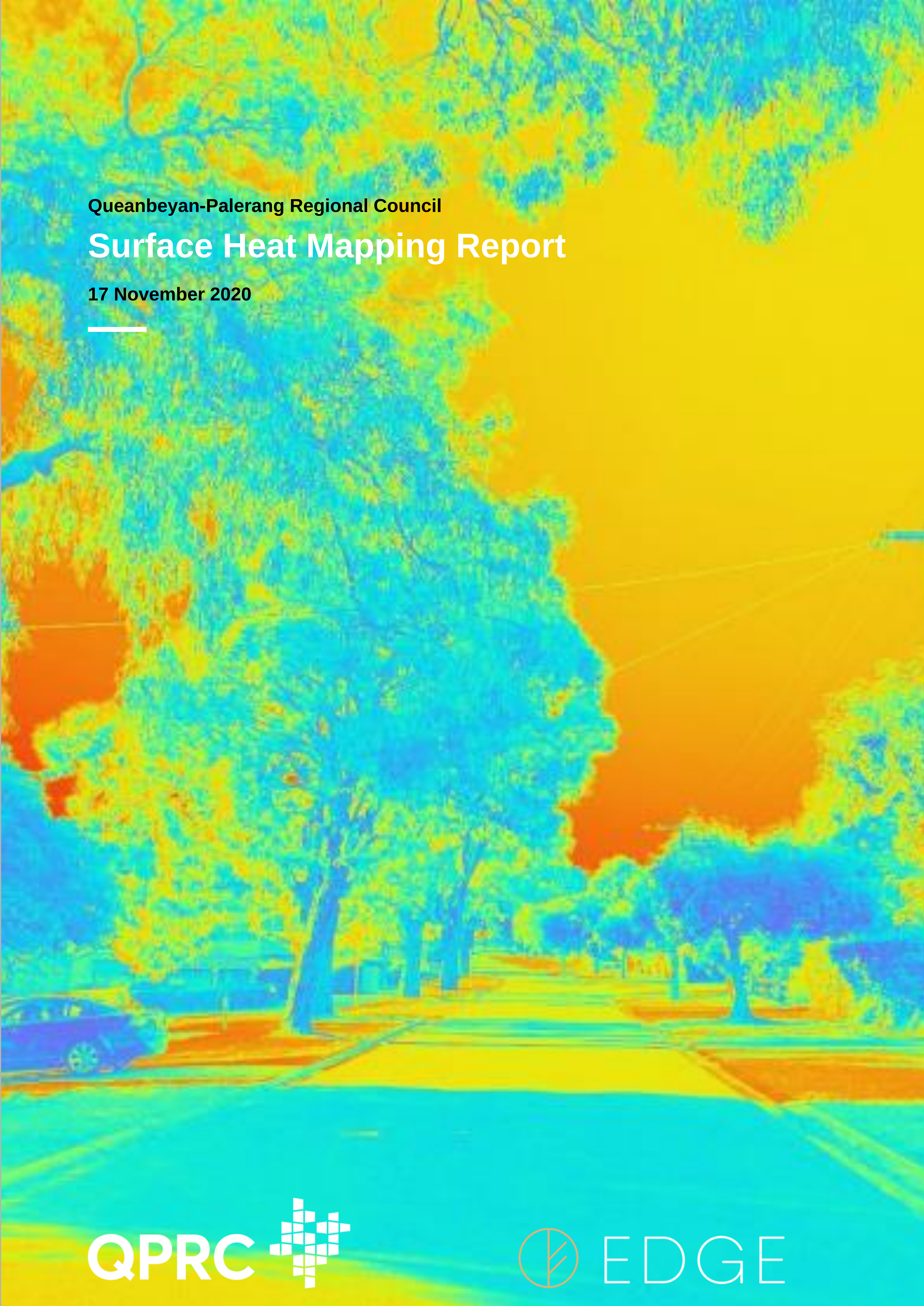

Queanbeyan-Palerang Regional Council

Surface Heat Mapping Report

17 November 2020

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Key Findings

1. Within Queanbeyan Palerang Regional Council (QPRC), the urban areas of Queanbeyan, Googong, and Bungendore all fall within the hotter north-west area while Braidwood falls within the cooler south-east area.
2. Within QPRC, 45% of the land was identified as being within an urban heat island[1], 22% of which fell within a severe urban heat island. Most of the heat islands were concentrated in west and north-west areas and across the Braidwood plain.
3. Within the urban areas, Googong (99.79%) and Bungendore (99.01%) classified entirely as a heat island, with most of Queanbeyan (91.46%) also classifying as a heat island. Googong (75.10%) had the highest proportion of severe heat island, with Queanbeyan (64.00%) and Bungendore (58.33%) being close behind. Braidwood (9.56%) had a very small portion of its area classified as urban heat island with no severe urban heat islands.
4. Of the five land uses analysed, green infrastructure (irrigated grass and trees) measured a full 3 °C cooler than built surfaces (bitumen, industrial, and residential).
5. Options for reducing the summer temperature in heat islands, especially in priority towns like Googong, Bungendore and Queanbeyan, include increased tree canopy cover and increased irrigation of open space and developing planning solutions that increase the ratio of permeable surfaces.
6. The overall average surface temperature within the QPRC region across summer (hot) days measured 29.43 °C, with Queanbeyan (32.15 °C), Googong (32.57 °C), and Bungendore (32.15 °C) all recording higher average temperatures, and Braidwood (29.18 °C) measuring slightly lower than the Council average.

[1] The term “urban heat island” is used here due to the methodology applied. Although this result includes many non-urban areas, urban heat island is used for consistency.

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1 Introduction

1.1 Context

Queanbeyan-Palerang Regional Council (QPRC) shares its western boundary with the Australian Captial Territory (ACT) and is the largest regional centre in south-east NSW. The Region comprises three main administrative centres: Queanbeyan, Bungendore, and Braidwood. The Region has experinced rapid population growth with an ongoing high growth rate of more than 50% projected to 2036. This is leading to a rapid transition of green open spaces to hard impervious built surfaces (e.g. increased housing development).

The conversion of green space to built or non-irrigated treeless surfaces is a primary driver of increasing heat in cities, underpinning the urban heat island effect. While small areas of hard surfaces can create localised hot spots at the scale of a few metres, large areas of heat can accumulate in “heat islands” at the block or neighbourhood scale. Living and working in these areas exposes people to much greater temperatures, which creates health and productivity risks for the community and economy. The presence of urban heat islands will be further exacerbated by climate change induced temperature rises and continued urban expansion and in-fill development.

Whilst the way in which urban areas are currently planned, developed, and managed has significant impacts on increasing heat, urban land managers are in an ideal position to control these impacts and help mitigate heat, through planning decisions informed by heat mapping and an understanding of the key drivers of heating and cooling.

1.2 Objectives

This project aimed to establish a thorough understanding of heat distribution, specifically surface temperature, across the QPRC region and four of its major urban centres: Queanbeyan, Googong, Bungendore, and Braidwood. Specifically, the project aimed to map the spatial patterns of heat, as well as exploring the role land use patterns (natural and built) have in determining patterns of high land surface temperature. Ultimately Council hopes this information will help the region mitigate and adapt to a changing climate, within the context of population growth and increasing urban development.

Further, the findings from this project will help inform development of an upcoming vegetation and heat adaptation strategy. In support of that strategy development, this report:

- identifies land surface temperatures for a hot summer day and night and cool winter day throughout the LGA;
- identifies urban heat islands within the four major urban centres (Braidwood, Bungendore, Googong, and Queanbeyan); and
- assesses the contribution that land use, tree cover and other built and natural characteristics have in determining patterns of high land surface temperature distribution[2].

[2] Air temperature is predominately influenced by surface temperature, however wind, humidity, shading, and other micro-climate factors also play a complex role in determining air temperature.

2 Identifying Urban Heat Priority Areas - Methods

To explore the thermal patterns over QPRC and the impacts of land use decisions, this report utilises the following data and analyses:

a) three satellite surface temperature datasets, representing: 1) summer days (hereafter 'hot days'), 2) summer nights (hereafter 'nighttime'), and 3) winter days (hereafter 'cold days') conditions, to provide direct assessment of the surface temperature patterns and magnitudes;

b) urban heat island analysis, to identify and measure areas of unnatural warmth across the four major urban areas during summer days; and

c) point-based land use temperature assessment to understand the thermal signatures of various land uses and to explore the contribution of various land uses to urban heat islands;

2.1 Urban heat mapping

To understand the patterns of urban heat under various conditions, three land surface temperature maps were generated representing: 1) hot days, 2) nighttime, and 3) cold days. These maps represent surface temperatures in absolute terms in degrees Celsius. Surface temperature, or skin temperature, measure the amount of energy radiating from the surface at a given timepoint. While surface temperature is the dominant influence on, and highly related to, air temperature immediately above the surface, it is not a direct measure of air temperature. This study exclusively examines surface temperature.

2.1.1 Data acquisition

Land surface temperature data was acquired from the Thermal Infrared Sensor (TIRS) aboard the Landsat 8 satellite platform. Landsat data provides 30 metre by 30 metre resolution (100 m resampled to 30 m) thermal data which covers the entire QPRC region within a single overpass allowing for direct comparison of surface temperatures across the urban areas. The freely available Landsat data was post-processed using geospatial software (Erdas Imagine, ArcGIS, & QGIS) to extract atmospherically- and emissivity-corrected surface temperature data (USGS 2019).

Satellite data is highly useful for assessing broad scale patterns of temperature across the landscape. The 30 metre resolution permits wide swaths of data to be taken in on single overflights. However, this resolution means that the data displays the averages of all values within a single pixel which obscures more detailed features. This effect is multiplied with thermal data as, due to the lower strength of thermal wavelengths compared to visible light, the resolution has to be further reduced to 100 metres (resampled to 30 metres for compatibility with other Landsat products) to obtain a useable signal from an altitude of 705 km.

For summer daytime (hereinafter ***Hot Days***) surface temperatures, two images from the 2018/2019 summer season were acquired: December 28, 2018 which had a maximum air temperature of 36.8 °C (BOM Canberra Airport), and January 29, 2019 which had a maximum air temperature of 35.7 °C. Daytime Landsat overpass occurs at 11:50 am, generally one to two hours before peak temperautre. Both image acquisition dates were preceded by at least two days over 31 °C meaning the landscape was thermally charged and provided the best signal of land use temperatures. These images were composited to develop a representative summer daytime surface temperature map (hot day map). Compositing multiple thermal images provides a more robust understanding of surface temperature by minimising the influence of any anomalies unique to single heat-wave events. The Landsat satellite maps every area on the planet, only once every 16 days, and while seven images were collected during the 2019/2020 summer season, all of these contained a significant cloud fraction and bushfire smoke or were not sufficiently warm. As such, the selected datasets provide the best recent data.

Nighttime Landsat surface temperature data is more difficult to acquire, as it is only collected by request. Only ten such images are available in the Landsat archive, and only six from the last two years. As such, data acquired December 17th, 2019 was selected to generate the nighttime surface temperature map (hereinafter ***Nighttime Surface Temperature Map***). Nighttime Landsat overpass occurs at 12:36 am. Weather conditions on this date recorded a very cool 12.1 °C minimum temperature (BOM Canberra Airport), although temperatures did rise to a maximum of 32.5 °C that day. Given the limited data availability, this is the best option for a nighttime surface temperature map. An additional daytime dataset acquired July 24th, 2019 (maximum temperature of 14.9 °C) was also analysed to provide a cold weather comparison (hereinafter ***Cold Days Surface Temperature Map***). Comparative spatial analyses were employed to explore how cold weather surface temperature patterns differ from hot day and night time patterns.

2.1.2 Analysis

Given the spatial proximity of Queanbeyan and Googong, findings for these areas are presented on the same maps, giving a total of three primary mapping outputs. Each of the three urban heat maps are presented in absolute temperatures. Within each dataset, the average value is calculated for each of the four urban areas and for the Council overall. These values are charted and compared to understand the thermal relationships between urban areas and provides the foundation for the land use assessment. Council and urban area boundary datasets were provided by QPRC.

2.2 Urban heat island identification

Using the daytime land surface temperature map, an Urban Heat Island (UHI) analysis was conducted to identify areas within QPRC that experience an unnatural build-up of heat. Heat islands are areas of excess heat accumulation above the baseline (natural) temperature. This baseline temperature was derived using the method developed by CSIRO (Devereux & Caccetta 2017), where nearby areas of native vegetation are used to represent the natural baseline temperature. For this assessment, baseline temperature was calculated from 35 control points in the forested area directly west of Queanbeyan, consistent with the CSIRO methodology[3]. This baseline temperature was subtracted from the absolute temperatures in the surface temperature map to provide a relative temperature for each 30 x 30 m area, presented as degrees Celsius above or below baseline temperature. The result is an Urban Heat Island Map that identifies areas 2 °C or more above baseline temperatures as Urban Heat Islands, and areas 4 °C or more above baseline temperatures as Severe Urban Heat Islands.

2.3 Land use temperature assessment

To understand how various surfaces contribute to urban heat and urban heat islands, a point-based land use temperature assessment was conducted using high resolution imagery. Five different land use types (irrigated grass, tree, bitumen, residential, industrial) were assessed. For each of the five land use types, five to eight examples were identified from the imagery and the surface temperature for each point was extracted from the surface temperature map. Due to the small sizes of Braidwood, Bungendore, and Googong, these areas lacked large clear examples required for the land use assessment, thus all land use type examples were taken from within the Queanbeyan urban area. Comparison of the thermal performance of each surface type reveal the thermal impact of land use features and can be used to inform the thermal impact of future land use decisions across the Council.

[3] The control site west of Queanbeyan demonstrated the most consistent temperatures of the possible control sites. Alternative control sites, namely Tallaganda National Park, were considered but ultimately dismissed due to higher ranges of elevation.

3 Urban heat in Queanbeyan-Palerang Regional Council - Results

3.1 QPRC urban heat results

3.1.1 Hot day surface temperatures

The hot day temperature map, composited from thermal imagery collected during two very warm summer days in the 2018-2019 summer season, shows a clear trend of warmer surface temperatures in the north-west third of the Council contrasted by cooler temperatures in the south-east two thirds (Figure 1). Within the Council, the urban areas of Queanbeyan, Googong, and Bungendore all fall withing the hotter north-west area while Braidwood falls within the cooler south-east area, although near a localised warm area.

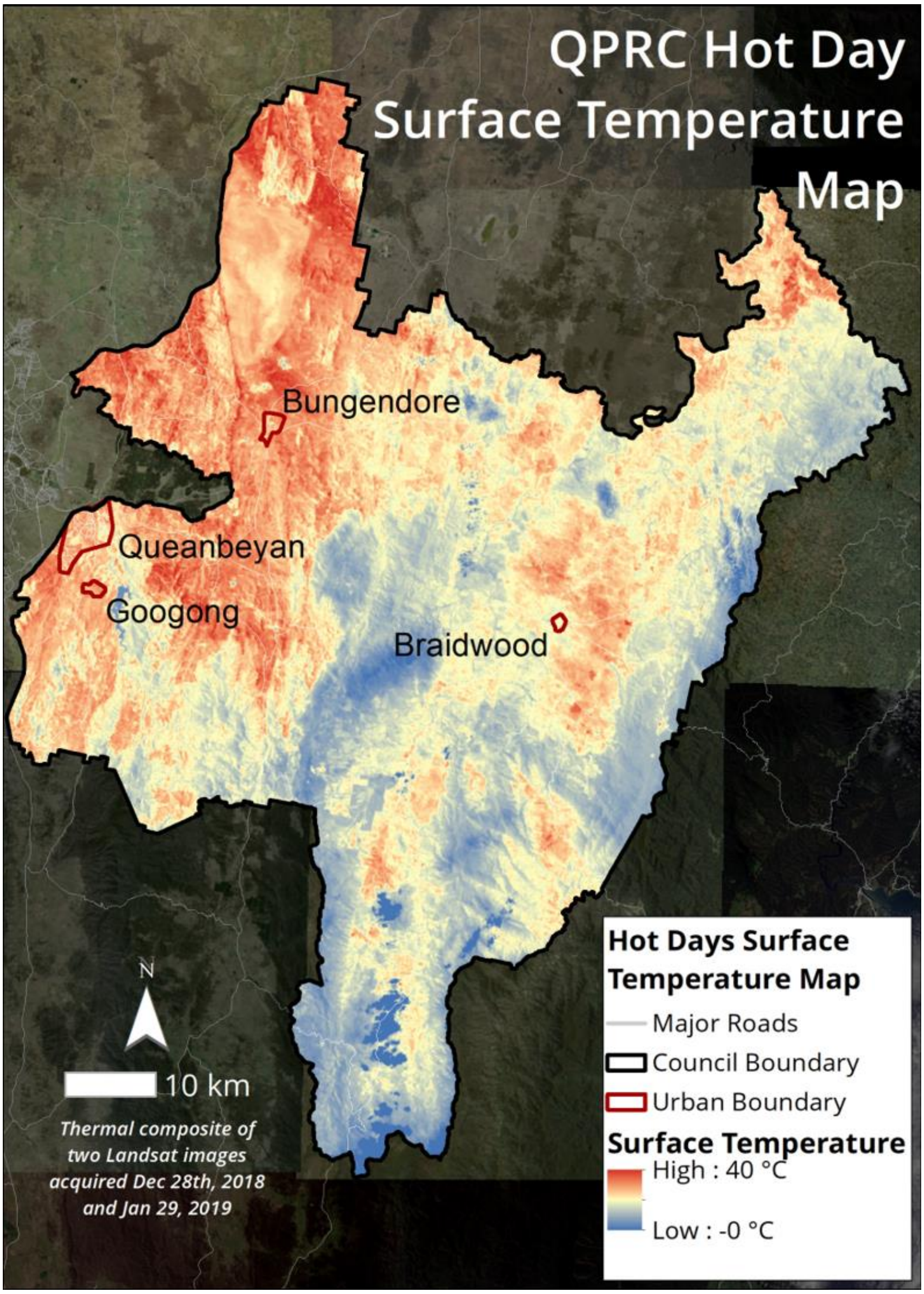

Figure 1. QPRC Hot Day Surface Temperature Map.

The overall average surface temperature within the QPRC region measured 29.43 °C, with Queanbeyan (32.15 °C), Googong (32.57 °C), and Bungendore (32.15 °C) all recording higher than average temperatures and Braidwood (29.18 °C) measuring slightly lower than the Council average (Figure 2).

In addition to the hot north-west areas, the other defining feature is a cool corridor running from the centre of the region through the southern tip. This correlates with the extent of Tallaganda National Park demonstrating the cooling influence of vegetation and altitude. By contrast, the plain surrounding Braidwood appears largely to be grazing paddocks within very few trees, which in turn registers as a local warm area (Figure 1).

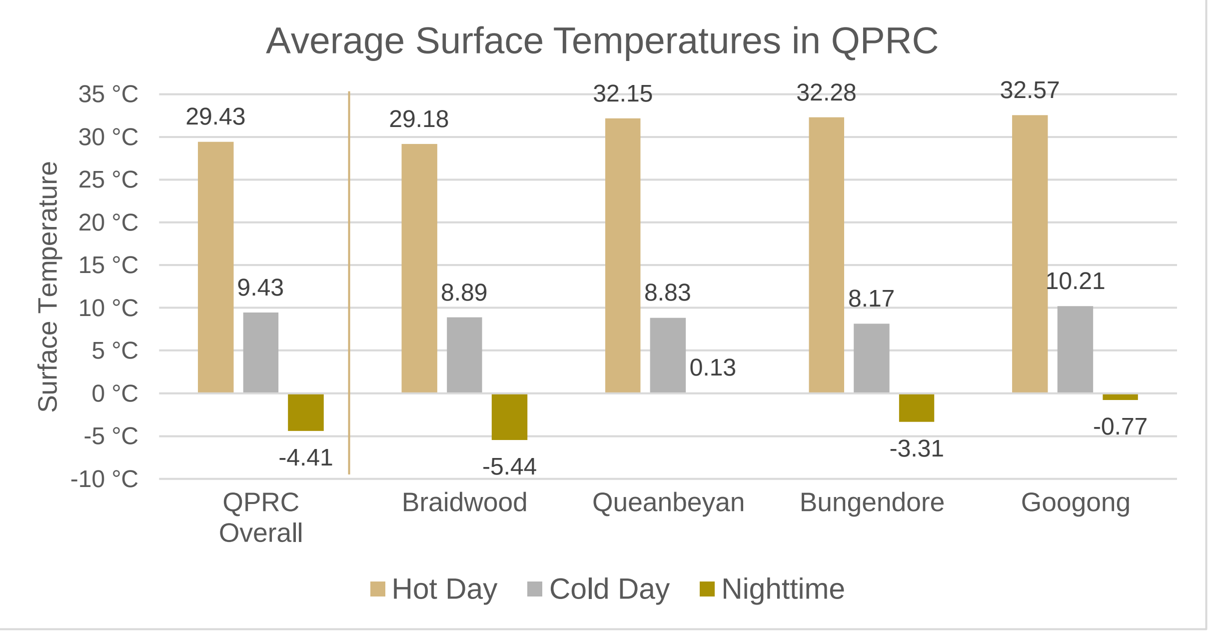

Figure 2. Average Surface Temperatures in QPRC

3.1.2 Nighttime surface temperatures

As surface temperature is a measure of energy radiating from the surface which drops off rapidly after sunset, nighttime temperatures appear substantially lower than the air temperatures, however the pattern of hot and cold regions remains useful in understanding heat distribution at night. Similar to the hot day map (Figure 1), the nighttime map (Figure 3) shows a hot area to the west and a cool area to the east. However, in the nighttime map, the western hot area is more intense to the south, with warmest temperatures occurring in Queanbeyan and southward (Figure 3). In the east, the Braidwood plain appears very cool in comparison to the hot day map, likely due to the lack of tall heat-trapping vegetation which allows heat to dissipate rapidly after sunset. The largest difference in the nighttime map is the appearance of a very warm area in the Araluen Valley in the south east corner of the council which may be produced by lower altitude and coastal influence.

The overall average surface temperature within the QPRC region measured -4.41 °C, with Queanbeyan (0.13 °C), Googong (-0.77 °C), and Bungendore (-3.31 °C) all recording above average temperatures and Braidwood (-5.44 °C) measuring slightly lower than the Council average (Figure 2).

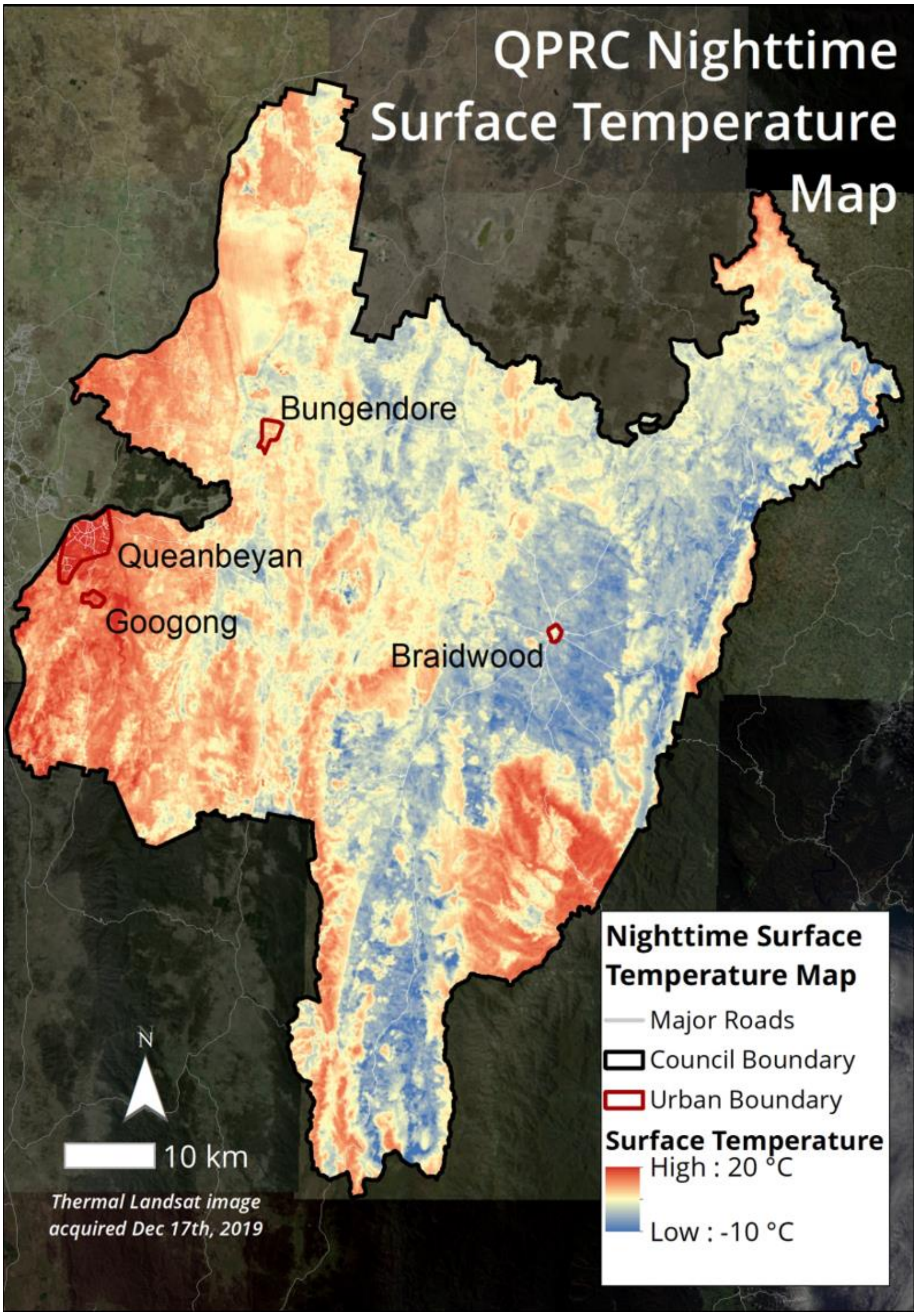

Figure 3. QPRC Nighttime Surface Temperature Map.

3.1.3 Cold day surface temperatures

Analysing the cold day heat map shows a more dynamic picture of temperature variation (Figure 4). The Braidwood plain appears warm, along with a very warm south-east corner, and largely mixed results across the rest of the area.

The cold day temperature patterns within the urban areas diverge from the hot day map. The overall average surface temperature within the QPRC region measured 9.43 °C, with Googong (10.21 °C) recording a higher than average temperature while Queanbeyan (8.83 °C), Bungendore (8.17 °C), and Braidwood (8.89 °C) all measured lower than the Council average (Figure 2).

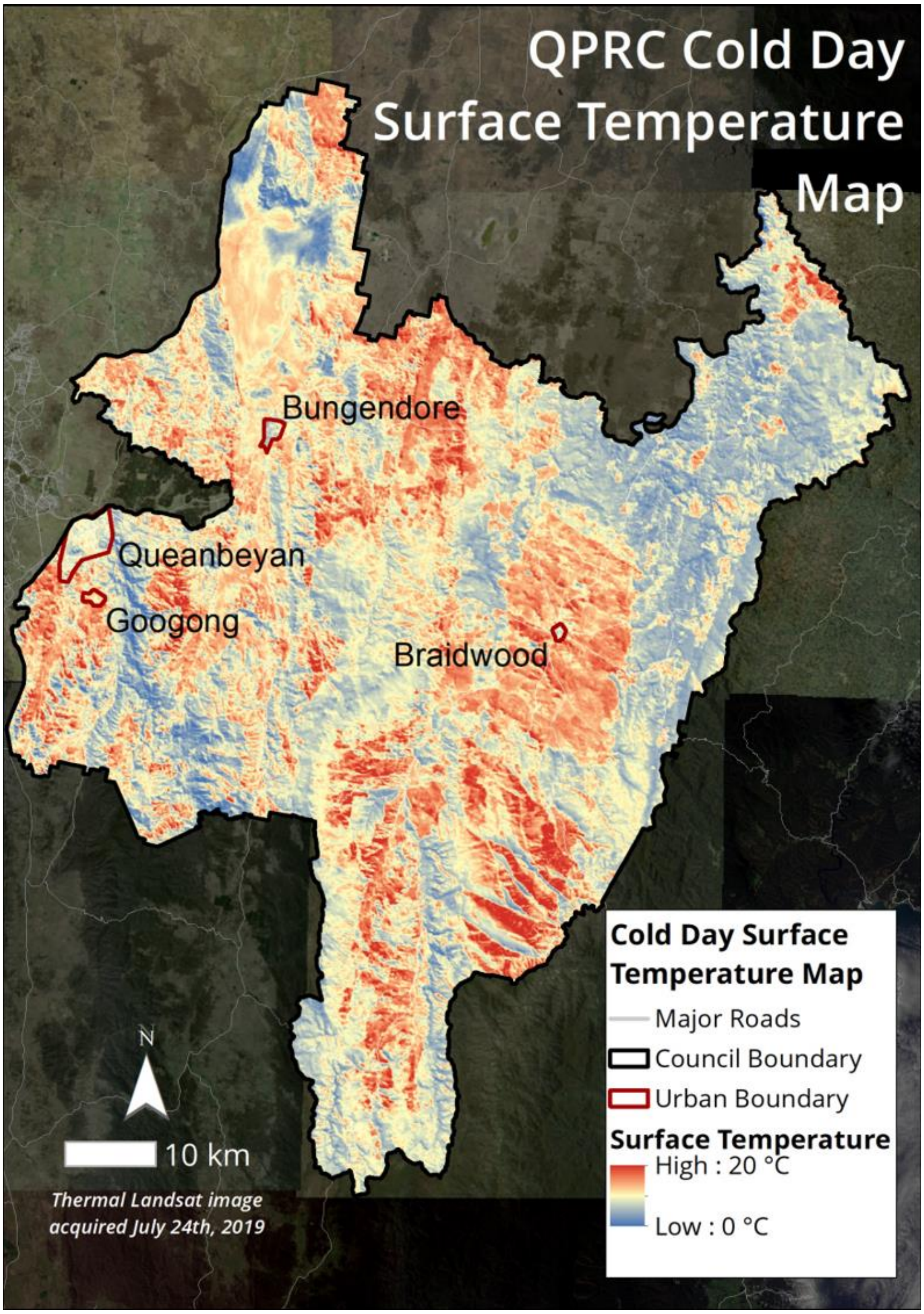

Figure 4. QPRC Cold Day Surface Temperature Map.

3.2 QPRC urban heat islands

To estimate how the current thermal landscape differs from a landscape without development, 35 control points in the forested area directly west of Queanbeyan were used to determine a baseline temperature. This baseline temperature was then subtracted from the hot days absolute surface temperature data, resulting in a relative temperature map with areas greater than 2 °C above baseline identified as an Urban Heat Island, and areas greater than 4 °C above baseline identified as a severe Urban Heat Island.

Within QPRC, 45% of the land was identified as being within an urban heat island, 22% of which fell within a severe urban heat island (Figure 5). Most of the heat islands were concentrated in the west and north-west areas and across the Braidwood plain (Figure 6). Within the urban areas, Googong (99.79%) and Bungendore (99.01%) classified entirely as a heat island, with most of Queanbeyan (91.46%) classifying as heat island. Googong (75.10%) had the highest proportion of severe heat island, with Queanbeyan (64.00%) and Bungendore (58.33%) being close behind. Braidwood (9.56%) had a very small portion of its area classified as urban heat island with no severe urban heat islands.

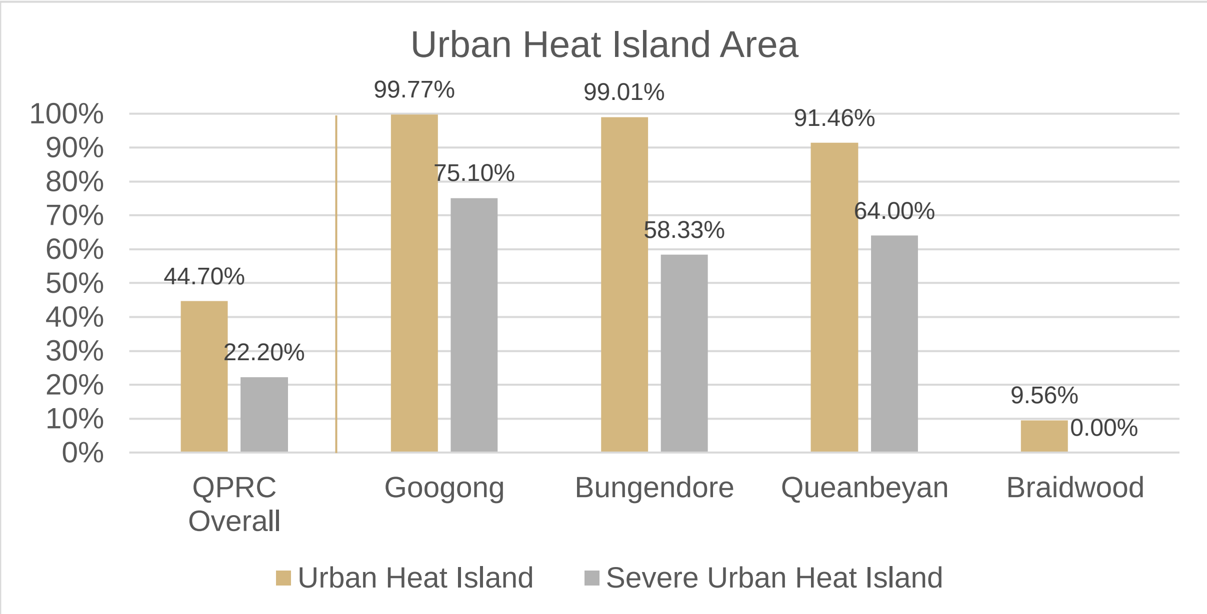

Figure 5. Urban Heat Island Area.

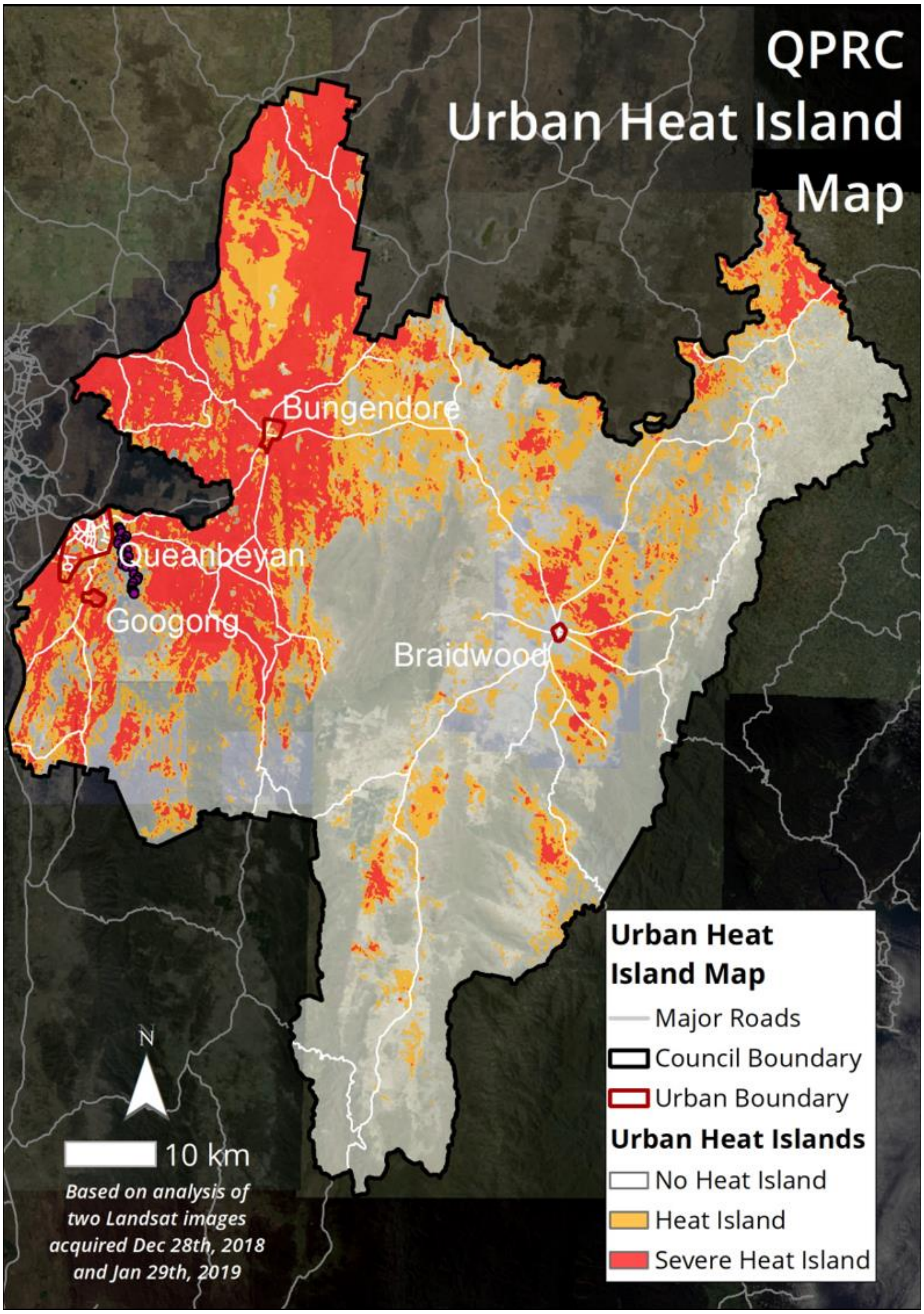

Figure 6. QPRC Urban Heat Island Map.

3.3 Land use temperature analysis

The composition of an urban landscape has been shown to influence the formation of urban heat islands as differing urban surfaces have very different thermal impacts. As demonstrated in the hot days map, heavily treed areas such as the Tallaganda National Park are often much cooler than urban areas or even grasslands. Other analyses undertaken by Edge highlights that high surface temperatures can occur over areas with dry, non-irrigated grass. To explore these impacts in QPRC, the thermal impact of five land use types was explored by measuring the surface temperatures at 30 points across Queanbeyan with clear examples of the target land use types. Examples were selected in Queanbeyan due to having larger and more diverse land use features identifiable in the Landsat data, whereas the other urban areas lacked clearly visible (i.e. >30 x 30 metre) examples of one or more land use types, which would have skewed comparability. Of the five land uses analysed, green infrastructure (irrigated grass and trees) measured a full 3 °C cooler than built surfaces (bitumen, industrial, and residential) (Figure 7). Bitumen was the hottest measuring 33.38 °C, followed by industrial buildings (33.14 °C), residential areas (33.10 °C), with irrigated grass (30.15 °C) and treed areas (30.08° C) measuring substantially cooler. Previous studies using similar methodologies over high resolution thermal imagery identified the same pattern, although at a much greater magnitude with treed areas measuring a full 10 °C cooler than bitumen (Seed Consulting Services ***et al***. 2017; 2018). The difference is attributed to the coarse resolution of satellite data and the actual pattern is likely to be closer to that found in the previous studies.

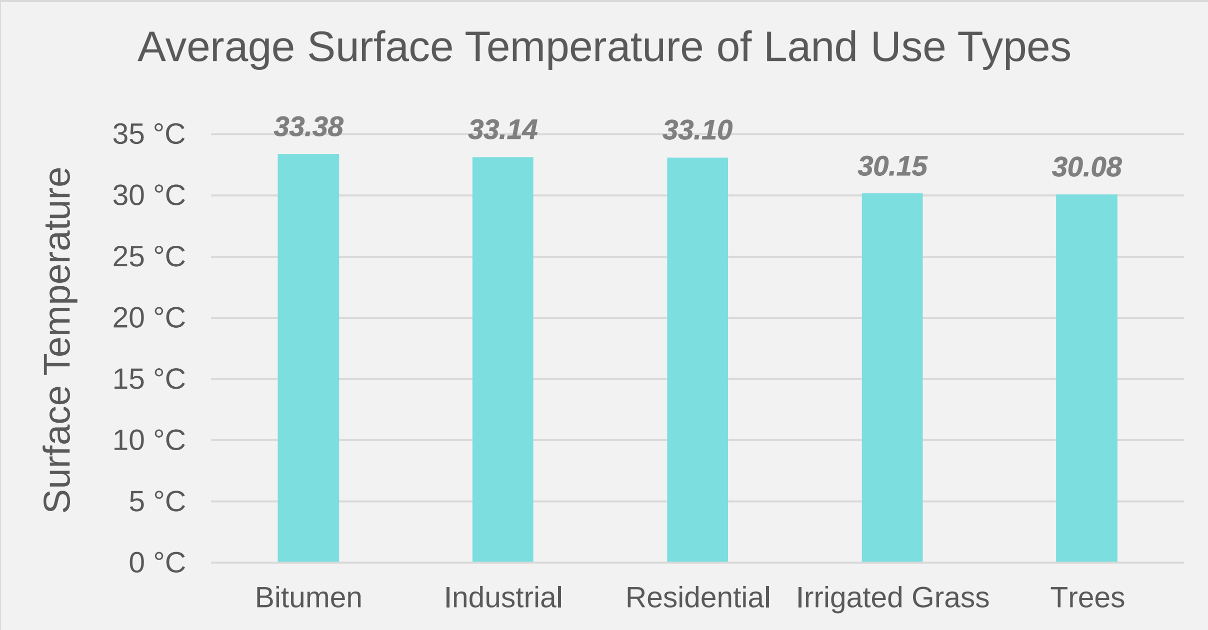

Figure 7. Surface Temperatures of Land Use Types.

3.4 Surface temperatures and heat islands in urban centres

3.4.1 Queanbeyan

In the Queanbeyan hot day map (Figure 8), the Queanbeyan Golf Club and the area around Mount Jerrabomberra had the lowest surface temperatures. The Queanbeyan River also emerges as a visible cool area. Conversely, Riverside Plaza emerges as the hottest spot in Queanbeyan, followed by high density residential areas south of Ellerton Drive. Given the scale of the satellite data, analysis is limited to general patterns of the thermal landscape. The influence of large features, such as shopping centres, can be identified but the influence of smaller features cannot be reliably assessed.

In the nighttime surface temperature map, Queanbeyan is highlighted by a dark red (hottest) colour within the urban boundary and a lighter red (cooler) outside the urban boundary (Figure 9). Dense urban materials retain heat long after sunset, compared with natural materials, the presence of which can clearly be depicted here. Most of Queanbeyan displays a similar temperature in the nighttime map.

In the cold day temperature map, Queanbeyan has milder relative temperatures compared to the hot days and nighttime maps (Figure 10). The Mount Jerrabomberra area and the Greenleigh suburb appear as the coolest areas with some high-density residential areas within the Karabar suburb having warmer temperatures.

Most of Queanbeyan (64%) falls within a severe urban heat island (more than 4 °C above baseline temperature) (Figure 11). In particular, Queanbeyan East, Crestwood, Queanbeyan West, Karabar, Jerrabomberra, among others, all classify as falling mostly under a severe heat island. Greenleigh is the only area under a non-severe heat island and the area around Mount Jerrabomberra is one of the few areas not under any heat island.

3.4.2 Googong

In the hot day map, nearly all of Googong appears very warm (Figure 8) and it measures warmest of all the urban areas (32.75 °C) and 3.14 °C warmer than the Council average (Figure 2). There are some very small cooler areas over Duncan Fields, Rockley Oval, and Googong Common - Bunburung Thina. Due to the small extent of Googong and the coarse satellite data, limited insights can be ascertained from the observed thermal patterns.

From the nighttime data, Googong was not the warmest urban area but it was again more than 3 °C warmer than the Council average (Figure 2). In the cold day data, Googong was the warmest urban area, though only 0.78 °C warmer than the Council average. In the nighttime map (Figure 9) and the cold day map (Figure 10), limited detail can be extracted from the imagery due to the small size and close setting of the features. During the hot days and nighttime data, the Googong was warmer than the surrounding paddocks, but in cold day map paddocks were slightly warmer.

In the urban heat island map, all of Googong (99.75%) falls under a urban heat island, with 75% falling under a severe heat island (Figure 11). However, 25% of the area only falls under a general urban heat island, including Googong Common - Bunburung Thina.

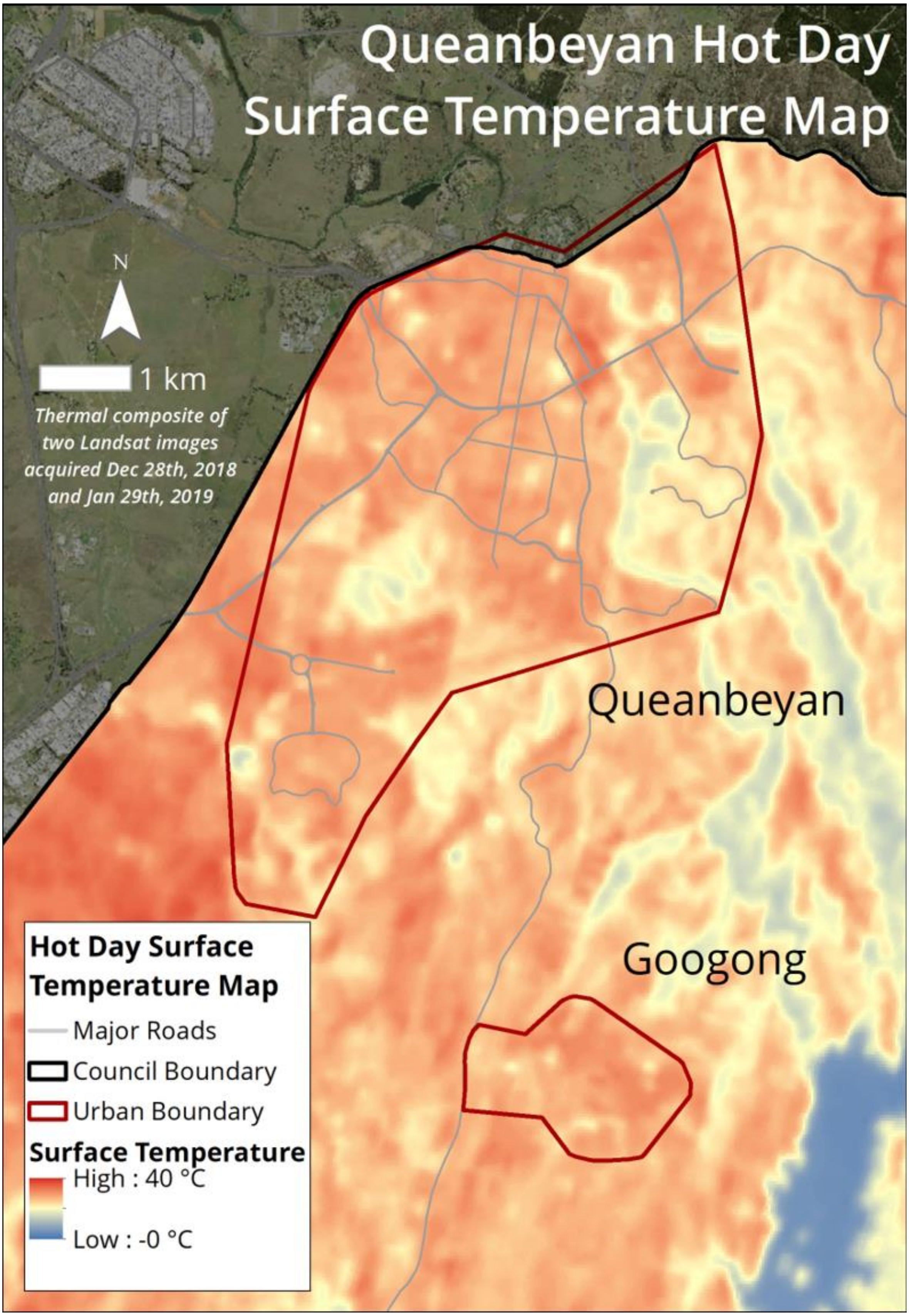

Figure 8. Queanbeyan and Googong Hot Day Surface Temperature Map.

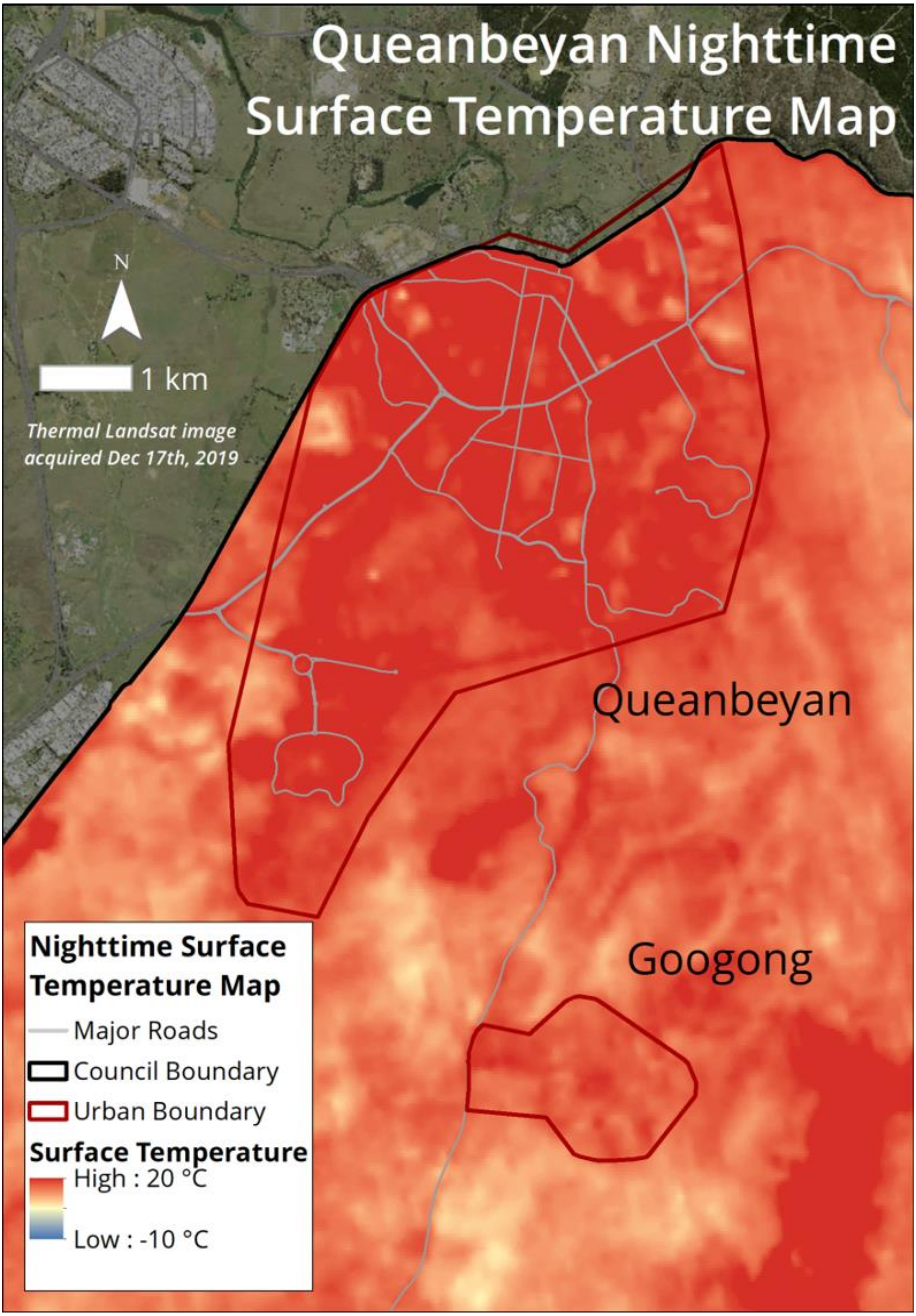

Figure 9. Queanbeyan and Googong Nighttime Surface Temperature Map.

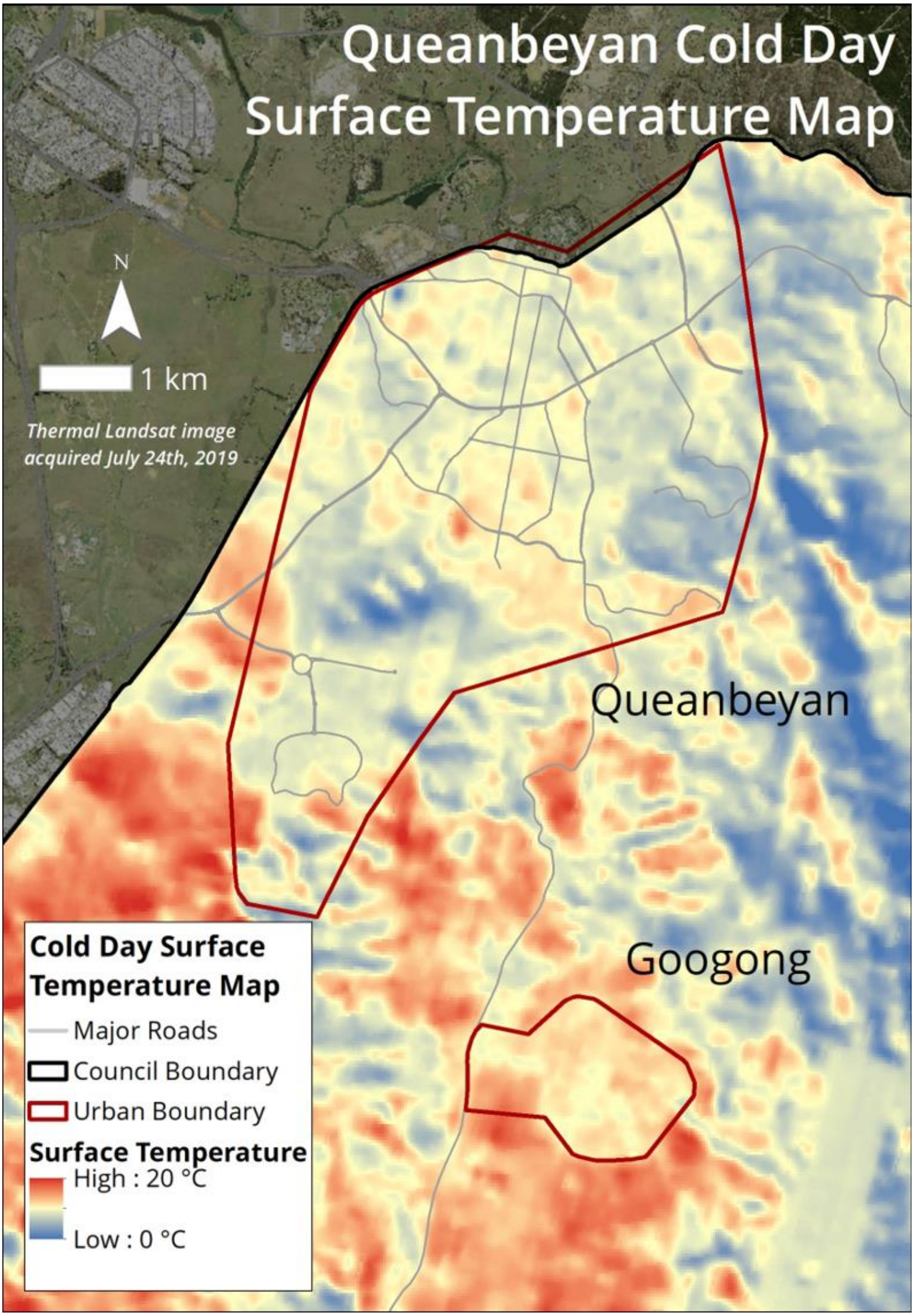

Figure 10. Queanbeyan and Googong Cold Day Surface Temperature Map.

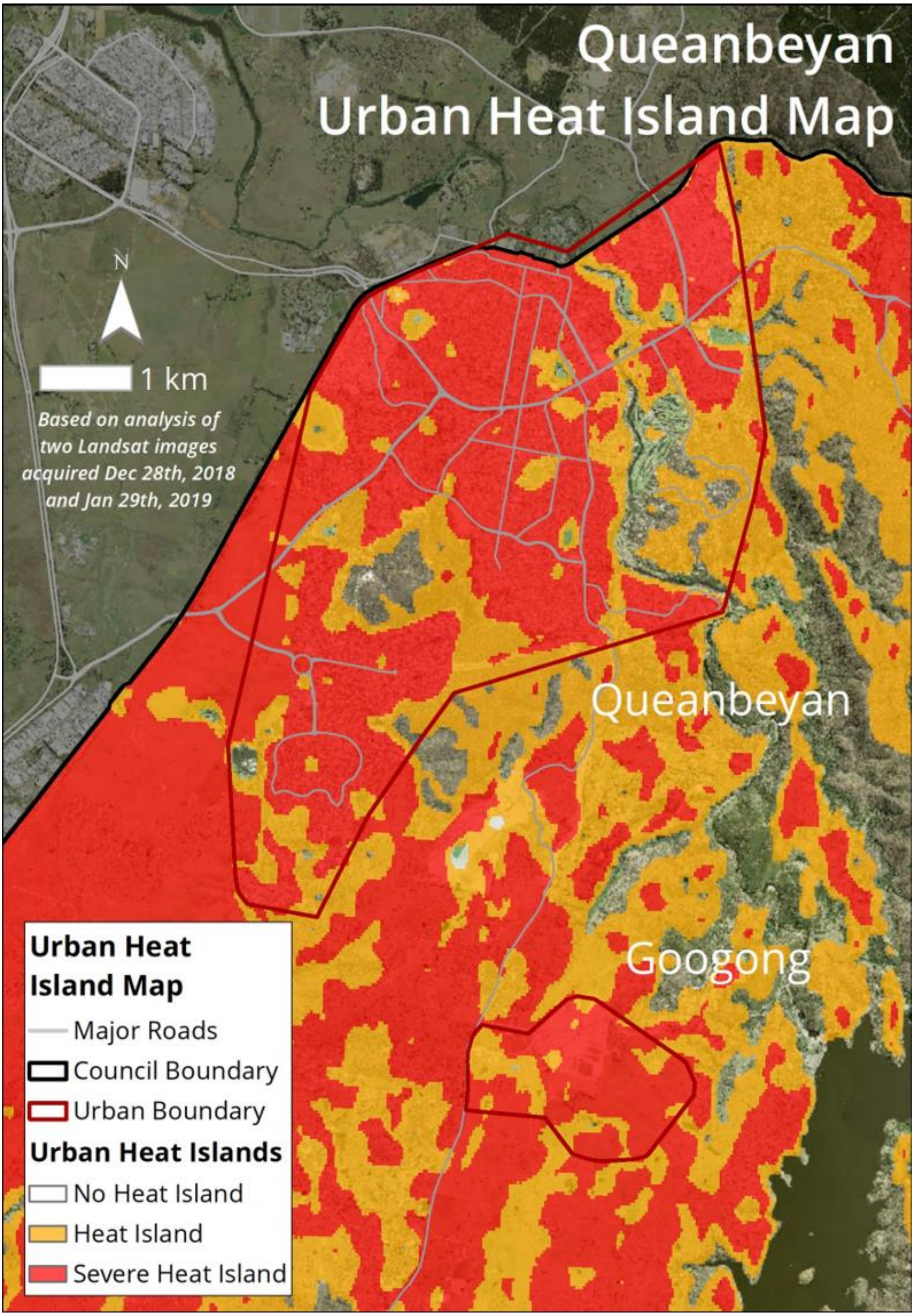

Figure 11. Queanbeyan and Googong Urban Heat Island Map.

3.4.3 Bungendore

In the hot day map, Bungendore appears warm to hot with heat concentrated in the north-east corner, east of Tarago Road and north of McMahon Drive (Figure 12). This aligns with the recently established Elmslea Estate and its associated young trees. Another hot area appears in the residential area between Ellendon Street and Trucking Yard Lane along Finch Street which has exceedingly few trees which likely contributes to high urban heat. The coolest area is found along Turallo Creek and Warren Little Oval. Bungendore was the second hottest urban area measuring 2.85 °C warmer than the Council average (Figure 12).

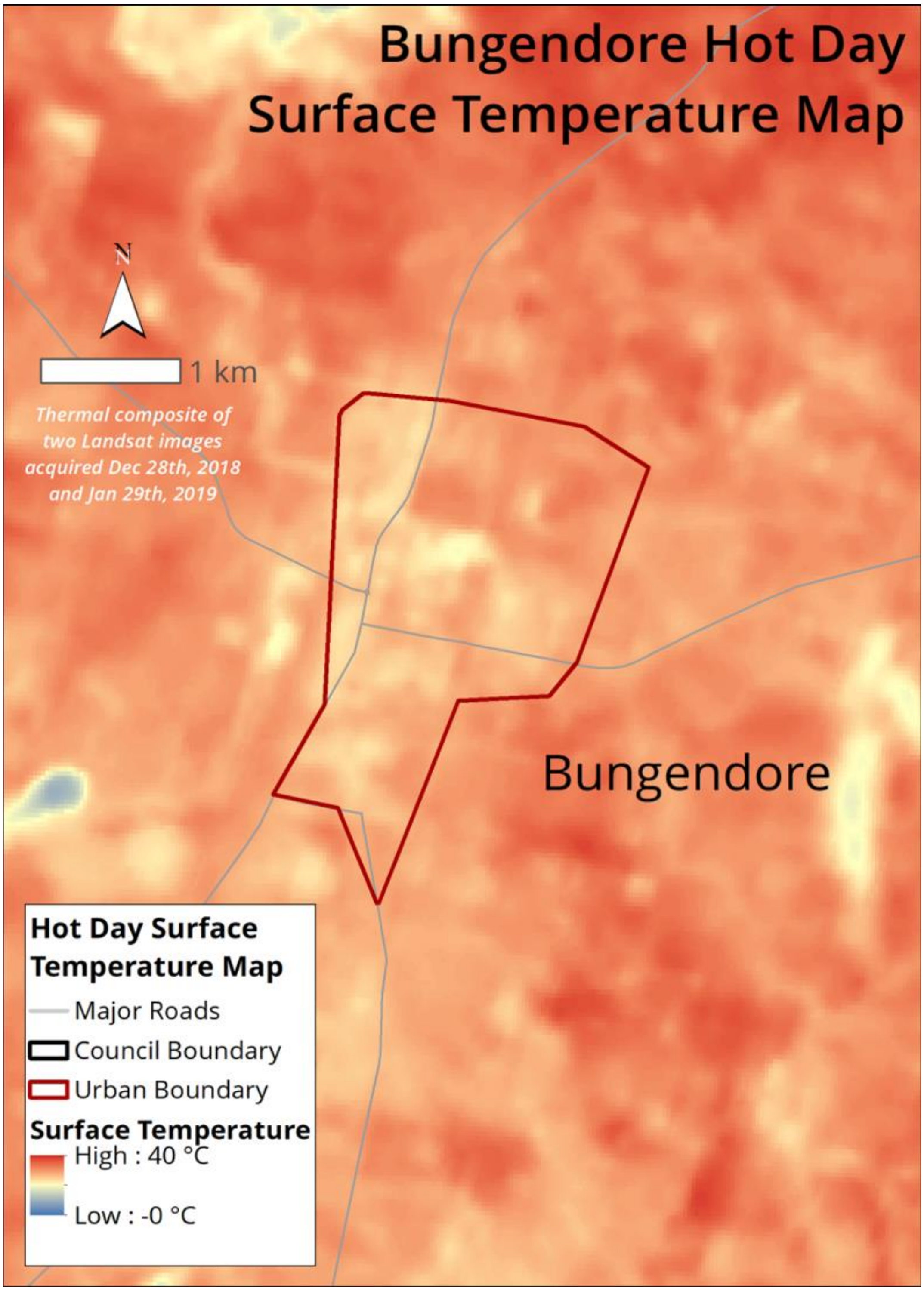

Figure 12. Bungendore Hot Day Surface Temperature Map.

Bungendore appears very warm in the nighttime temperature map particularly in the south/south east area (Figure 13). The coolest area remains along Turallo Creek. Bungendore measured 1.10 °C warmer than the Council average in the nighttime data (Figure 2).

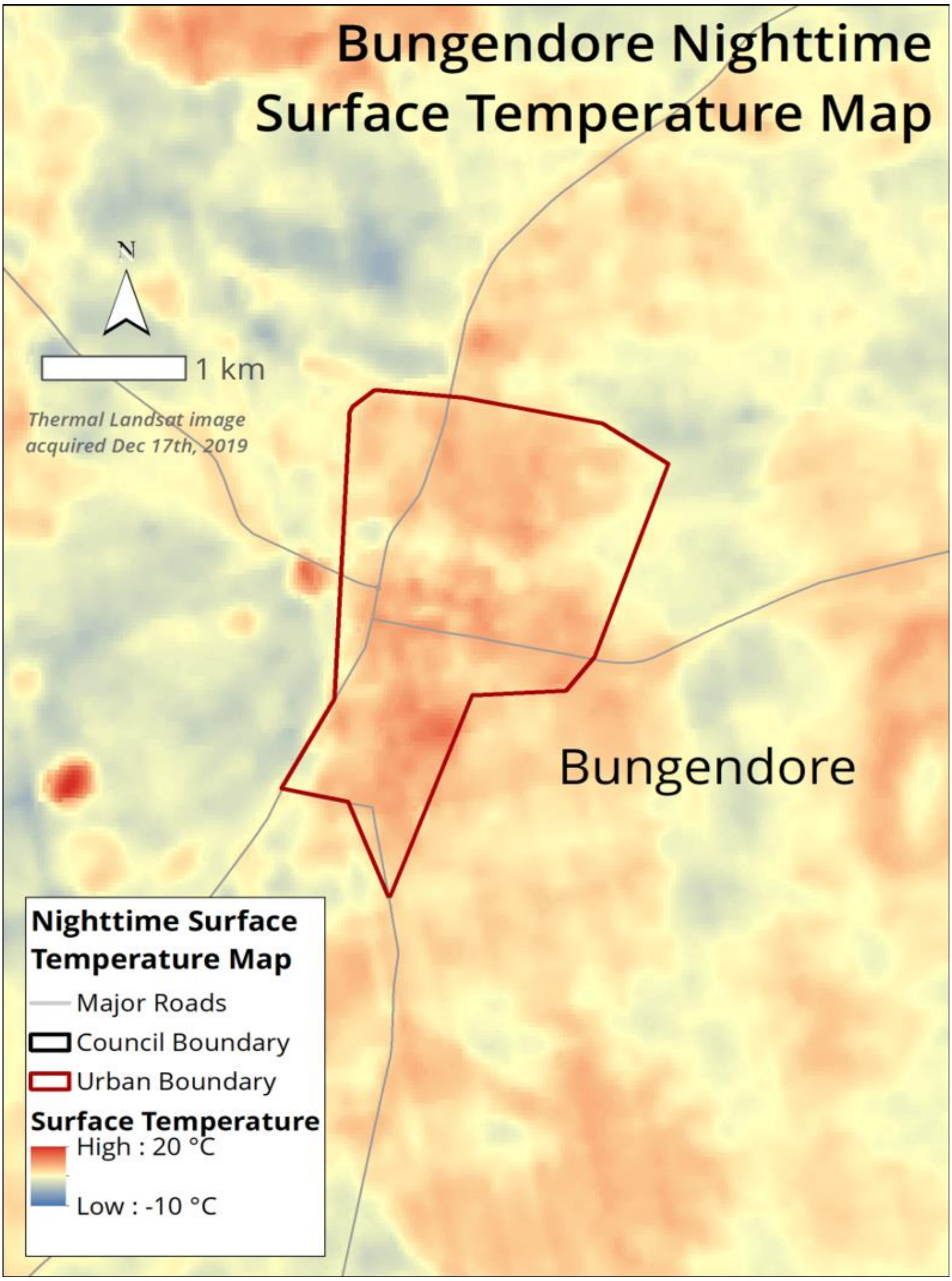

Figure 13. Bungendore Nighttime Surface Temperature Map.

In the cold day map, Bungendore displays very cool temperatures compared to surround areas especially in the north-west areas west of Tarago Road (Figure 14). Bungendore had the coolest temperatures of any urban area measuring 1.26 °C below the Council average (Figure 2).

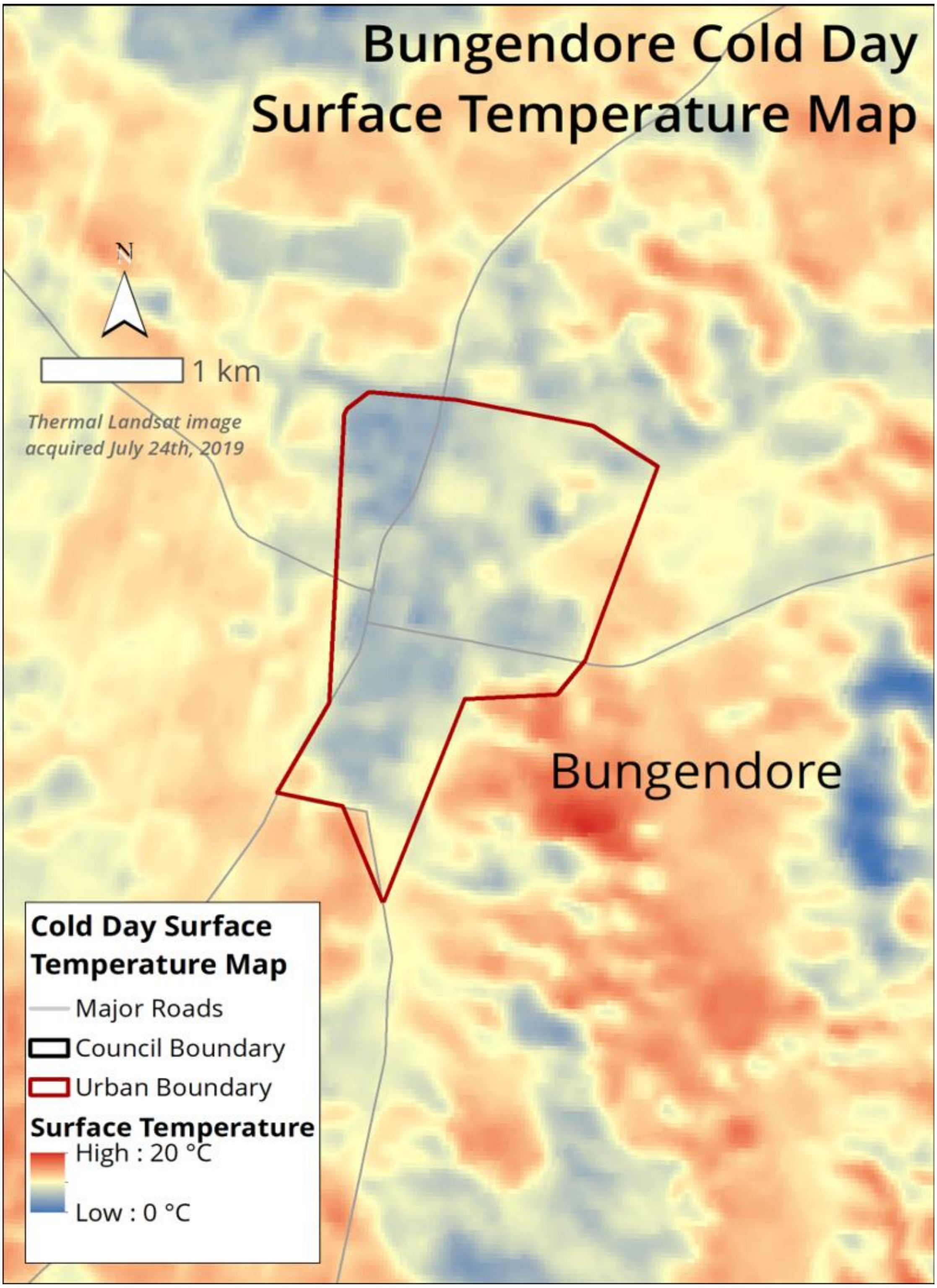

Figure 14. Bungendore Cold Day Surface Temperature Map.

The Bungendore urban heat island map shows a very distinct pattern of severe urban heat islands in the north east and south east and general heat islands in the west and central areas (Figure 15). The severe urban heat islands are the same hot areas identified in the hot days map. The general urban heat islands concentrate along Turallo Creek but extend west to include all area to the west of Tarago Road. Bungendore had the second highest proportion of urban heat island (99.01%) although only third highest proportion of severe urban heat island (58.33%) (Figure 5).

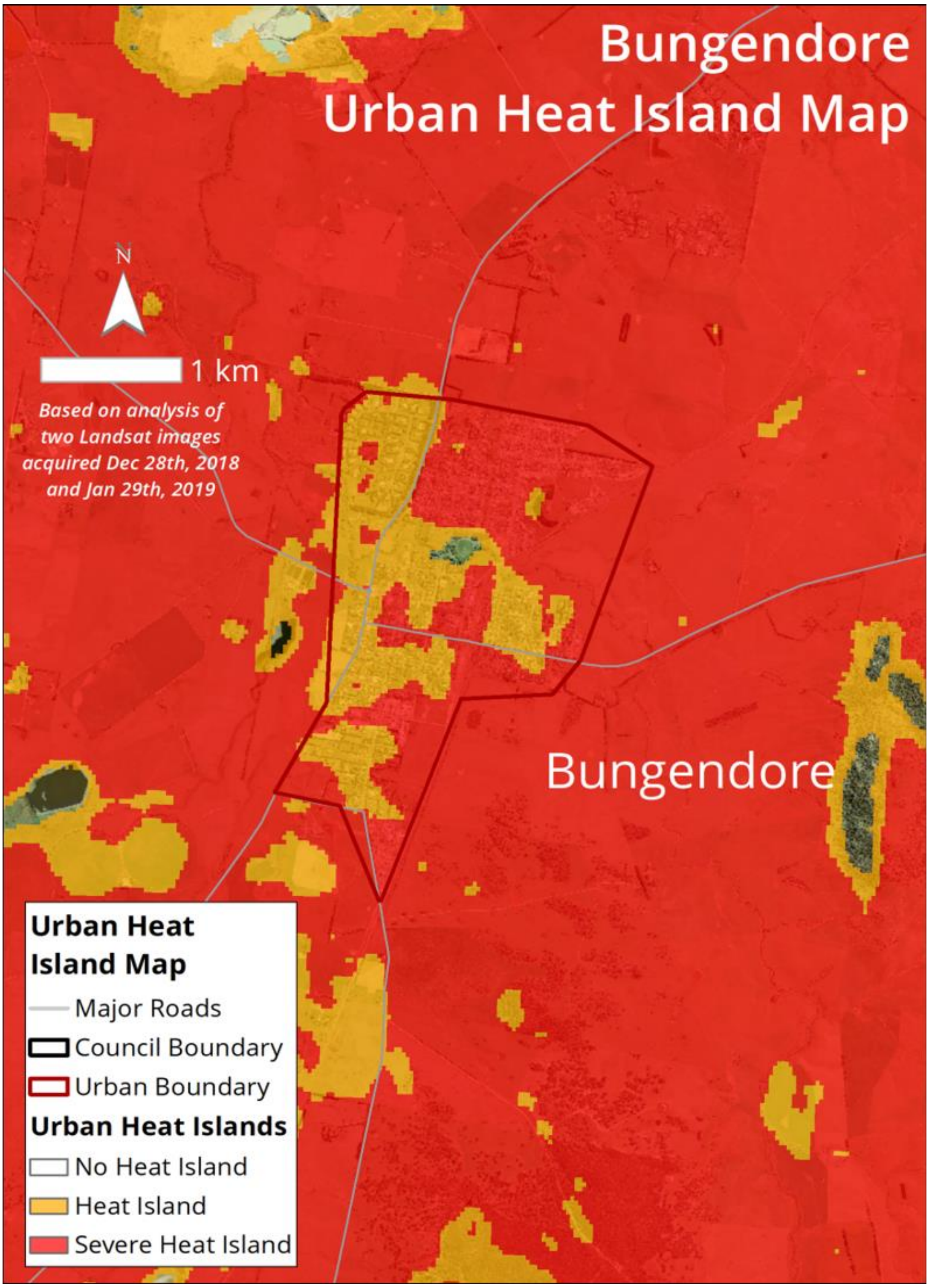

Figure 15. Bungendore Urban Heat Island Map.

3.4.4 Braidwood

In the hot day surface temperature map, Braidwood displays a warmer centre and cooler surrounding area (Figure 16). The warmer central area corresponds to the residential neighbourhoods and the cooler areas correspond to the Servicemen's Club and Golf Course and Gillamatong Creek. However, the hottest area within Braidwood lies along the far east, south of Wilson Street/Little River Road and east of Monkittee Street, which appears to align with a new high-density residential development with minimal green infrastructure. Braidwood was the coolest of the all the urban areas (29.18 °C) measuring 0.25 °C cooler than the Council average (Figure 2).

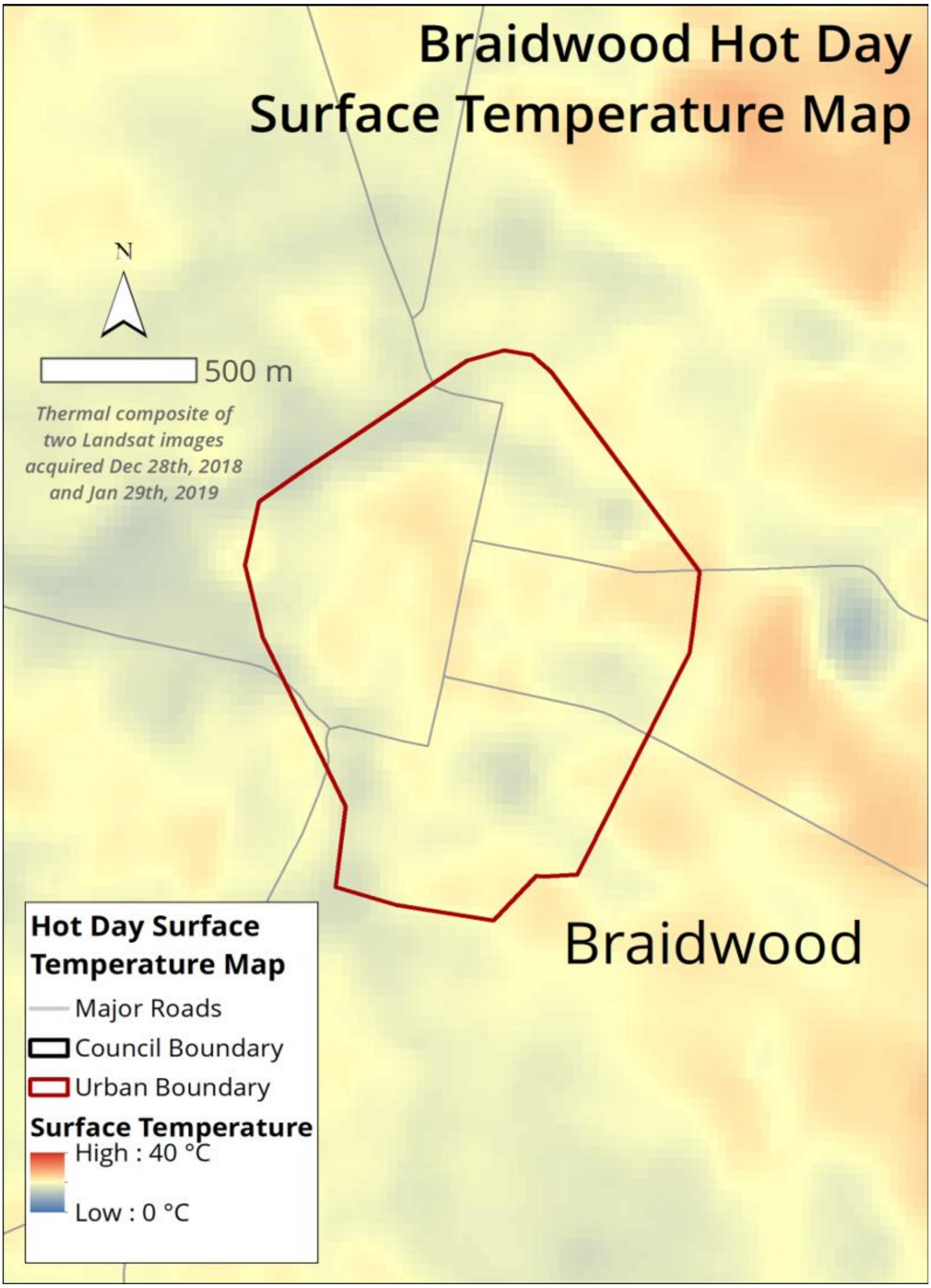

Figure 16. Braidwood Hot Day Surface Temperature Map.

Most of Braidwood appears to be quite cool in the nighttime data with the exception of a warm area over the intersection of Wilson and Wallace Streets (Figure 17). Braidwood was the coldest of all urban areas in the nighttime data measuring 1.03 °C cooler than the Council average (Figure 2).

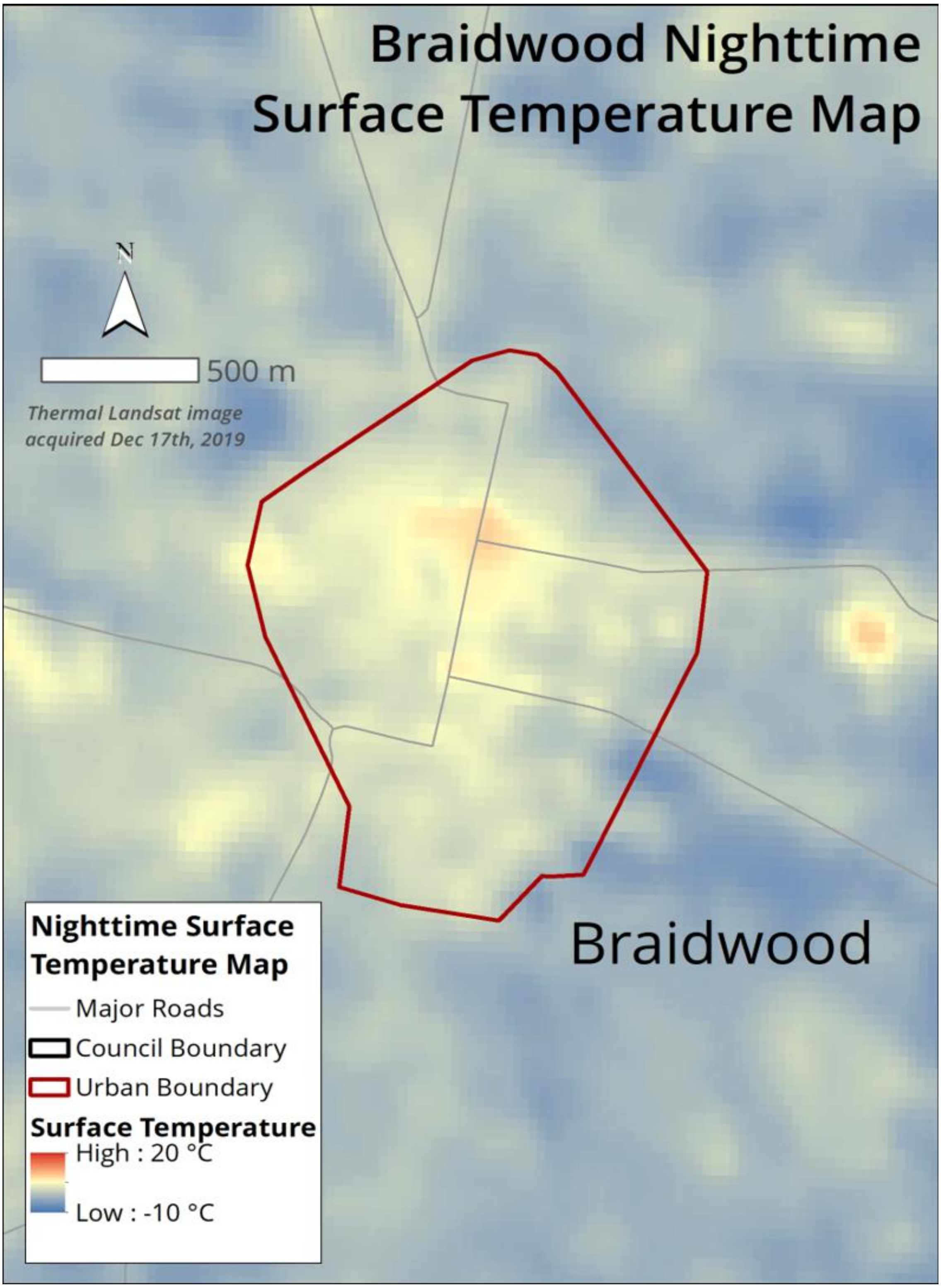

Figure 17. Braidwood Nighttime Surface Temperature Map.

In the cold day map, Braidwood displays very cool temperatures across most of its area with warm bands along the south and a few isolated warmer spots over a school sports field and others areas (Figure 18). Due to the smaller size of these warm spots, the underlying driver of this heat is not clear. Braidwood had the second warmest temperatures of any urban area in the cold day data but still measured 0.54 °C cooler than the Council average (Figure 2).

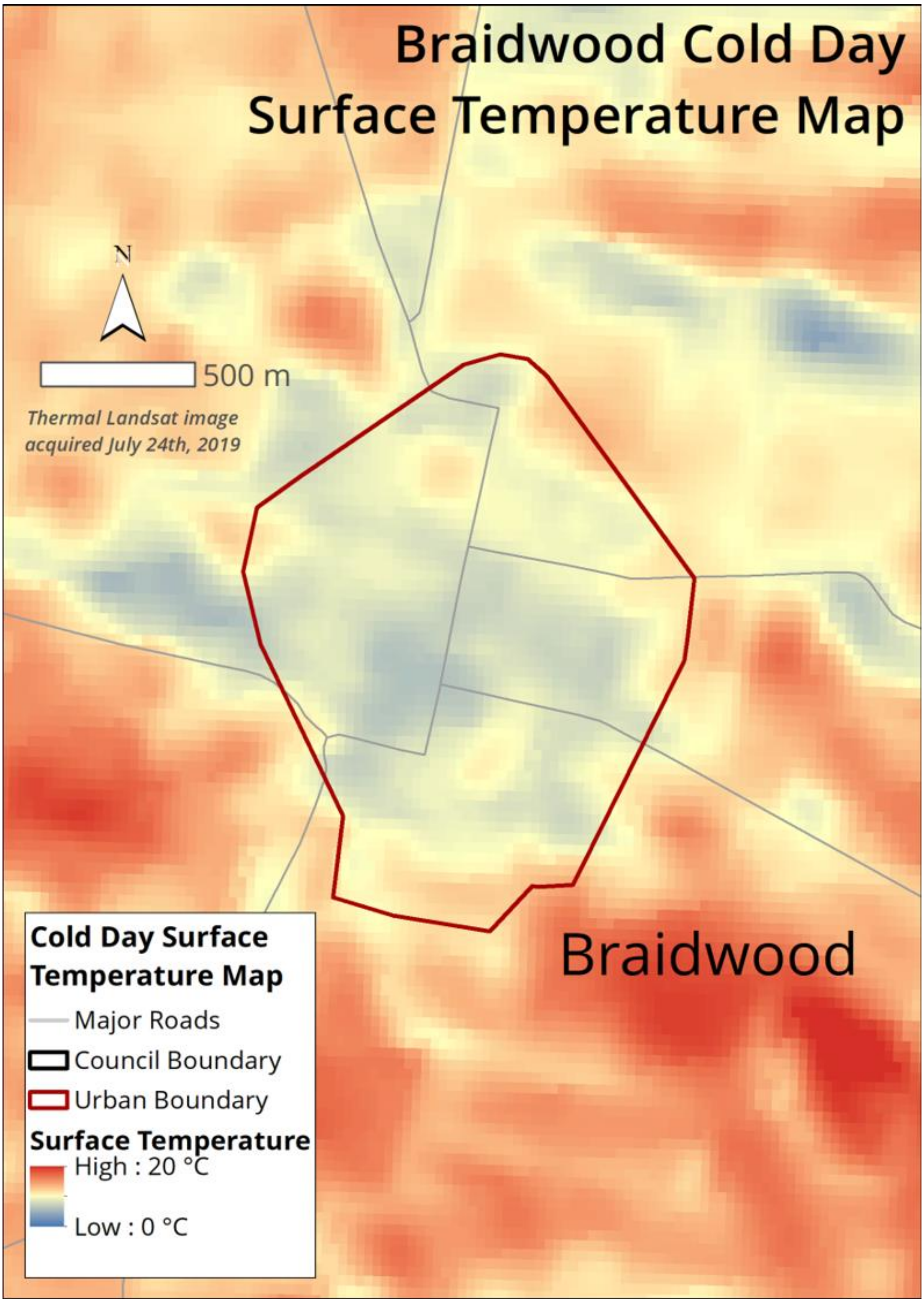

Figure 18. Braidwood Cold Day Surface Temperature Map.

Braidwood had the least area under an urban heat island (9.56%) and was the only urban area with no severe urban heat islands (Figure 19). The small urban heat islands that do exist fall along the central north-south corridor just west of Wallace Street, and in the far east corresponding to the high-density residential development.

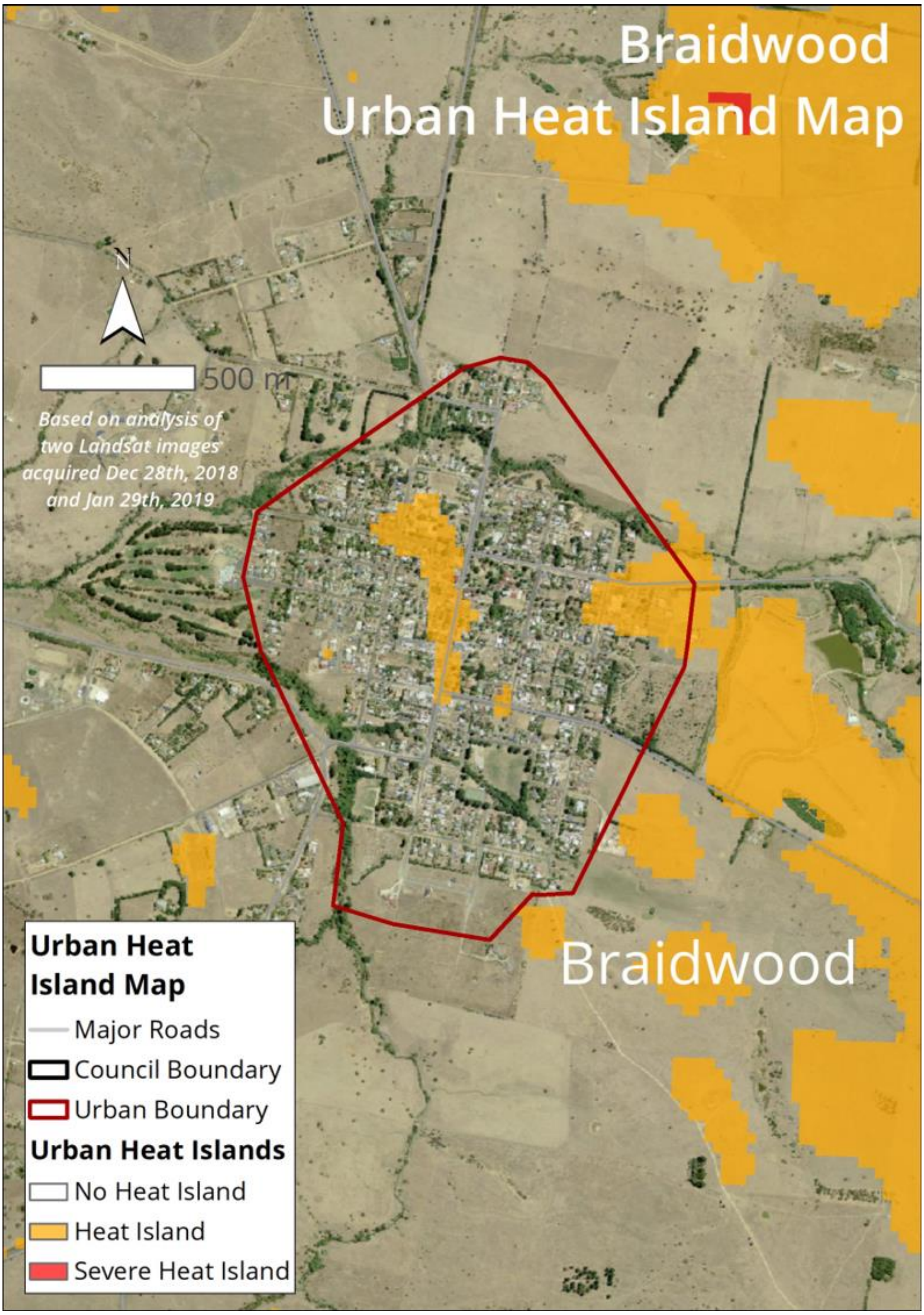

Figure 19. Braidwood Urban Heat Island Map.

4 Mitigating Urban Heat

As expected from previous studies, the cooling effect of vegetation and waterways was evident in the QPRC region, with increased heat occurring in areas with more built surfaces and less irrigated vegetation and open water areas. For example, some of the coolest locations coincide with the Tallaganda National Park, the Queanbeyan River, the vegetated areas around Mount Jerrabomberra, and the well-irrigated Queanbeyan Golf Club.

One anomaly was observed in the Region in the nighttime mapping, where a very warm area in the south-east could not be readily explained by land use. The area aligns with cleared paddocks on the eastern aspect slopes of the Great Dividing Range around Cooranbene Mountain area. One potential explanation could include a combination of large expanses of non-irrigated grass on the sheltered side of the mountain range, which may cause a heat trap during the day that is most comparatively evident at night. This anomaly though warrants further investigation.

4.1 Priority areas for heat mitigation

At a whole of Council scale, Googong and Queanbeyan were found to be the hottest urban centres and so should be priority areas for heat mitigation and further detailed investigation.

More localised priority areas for heat mitigation are listed below. Note though that the scale of imagery assessed in this project limited analysis of heat to general patterns, such as large features like shopping centres, whereas the influence of smaller features cannot be reliably assessed:

- Googong (whole area)
- Queanbeyan
    - Riverside Plaza;
    - some high density residential areas south of Ellerton Drive;
    - Queanbeyan East
    - Crestwood
    - Queanbeyan West
    - some of the high density residential areas in Karabar
    - Jerrabomberra
- Bungendore:
    - north-east corner, east of Tarago Road and north of McMahon Drive
    - south-east areas
    - residential area between Ellendon Street and Truckling Yard Lane along Finch Street
- Braidwood
    - far east of the suburbs, south of Wilson Street/Little River Road and east of Monkittee Street (appears to align with the hospital a new high-density residential development with minimal green infrastructure)
    - Central north-south residential corridor just west of Wallace Street
    - Intersection of Lascelles and Elrington Streets

4.2 Mitigating urban heat and future directions

4.2.1 Greening cooling mechanisms

Increasing greening is a key mechanism for mitigating urban heat. The cooling effects of irrigated, healthy growing vegetation is widely understood and accepted. Trees in particular offer the best cooling outcomes as they cool via direct shading as well as evapotranspiration[4]. Trees and other green spaces must be prioritised and viewed as critical urban infrastructure. However, there are numerous approaches and application for increasing greening. The choice of approach/es is highly context specific and will be influenced by factors such as: the driver of heat, the physical and social barriers and opportunities for applying mitigation approaches, and resource availability. The following provides a high-level summary of urban greening approaches that should be considered by Council to help mitigate their priority heat islands.

Increase canopy cover

By far the urban greening mechanism currently receiving the highest focus globally, planting and protecting trees to increase canopy cover offers a range of environmental, social, and economic benefits (e.g. Heart Foundation 2013; Ulmer et al. 2016). However, in planning for increased canopy, it is important to have a clear understanding of where and to what extent the total urban forest cover can be increased, including the total available plantable space on public and private land, the spread of tree canopy over the public and private land, the number of trees to be planted to achieve a target canopy, and the resources required to achieve this. To maximise the cooling benefits of trees, they should be located to shade existing impervious surfaces, such as street trees located to shade roads and footpath surfaces and shade buildings.

Green walls and roofs

This is becoming an increasingly popular mechanism in urban areas worldwide, both as a way to complement tree planting actions, and also to provide cooling benefits where it is not feasible to plant a tree. A key benefit of green walls and roofs is that they can be applied to new developments as well as be retrofitted to existing structures. Innovative applications of green walls and roofs are starting to emerge, such as vertical gardens established on transport flyover support pillars, green roofs supporting edible gardens and bee populations, and internal green walls being used to help regulate internal thermal environments (e.g. Al-Kayiem et al. 2020; Nugroho 2020; Hao & Lin 2019)

Increase irrigation of open spaces

Dry grass or bare ground can result in major heat islands, as demonstrated by the results of this project. Maintaining such areas as green cover will be an important future strategy, especially in areas where tree planting is not practical or feasible. Maintaining or expanding areas of green cover should also consider how this can be done so as to support complementary Council objectives relating to, for example, biodiversity.

Revitalising disused infrastructure

Rethinking derelict spaces and disused infrastructure can provide substantial cooling benefits, as well as revitalising areas for community benefit. Examples from other cities include: Madrid's ***Madrid + Natural***[5], Melbourne's ***Green Your Laneway***[6], NYC's ***The High Line***[7], and Paris' ***Coulée verte René-Dumont*** (or ***Promenade Plantée***)[8].

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[4] Evapotranspiration is the sum of evaporation (i.e. transformation of soil and surface water to water vapor) and transpiration (i.e. water vapor emission from plant surfaces, especially leaves, during photosynthesis). The rate of evapotranspiration is influenced by factors such as: wind, air temperature, humidity, and water availability.

[5] https://www.arup.com/perspectives/publications/research/section/madrid-and-natural

[6] https://participate.melbourne.vic.gov.au/greenlaneways

[7] https://www.thehighline.org/

[8] https://www.paris.fr/equipements/coulee-verte-rene-dumont-ex-promenade-plantee-1772

4.2.2 Non-greening cooling mechanisms

To help maximise cooling benefits, greening actions should be complemented by non-greening cooling mechanisms. Examples of such mechanisms include:

Roof and pavement colour

Lighter coloured surfaces reflect, rather than absorb heat, leading to overall cooler areas during the day and night. Where possible, built surfaces such as roofs and pavements should be lighter, rather than darker, in colour. This can be achieved through material selections during new developments, but existing roofs and pavements can also be readily lightened by applying specifically designed cool coating products, such as Cool Seal. Whilst a seemingly simple solution, research has shown that the impacts can be significant. Research by NASA, for example, suggested that on a hot New York summer day, white roofs can be up to 23 degrees cooler than back roofs (Gaffin et al. 2012). Similarly, initial findings from Los Angeles indicate that converting traditional black roads to white by applying a cool coating can create local cooling of between 6-13 degrees Celsius

Materials selection

In new developments especially, the selection of materials that will encourage cooler environments is recommended. For example, permeable paving (e.g. Ferguson 2018) is an increasingly popular selection in urban developments to help cool the environment, by allowing rainfall to permeate the ground on which it falls, rather than runoff into stormwater systems as happens with traditional non-permeable surfaces. Permeable paving has the added benefit of facilitating water access to nearby plantings leading to healthy plants and improved environmental cooling.

Water

Water has long been used as a way to cool cities and is one of the reasons why trees provide such good cooling benefits (i.e. due to evapotranspiration from its leaves). Installing water features such ponds, fountains, pools, sprinklers, and misting systems can significantly cool urban environments, especially when combined with other cooling mechanisms. For example, studies conducted in western Sydney showed that temperature were up to 10 degrees Celsius cooler adjacent to water features, and further that the combined effect of water features and cool coatings can reduce cooling needs by 29-43% leading to an overall lower average air temperature of 1.5 degrees Celsius (Sydney Water Corporation 2017).

Urban design

For new developments, and ongoing developments, consideration of the impacts of urban design on airflow and urban heat is important. Planning developments that actively facilitate air flow and prevent heat being trapped can help to mitigate the creation of heat islands. Further, designs that provide shading of impervious surfaces can further contribute to cooling the urban environment and should be considered where shading by trees is not a feasible option.

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