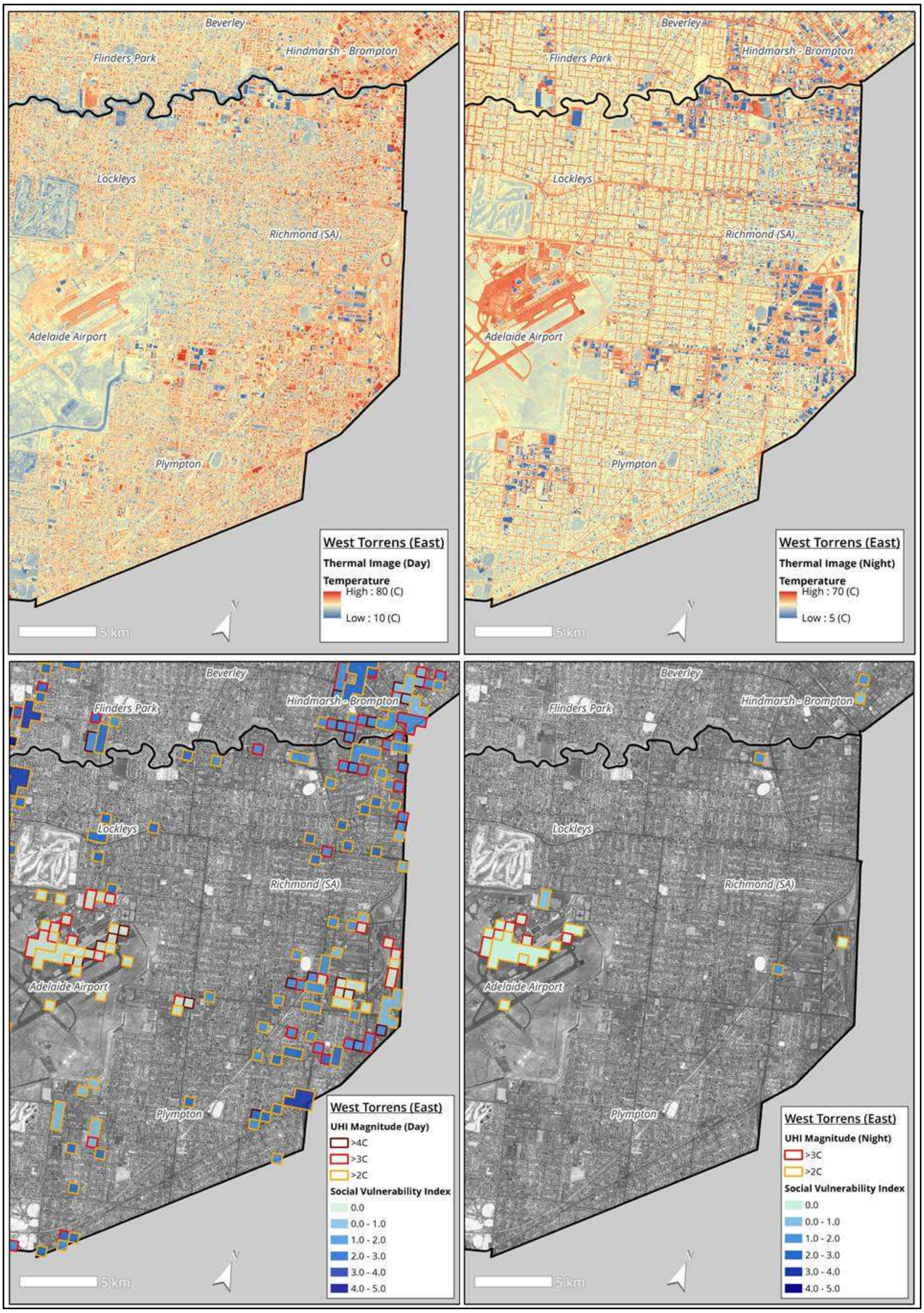

Figure A2.8. West Torrens East Thermal Map Series.

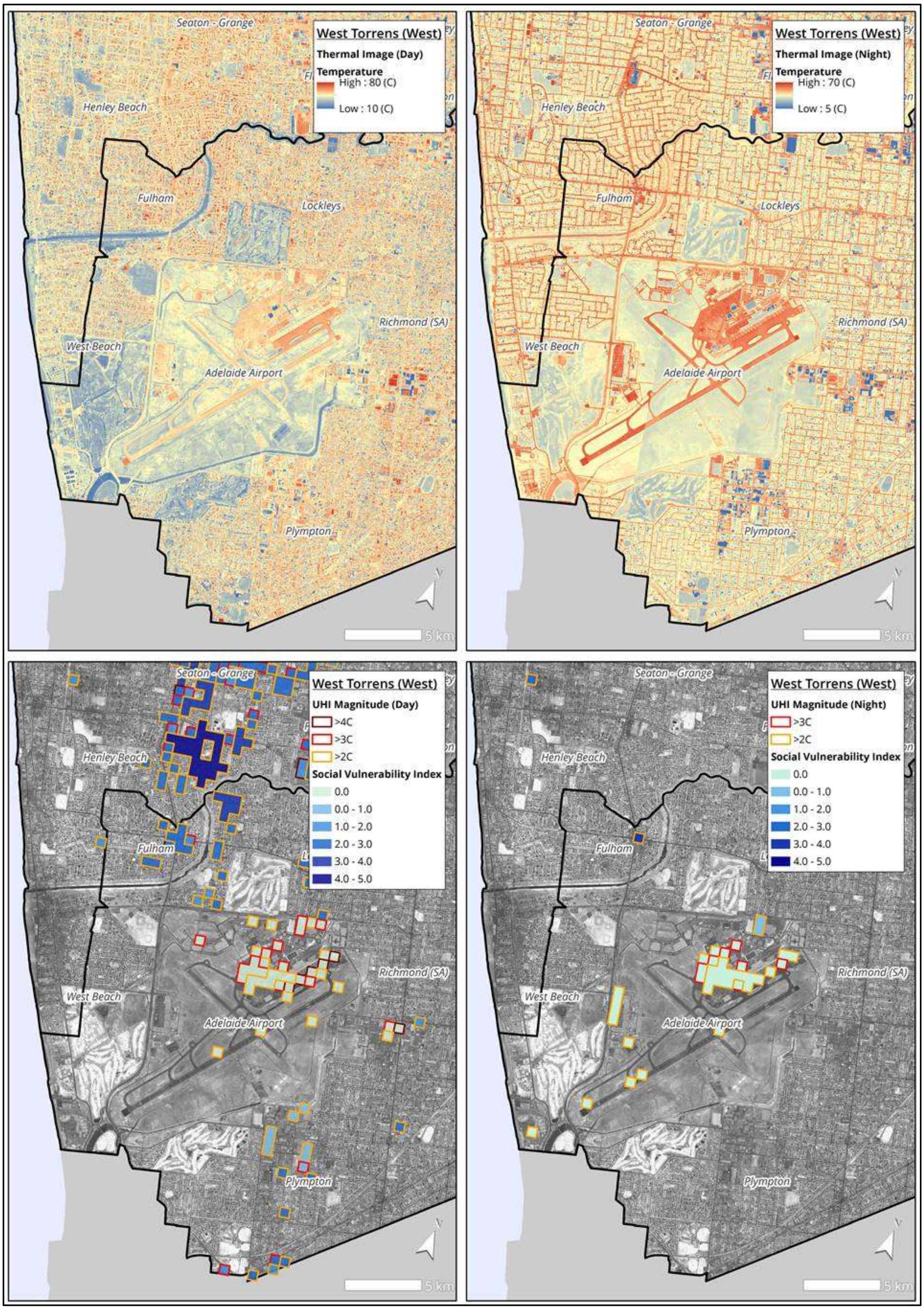

Figure A2.9. West Torrens East Thermal Map Series.

Annex 3: NDVI maps

Normalized Difference Vegetation Index (NDVI) data identifies the amount of healthy vegetation present at any given location. For the purpose of this study, the effect of green infrastructure on temperature has been analysed by comparing NDVI values with temperature data at land-use analysis points.

The following three council scale NDVI maps are provided:

1. City of Charles Sturt (Figure A3.1)
2. City of Port Adelaide Enfield (Figure A3.2)
3. City of West Torrens (Figure A3.3)

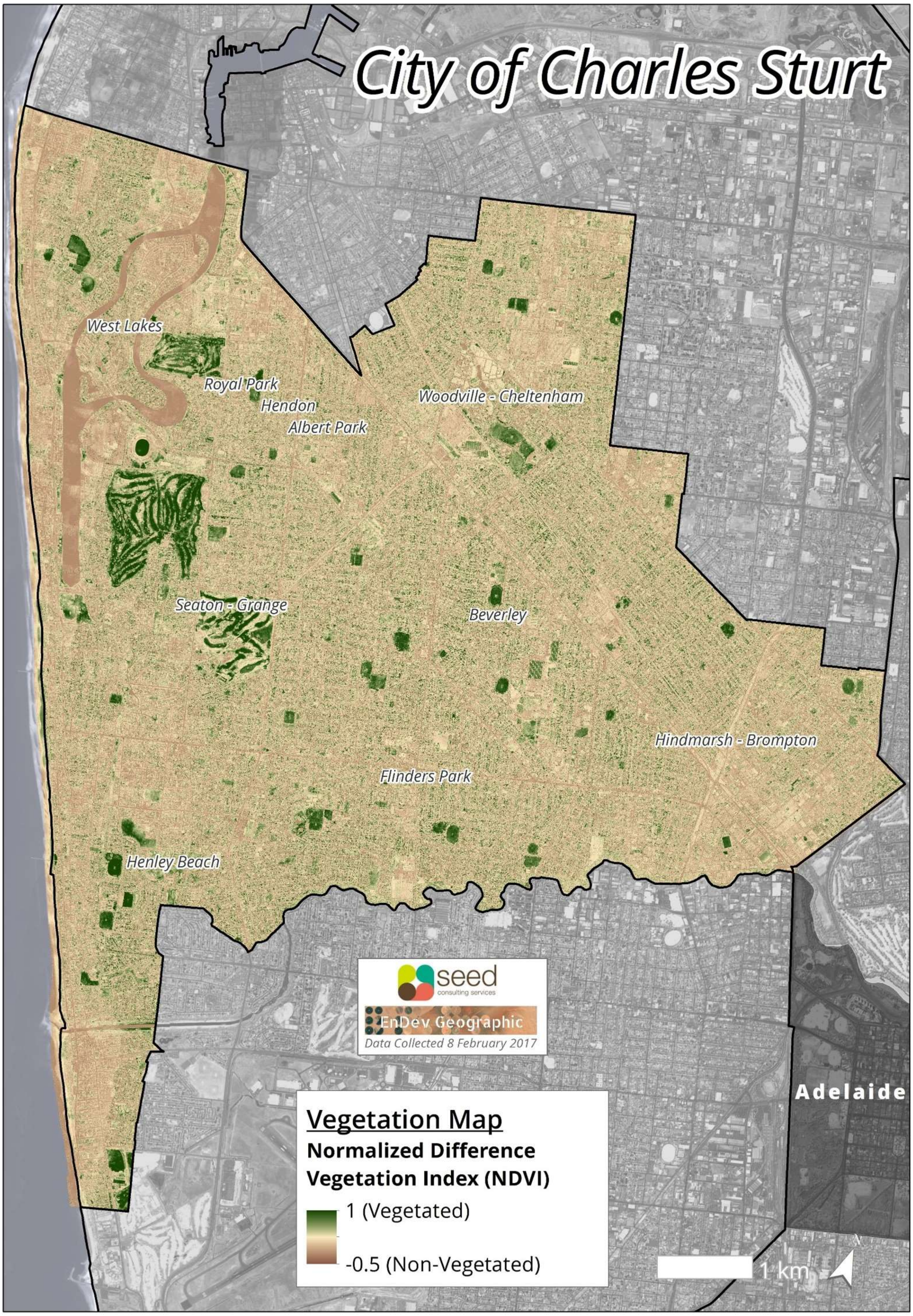

Figure A3.1. NDVI map for the City of Charles Sturt.

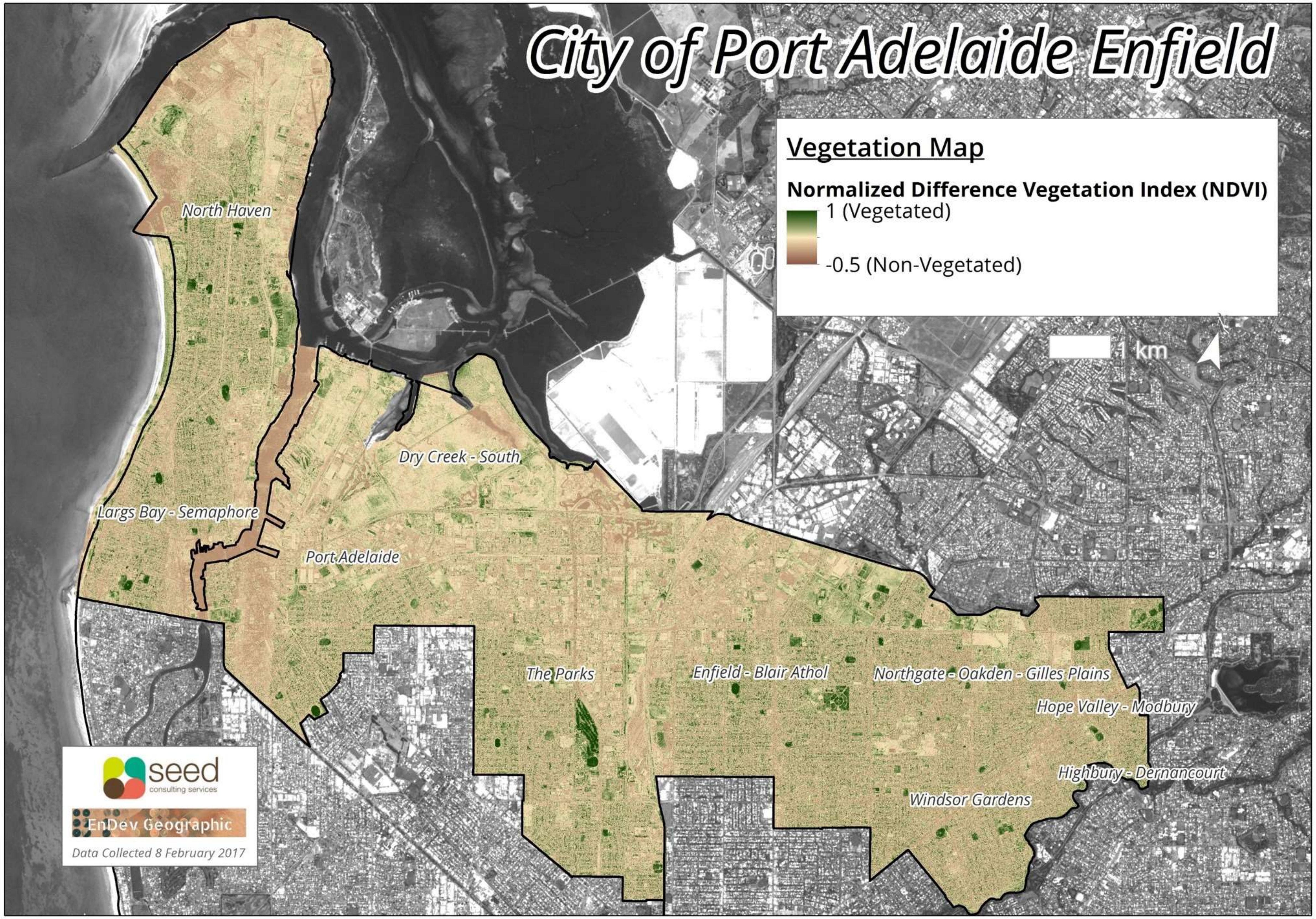

Figure A3.2. NDVI map for the City of Port Adelaide Enfield.

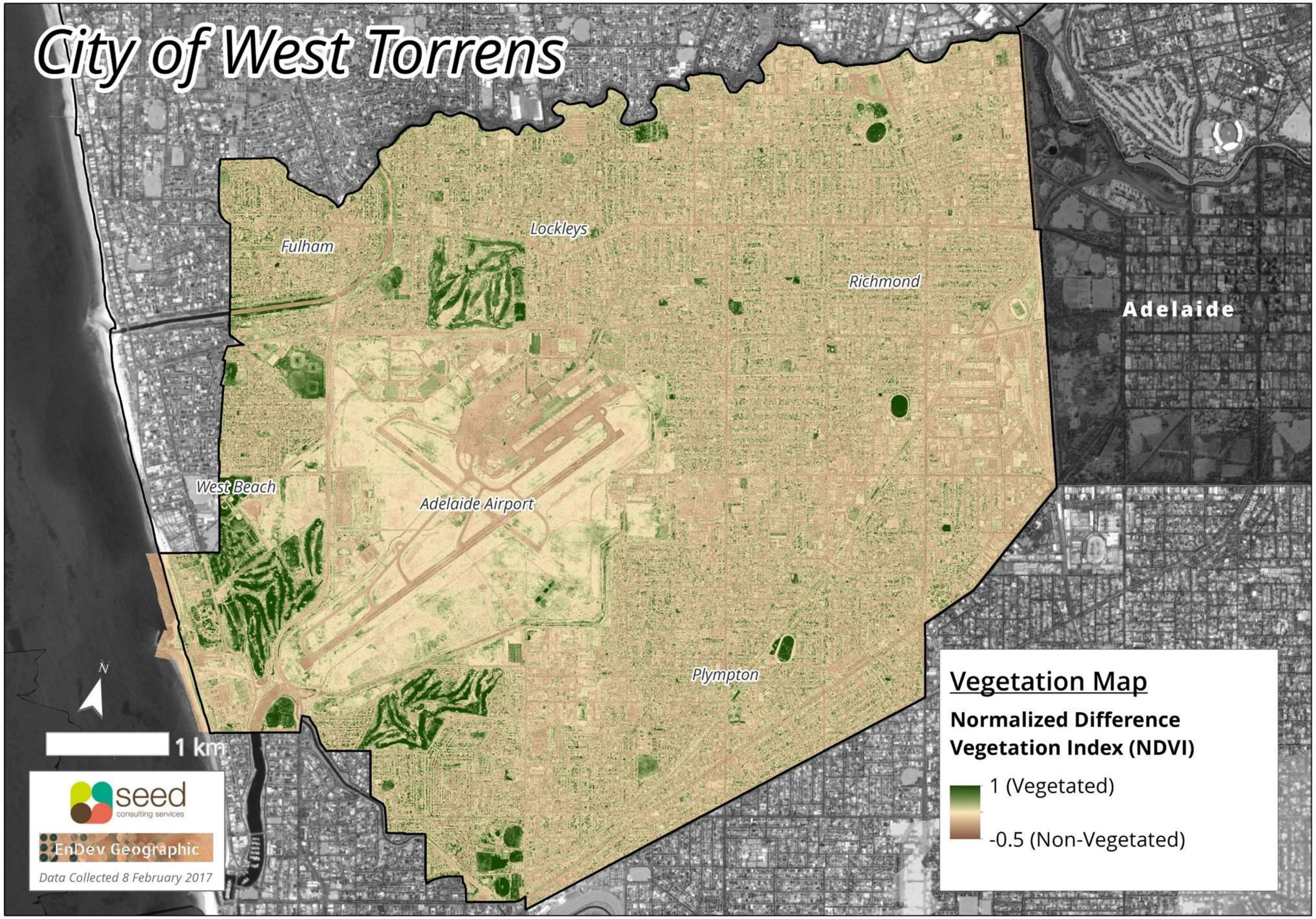

Figure A3.3. NDVI map for the City of West Torrens.

Annex 4: Suburb analysis tables

The tables in this Annex provide further information about the social vulnerability of the suburbs considered in this analysis.

Suburb Name	LGA	Population	Population over 75	Dwellings	English Second Language	Needs Assistance (Persons)	SEIFA Score	Age (Median)	Weekly Rent (Median)	Weekly Income (Individual)	Temperature (Day, Mean)	Temperature (Night, Mean)
Council Averages		53152	5405	22362	2228	3041	903	34	222	505	38	24
Adelaide Airport	WTC	0	0	0	0	0	0	0	0	0	36.78	24.94
Ashford (SA)	WTC	835	99	381	21	33	1019	37	248	648	40.18	24.20
Brooklyn Park	WTC	4515	382	1942	184	196	955	36	226	534	38.19	25.06
Camden Park (SA)	WTC	3060	302	1427	82	124	976	37	237	622	38.46	24.32
Cowandilla	WTC	1359	174	532	89	169	934	37	234	497	37.51	24.74
Fulham (SA)	WTC	2588	492	1075	75	188	1013	46	235	534	37.66	25.70
Glandore	WTC	1192	79	507	29	50	1006	39	204	591	39.26	23.86
Glenelg North	WTC	978	69	361	0	22	1063	36	323	728	36.53	24.93
Hilton (SA)	WTC	835	64	349	50	45	983	34	236	521	38.31	24.11
Keswick	WTC	680	25	302	42	24	981	32	240	609	39.98	23.72
Kurralta Park	WTC	2569	148	1117	114	99	983	32	247	558	39.80	24.23
Lockleys	WTC	5450	612	2146	110	276	1041	42	291	592	37.02	24.85
Marleston	WTC	1666	223	711	97	161	954	37	222	540	39.23	24.44
Mile End	WTC	4415	255	1808	302	274	981	35	249	542	38.91	24.22
Mile End South	WTC	0	0	0	0	0	0	0	0	0	39.77	24.13
Netley	WTC	1741	294	737	57	119	968	36	212	376	38.36	24.51
North Plympton	WTC	3005	674	1216	100	440	974	46	219	541	38.67	24.66
Novar Gardens	WTC	2323	210	949	64	99	1022	38	209	442	35.71	24.22
Plympton	WTC	4503	326	1990	153	163	987	36	255	587	38.50	24.49
Richmond (SA)	WTC	3073	276	1344	153	128	966	35	241	547	38.94	24.54
Thebarton	WTC	1321	129	579	85	81	967	38	237	523	39.64	23.86
Torrensville	WTC	3863	311	1593	283	205	976	38	257	509	37.69	24.45
Underdale	WTC	2260	185	921	100	93	997	35	288	564	37.98	24.89
West Richmond	WTC	921	76	375	38	53	938	37	214	515	37.31	24.68

Table A4.1. City of West Torrens suburb-level data of social vulnerability indicators and temperature measurements.

Suburb Name	LGA	Population	Population over 75	Dwellings	English Second Language	Needs Assistance (Persons)	SEIFA Score	Age (Median)	Weekly Rent (Median)	Weekly Income (Individual)	Temperature (Day, Mean)	Temperature (Night, Mean)
Council Averages		**106688**	**10629**	**43003**	**4672**	**6644**	**965**	**40**	**237**	**540**	**38.47**	**24.79**
Albert Park (SA)	CSC	1474	131	597	59	101	924	39	211	494	40.15	25.33
Allenby Gardens	CSC	1891	96	739	40	73	1017	38	270	626	38.04	24.93
Athol Park	CSC	1670	88	560	230	100	850	33	235	414	39.38	24.15
Beverley (SA)	CSC	1419	75	565	60	87	933	37	220	520	37.52	24.14
Bowden	CSC	618	33	303	24	45	901	40	141	500	40.46	24.45
Brompton	CSC	2931	283	1215	239	321	977	37	257	617	40.35	24.17
Cheltenham (SA)	CSC	2133	153	851	52	110	972	41	206	567	39.45	25.00
Croydon (SA)	CSC	1399	110	544	106	73	973	38	232	525	38.60	24.78
Findon	CSC	5711	694	2292	341	446	919	39	221	439	38.64	25.00
Flinders Park	CSC	4631	454	1816	192	210	987	40	267	508	37.72	24.89
Fulham Gardens	CSC	5875	604	2270	247	247	1009	44	283	503	38.90	25.45
Grange (SA)	CSC	5855	782	2339	65	485	1031	45	265	569	36.80	24.59
Hendon (SA)	CSC	1365	236	561	85	189	914	28	121	321	39.47	24.89
Henley Beach	CSC	5553	419	2314	75	189	1041	41	249	674	36.93	25.02
Henley Beach South	CSC	2493	210	1010	24	90	1034	39	240	707	36.43	25.20
Hindmarsh (SA)	CSC	158	14	66	3	9	955	34	305	700	40.63	24.75
Kidman Park	CSC	3327	354	1295	136	128	1003	47	283	516	38.46	25.05
Kilkenny	CSC	1631	207	634	127	103	929	46	246	472	39.25	24.95
Ovingham	CSC	514	15	233	16	18	959	34	220	580	40.12	24.73
Pennington	CSC	3649	344	1340	304	306	866	39	167	403	39.54	24.59
Renown Park	CSC	1586	146	716	126	102	893	38	156	431	40.34	24.48
Ridleyton	CSC	1070	54	482	57	56	944	36	197	550	40.97	24.64
Royal Park	CSC	2862	278	1199	154	196	919	40	194	596	38.97	24.55
Seaton (SA)	CSC	9849	1150	4154	566	836	916	40	220	450	38.82	24.93
Semaphore Park	CSC	4223	530	1897	48	334	926	46	206	523	36.61	24.94
Tennyson (SA)	CSC	1117	89	480	10	23	1090	48	310	771	35.59	24.59
Welland	CSC	841	58	344	67	47	947	40	214	470	38.38	24.96
West Beach (SA)	CSC	4484	428	1850	45	198	1046	41	229	592	35.10	24.85
West Croydon	CSC	4072	315	1483	252	282	987	37	277	548	38.20	24.84
West Hindmarsh	CSC	1571	99	663	79	75	959	35	263	514	38.44	25.19
West Lakes	CSC	5710	793	2381	126	234	1045	53	336	589	35.36	25.09
West Lakes Shore	CSC	2984	279	1180	33	102	1047	47	307	635	37.57	24.94
Woodville (SA)	CSC	2198	176	851	91	151	989	37	251	577	38.41	24.77
Woodville North	CSC	2307	198	902	269	119	889	37	200	424	38.84	24.08
Woodville Park	CSC	1718	102	630	82	81	978	37	261	552	37.81	24.34
Woodville South	CSC	2958	300	1132	120	241	990	40	268	581	38.11	24.81
Woodville West	CSC	2841	332	1115	122	237	938	39	225	535	39.00	25.05

Table A4.2. City of Charles Sturt suburb-level data of social vulnerability indicators and temperature measurements.

Suburb Name	LGA	Population	Population over 75	Dwellings	English Second Language	Needs Assistance (Persons)	SEIFA Score	Age (Median)	Weekly Rent (Median)	Weekly Income (Individual)	Temperature (Day, Mean)	Temperature (Night, Mean)
Council Averages		**112921**	**8996**	**44620**	**5643**	**7300**	**909**	**36**	**203**	**493**	**39.25**	**24.47**
Alberton (SA)	PAE	1915	148	819	53	85	954	41	219	559	39.12	25.22
Angle Park	PAE	1468	168	508	166	214	875	41	65	647	39.84	25.07
Birkenhead	PAE	1715	110	686	25	78	964	38	238	630	39.29	25.07
Blair Athol (SA)	PAE	4366	372	1597	340	267	878	33	218	415	40.32	24.27
Broadview	PAE	2224	231	939	73	110	974	36	231	555	40.59	24.08
Clearview	PAE	3452	327	1371	167	178	909	30	208	419	39.95	24.03
Croydon Park (SA)	PAE	4000	429	1525	477	279	879	37	206	378	39.70	24.61
Dernancourt	PAE	226	14	76	0	12	1076	43	295	657	37.27	23.97
Devon Park (SA)	PAE	901	69	427	37	58	928	38	188	473	39.80	23.96
Dry Creek (SA)	PAE	197	9	88	23	18	845	20	115	254	37.08	23.65
Dudley Park (SA)	PAE	399	34	186	21	45	781	20	109	187	39.72	23.42
Enfield (SA)	PAE	4901	597	1893	273	443	914	37	225	456	40.88	24.23
Ethelton	PAE	1200	64	506	17	43	930	40	250	519	37.27	24.87
Exeter (SA)	PAE	1100	73	503	0	56	948	41	193	586	38.28	24.70
Ferryden Park	PAE	4105	233	1473	512	253	883	36	169	395	40.25	24.90
Gepps Cross	PAE	593	31	207	34	20	900	13	87	153	39.81	23.38
Gilles Plains	PAE	1961	140	782	86	160	886	35	181	439	40.80	23.93
Glanville	PAE	678	40	302	15	27	912	41	228	528	37.35	25.01
Greenacres	PAE	2412	171	1005	87	122	939	34	216	478	40.47	24.55
Hampstead Garden	PAE	1363	114	561	74	67	944	35	238	485	40.79	24.79
Hillcrest (SA)	PAE	3087	241	1237	106	173	954	34	226	546	41.02	24.44
Holden Hill	PAE	575	32	257	20	34	888	35	204	456	40.28	23.76
Kilburn	PAE	5099	356	2017	511	451	797	31	142	362	40.62	23.76
Klemzig	PAE	5601	619	2423	229	382	970	38	221	506	39.88	24.55
Largs Bay	PAE	3956	426	1504	32	315	1009	40	252	558	38.27	25.11
Largs North	PAE	3268	414	1307	7	223	969	37	213	491	38.52	24.88
Manningham	PAE	1302	110	492	7	35	1058	39	274	665	40.24	24.75
Mansfield Park	PAE	3360	218	1169	507	216	852	33	181	390	39.41	24.34
New Port	PAE	898	19	402	15	6	1025	21	205	586	37.56	25.61
North Haven (SA)	PAE	5804	384	2242	22	205	1015	46	288	640	36.69	24.65
Northfield	PAE	3870	280	1283	143	190	879	37	193	391	39.79	24.07
Northgate (SA)	PAE	3579	58	1189	85	185	1089	33	317	814	40.84	24.34
Oakden	PAE	3673	264	1376	137	347	989	40	196	532	40.25	24.30
Osborne (SA)	PAE	1837	149	755	9	127	899	41	207	455	38.14	24.25
Ottoway	PAE	2416	182	944	255	175	850	38	200	392	39.92	24.57
Outer Harbor	PAE	24	0	13	0	4	866	55	0	460	35.84	24.51
Peterhead	PAE	1142	84	529	10	48	912	40	228	606	39.89	25.01
Port Adelaide	PAE	1292	63	600	38	82	897	43	140	651	38.65	24.84
Queenstown (SA)	PAE	1804	190	838	73	152	885	43	193	453	37.65	24.96
Regency Park	PAE	176	65	0	31	64	0	13	0	159	40.06	24.11
Rosewater	PAE	3342	231	1410	163	195	890	40	206	496	39.94	25.29
Sefton Park	PAE	723	77	315	28	35	976	37	227	532	40.88	24.08
Semaphore	PAE	2823	208	1062	26	234	1004	43	237	617	36.17	24.81
Semaphore South	PAE	982	94	430	6	53	1011	40	268	623	35.75	24.72
Taperoo	PAE	3130	187	1320	43	241	821	40	178	412	38.17	24.48
Valley View	PAE	1939	157	742	49	150	961	44	272	476	39.18	23.93
Walkley Heights	PAE	366	4	129	8	12	1070	34	310	704	42.95	24.59
Windsor Gardens	PAE	4824	320	2071	146	239	971	38	236	518	39.81	23.97
Wingfield	PAE	473	24	205	62	30	810	41	308	591	39.22	24.39
Woodville Gardens	PAE	2380	166	905	395	164	803	34	149	345	38.29	24.54

Table A4.3. City of Port Adelaide Enfield suburb-level data of social vulnerability indicators and temperature measurements.

Annex 5: Instrumentation, data collection and analysis

Instrumentation

Instrumentation specifications are provided here for the thermal camera, precision navigation units and aircraft. Further information on other instruments can be provided by Airborne Research Australia on request.

Thermal camera

The thermal camera used for this project was a FLIR model A615. The camera was controlled via a gigabit ethernet interface using Airborne Research Australia-developed software running on the aircraft's main on-board computer, communicating across the aircraft's local network. The images were time-stamped, and recorded to a solid-state hard drive in the main science computer.

Superior to the older-generation camera used by Airborne Research Australia until 2013, the A615 has a 640 by 480-pixel uncooled micro-bolometer array giving a thermometric resolution of approximately 50mK (one twentieth of a degree C). The camera's internal control electronics monitor the thermal stability of the system and periodically switches a blackbody calibration target into the optical path for a short period (~0.5s) to recalibrate the sensor.

This camera was mounted in a wing-mounted insulated enclosure along with one of the precision navigation units (each instrument mounting location on the aircraft requires its own navigation unit to accurately record the instrument's position and orientation). The thermal stability offered by this insulated enclosure, and by a period of temperature stabilisation flying at a constant altitude before the imaging flight lines (approximately 20 minutes), minimise field-dependent temperature sensing offsets caused by drifts in the physical temperature of the camera (and more particularly, of the embedded detector array).

Instrument settings, controlled by the mission scientist aboard the aircraft during the survey via the operating/logging software, optimise the thermometric resolution, camera focus and data capture rate for the survey conditions.

OxTS RT4003 IMU

A precision navigation unit is required for each instrument station. There being two instrument stations employed, two RT-4003 units from Oxford Technical Solutions were used. These units incorporate a dual-GPS system, accelerometers and gyroscopes to form a full IMU (Inertial Measurement Unit) and were mounted to the same rigid structure as the camera to allow accurate measurement of the position and orientation of the camera.

seed consulting services

Before each measurement flight, the IMU/GPS systems were dynamically initialised by taxiing in a straight line at a speed higher than the set threshold speed as set in the configuration of the units (usually 5m/s).

Raw IMU and GPS data were logged internally in the RT4003 units, allowing the most accurate post-processing analysis to provide the best possible position data.

Airborne platform

VH-EOS, one of Airborne Research Australia 's two Diamond Aircraft HK36TTC ECO-Dimonas was used as the airborne platform for the survey. This aircraft type was designed specifically as an environmental sensing platform. The pilot had considerable expertise in carrying out such operations in complex airspace and fully understood the subsequent data processing and interpretation and could therefore factor this into the flight considerations and procedures. The mission scientist/instrument operator was also a pilot, and subsequently carried out the bulk of the data processing.

The ECO-Dimonas have safety features which are unmatched by standard single-engine survey aircraft, the most relevant of them being their extended glide ration (1:25) in the case of engine failure. From the proposed flying altitude of 3,000 m, the aircraft would have been able to glide back to Parafield Airport (without use of the engine) from anywhere within the survey area.

Airborne Research Australia 's aircraft were also equipped with live Internet connection at all times, as well as a traffic avoidance system showing the relative position of other aircraft around it on a dedicated display.

Flyover

Data collection plan

To produce the specified imagery, Airborne Research Australia used one of its purpose-built ECO-Dimona aircraft, fitted with a thermal imager for the heat mapping. Supporting instrumentation and infrastructure was also carried, producing supporting datasets.

To achieve the required imagery spatial sampling intervals (GSD), the aircraft was planned to be flown at a nominal height of 3,000 m above ground. This altitude was selected on the basis of matching the required on-ground resolution for the various instrumentation (primarily the thermal imagery), while completing the survey in the minimum time, and simultaneously avoiding delays due to conflicting commercial air traffic to and from Adelaide Airport. A series of parallel, overlapping flight lines were flown to ensure full coverage of the required areas.

The image swath of the FLIR thermal imager (narrowest field-of-view instrument here) was approximately 1,200 m, and so a 600 m line-spacing was planned to give suitable cross track overlap.

The daytime flights were conducted in a north-south direction to minimise cross-track BRDF (Bidirectional Reflectance Distribution Function) effects for the multispectral and panchromatic imagers. The nighttime flights followed the same ground tracks for convenience.

In addition to the primary thermal imaging instrumentation, the aircraft carried other instruments for supporting measurements. Notably, a DSLR camera was carried and operated for conventional RGB (red green blue) aerial photography, a panchromatic linescanner for broad-band imaging suitable for deriving an albedo product, multispectral imagers collecting bands suitable for deriving an NDVI product and a visible and near-infrared (VNIR) hyperspectral linescanner (~200 bands spanning 400 to 1000 nm). These instruments are likely to yield valuable additional data for urban heat island analysis, and resultant products are also project deliverables.

Instrument	**Data**	**Pixel size @3000m**
Thermal imager (FLIR A615)	At-sensor brightness temperature	2 m
DSLR (Canon 1D)	Aerial photography	<1 m
Runner linescanner (panchromatic)	Brightness image – for albedo	1 m
CIR imager (modified Canon 6D	G-R-NIR image: for NDVI	<1 m
Specim AISA Eagle-2	VNIR hyperspectral imaging, 400 to 1000 nm in ~200 bands	2 m

Table A5.1. Instrumentation and sampling specifications. Note: Runner, Eagle and DSLRs only used for daytime flights.

Timing

The trigger for undertaking the flight as agreed with the City of West Torrens was two or more consecutive days with the average temperature greater than or equal to 33°C. An extended effort was made to collect data in suitable meteorological conditions. The aircraft and crew remained on standby through most of December 2016 and January 2017 awaiting suitable weather. The summer turned out to be unseasonably wet and several hot spells were rejected as unrepresentative of the desired measurement conditions due to excessive soil moisture, which would have affected the partitioning of energy and hence the surface temperature distribution.

It became apparent in the first week of February that a suitable period of weather was approaching, and the surveys were flown around solar noon of 9 February 2017 from approximately 11am to 4pm, and on that night, from approximately 11pm to 3am (i.e. 10 February 2017). The actual flight paths are shown in Figure A5.1, which consisted of an array of 31 north-south parallel flight lines.

Data processing

It is normal with scientific remote sensing that the total effort is dominated by the data processing and analysis, with the field work being a relatively small component. Data processing commenced on the survey day immediately post-flight, with data download, backup and preliminary quality assurance. The volume of data collected for the proposed survey meant the data download alone took longer than the flights themselves.

After duplicate off-aircraft raw data backups were complete, the raw data was subject to an initial inspection, and preliminary processing of the recorded navigation data. This confirmed there were no fundamental issues such as instrument misbehavior, navigation problems, missed portions of the imaged area, or environmental issues reducing data quality (e.g. excessive cloud shading of the surface). In fact, there was a thin layer of broken cloud casting shadows across the imaged ground for approximately the first 30 minutes of the daytime part of the survey, however, this was not significant for the thermal imaging or NDVI derivation, and only has a minor effect on the retrieved albedo, and not much effect on any of the other data. It is concluded that the survey took place on the most suitable day of the season.

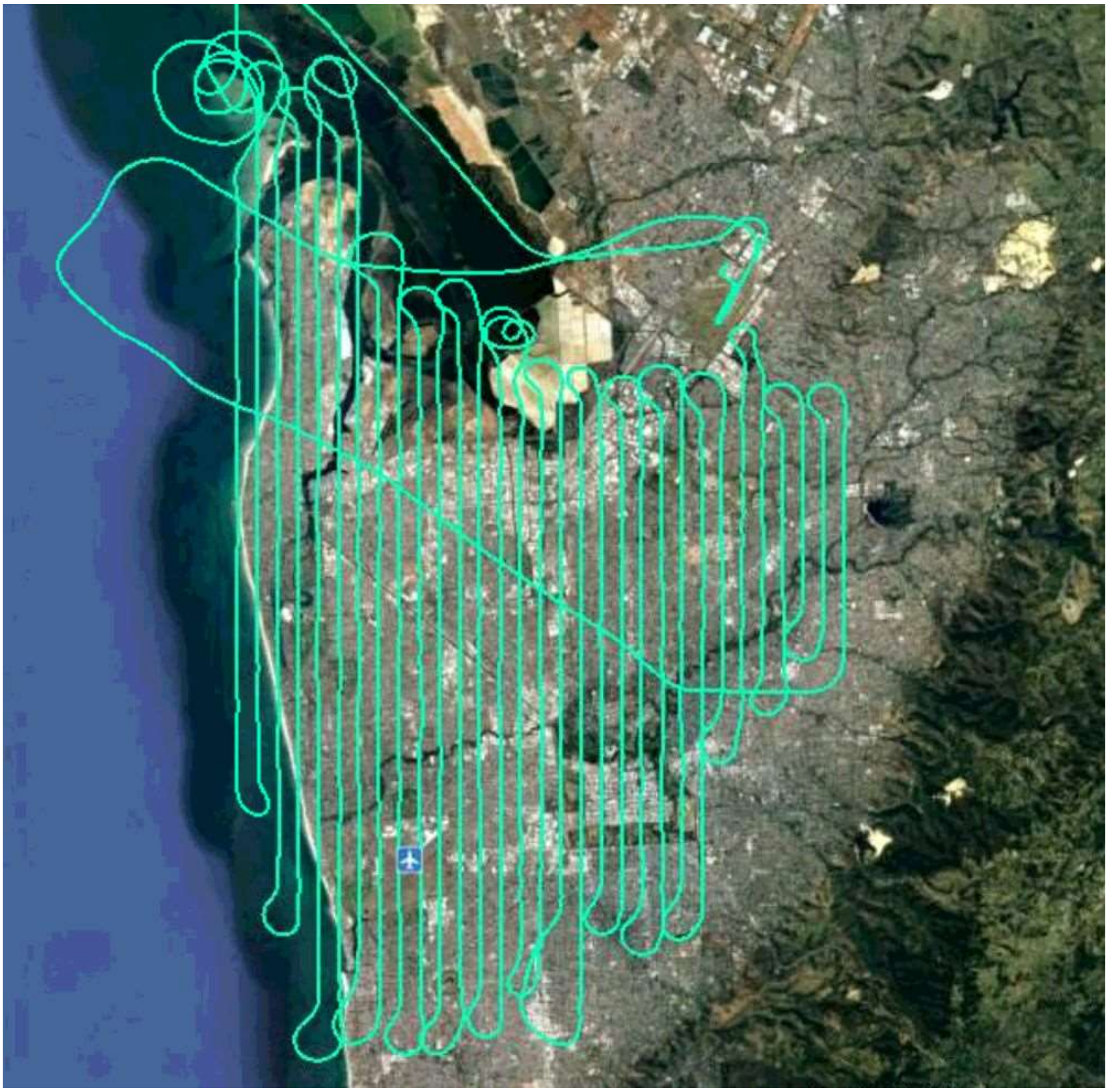

Figure A5.1. Flight paths flown over the study area from the daytime part of the survey. The westernmost lines were flown first, heading south before turning anti-clockwise and travelling north. Successive lines were flown sequentially from west to east. The circular pattern in the top left of the image shows where the plane rose to its target altitude before conducting the survey.

Geo-rectification of any of the imagery requires precise knowledge of the location and orientation of the sensor for each raw image collected, and so each instrument is rigidly coupled to an accurate IMU, and the data from these navigation units was processed extremely carefully to achieve the best possible instrument navigation data. This required substantial post-processing effort, which incorporated data from GPS base stations and precision GPS satellite orbital ephemeris data which was only available about a week after the event.

FLIR[3], Runner and multispectral data was radiometrically and geometrically processed to give radiometric data in geotiff form, from which were derived the deliverable products (heat map from the FLIR data, albedo map from the Runner and NDVI map from the multispectral data), to the agreed data collection specifications.

Urban heat island and hot spot identification

Underlying each heat island is a mixture of landscapes, land-uses, and land-covers resulting in different characteristics of each heat island. Analysing social vulnerability within heat islands reveals who lives within these areas, identifies social groups that are disproportionately affected by heat, and helps prioritise which areas of heat are most in need of remediation. How to cool heat islands depends on what lies within heat islands. Landscape analysis investigates various land cover types to identify their impact as a basis for developing heat reduction strategies for effective land use planning.

Urban heat islands and hot spots occur at any location where the built environment causes the temperature to be warmer than it would have been in its natural state. With no way of knowing the natural temperature of an area without the built environment, baseline temperatures are taken as the average temperature of the local area and hot spots are identified as exceedingly warm areas compared to this baseline. Urban heat islands and hot spots are defined for this project as any location where the temperature exceeds 2°C above the mean temperature of the local area. To account for surface warming during the data collection process, a moving average threshold was used to establish the expected mean temperature for four zones (Figure A5.2). Areas of built-up heat were identified as exhibiting a temperature greater than 2°C, 3°C or 4°C above the local mean temperature at the time of measurement.

As urban heat islands typically have larger diffuse effects, the analysis aggregated thermal data from 2 m to 125 m resolution to identify general areas of built up heat and to understand how they relate to the people who live in those areas. Hot spot analyses use 2 m resolution thermal data to explore thermal impacts of specific land-uses.

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[3] FLIR is a commercial company specialising in the production of thermal imaging cameras, components and imaging sensors.

Land use analysis

To explore the relationship between land use and heat, ten predominant land surface types were chosen across four categories: impervious surfaces, green infrastructure, buildings, and water. For each of the ten surface types, 45 to 96 points were selected (depending on prominence of each surface in the landscape) that represented clear examples of each surface type. Day temperature, night temperature, and NDVI values were calculated for each point.

An average of 70 points were analysed for each land-surface category to understand the mean temperatures of surface over the whole of the study area, providing broader, more robust results to supplement and contextualize the individual case studies. The combined land use-case study investigations illustrate local examples with robust analysis to reveal patterns of urban heat, quantify the magnitude of those patterns, and highlight effective lessons for urban heat management.

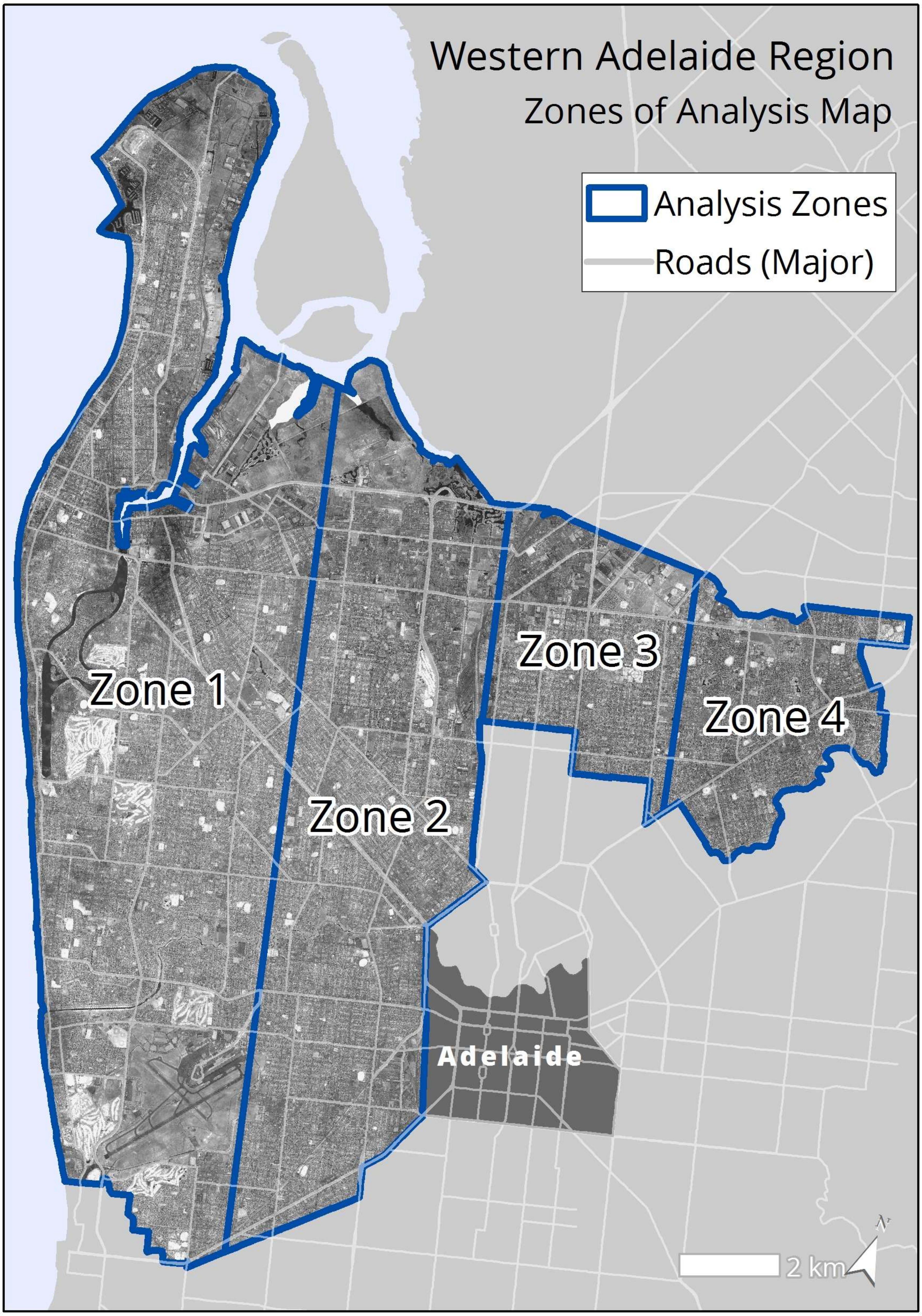

Figure A5.2. The four zones of analysis used in calculating baseline temperatures for each area.

Social vulnerability analysis

The tools for mitigating urban heat (proximity to water, green infrastructure, white roofing) generally come at additional costs, which tends to result in heat islands having a more pronounced effect upon residents of lesser means. To assess whether heat disproportionately affects any particular groups within the Western Adelaide Region, social vulnerability data was acquired from the 2011 census. Building upon the Western Adelaide Region's AdaptWest Climate Change Adaptation Plan, key social vulnerability indicators were identified as:

- elderly population (>75 years old);
- people who need assistance due to disabilities;
- people who speak English as a second language not well or not at all;
- median rent paid by residents; and
- Socio-Economic Indexes for Areas of Disadvantage (SEIFA Score).

Data were acquired from the 2011 Census at the Statistical Area Level 1 (SA1). These data were used to create a simple Social Vulnerability Index (SVI), normalizing each dataset from 0 to 1 and summing the results to give an index value of 0 to 5 representing low to high vulnerability. The SVI was calculated for each urban heat island informing where heat and vulnerability co-exist.

Data outputs

All collected and processed data was provided as part of this project in geodatabase format, with an individual geodatabase provided for each council. All data are spatially referenced to Geocentric Datum of Australia 1994 Map Grid of Australia Zone 54. Each geodatabase contains the following data:

- day-time thermal data (2 m x 2m);
- day-time hotspot layer showing all areas warmer than 2°C above average (2 m x 2m);
- day-time heat island layer showing all large areas (125 m x 125 m) and warmer than 2°C above average and associated social vulnerability indicators (provided as vector data);
- night-time thermal data (2 m x 2m);
- night-time hotspot layer showing all areas warmer than 2°C above average (2 m x 2 m);
- night-time heat island layer showing all large areas (125 m x 125 m) and warmer than 2°C above average and associated social vulnerability indicators (provided as vector data); and
- summary results table.

Limitations

Limitations of this analysis that should be noted when interpreting the results are as follows:

- While the urban heat island is a large-scale phenomenon, the effects of the heat island manifest in highly localised temperature variation. The scale of urban heat islands in this analysis (125m^2) intentionally overlooks highly localised detail. This scale especially affects night urban heat island mapping as important linear features such as roads exist below this resolution, suggesting that hot spot analysis is a vital supplement.

- The rolling average method of determining baseline temperatures was necessary due to the several hours that lapsed between the beginning and end of each data acquisition. During this time, ambient temperatures likely varied. The four-zone rolling average method attempted to minimize the influence of time-temperature variation. An improved result may be attained from creating more analysis zones, potentially calculating the mean baseline temperature for each individual image, however this approach may be skewed by having dominant hot or cold landscapes within a single image. The four-zone method provides improved but imperfect temporal accuracy while maintaining significant spatial coverage.

- Social vulnerability data were downscaled to spatially represent each indicator. These values were then re-summed to calculate the social vulnerability for each urban heat island. The method has a 3.5% margin of error between actual and estimate values. More accurate approximations could be provided with more detailed data.