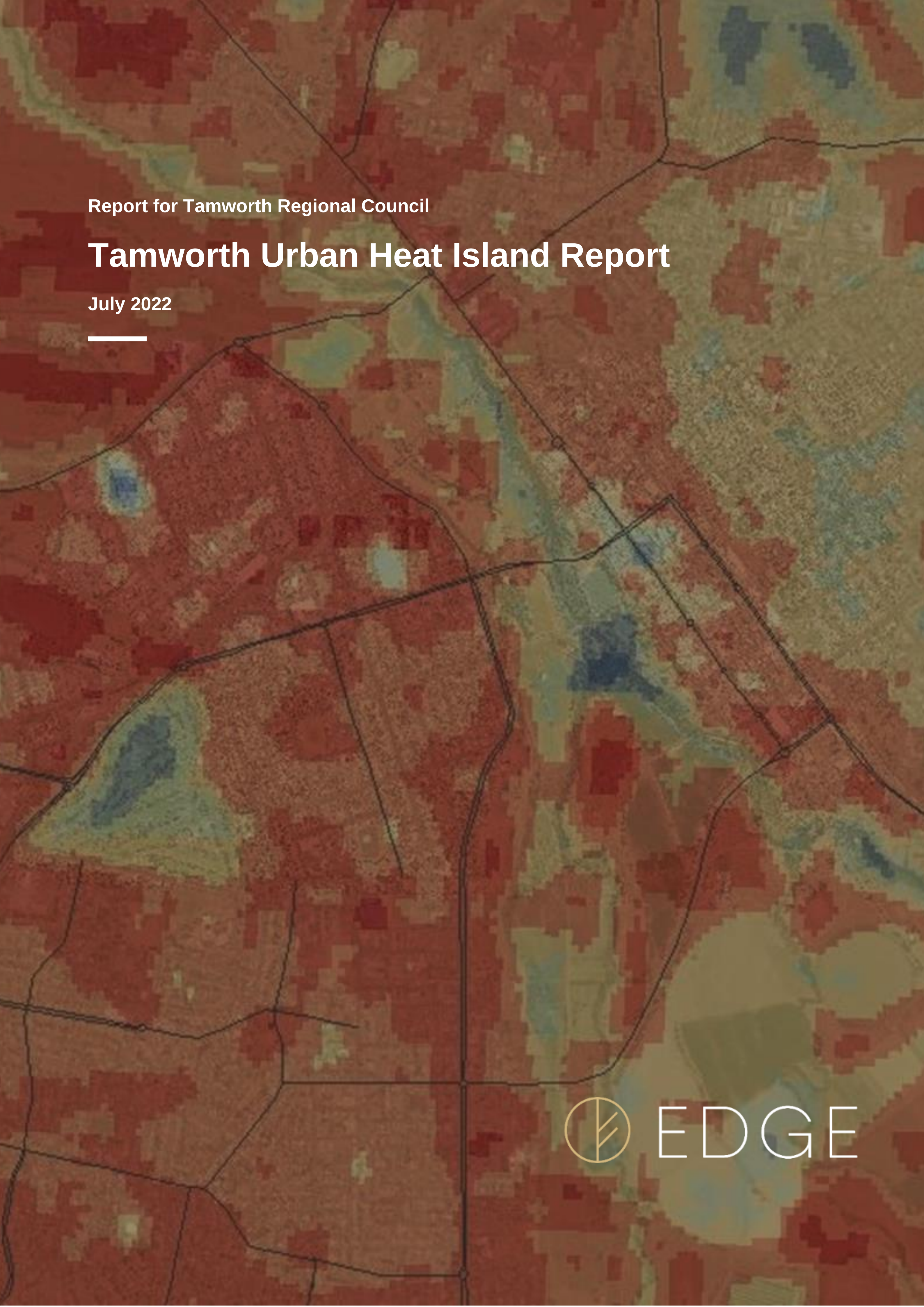

Report for Tamworth Regional Council

Tamworth Urban Heat Island Report

July 2022

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Acknowledgement of Country

We acknowledge the Traditional Custodians of the lands on which we live and work and their continuing connection to Country. We pay respects to their elders past and present and extend that respect to all Aboriginal and Torres Strait Islander peoples.

Notice of Adoption

The Tamworth Urban Heat Island Report was adopted by Tamworth Regional Council at the Ordinary meeting of Council on 27 September 2022.

Revision	Revision Details	Author	Approved by	Date Approved
V1.1	Draft v1	JVB	JG	16 June 2022
V1.2	Draft v1	JVB, JG	JG	20 June 2022
V1.3	Final edits	JVB, JG	JG	12 July 2022
V1.4	Final edits	JVB, JG	JG	21 July 2022

Executive Summary

Key Findings

- The Tamworth study area is located in a daytime urban heat island measuring 2.54°C warmer than the baseline temperature, which although classified as a heat island (i.e. >2°C above baseline) is not considered a severe urban heat island (i.e. >4°C above baseline).
- The Tamworth study area also experiences a night-time urban heat island, measuring 2.03°C warmer than the baseline temperature.
- The Bridge Street Precinct experiences a stronger heat island effect, measuring 1.3°C warmer than the CBD Precinct.
- The hottest areas are found within the Bridge Street Precinct, in the residential areas near the Tamworth Shopping World and the adjoining railroad corridor.
- The coolest areas are found in:
  - CBD Precinct - along the tree-lined Peel Street corridor;
  - Along the Peel River; and
  - Bridge Street Precinct - directly over Tamworth Shopping World.
- Residential areas, barren ground, and exposed bitumen are generally the hottest surfaces in the study area.
- Vegetated areas, predominately white roofed areas, and water-adjacent areas are generally the coolest surfaces in the study area.
- Water bodies, such as the Peel River, provide cooling during the day but are a relatively warm surface during night-time on account of high thermal inertia and slowly releasing heat throughout the night.
- In times of drought, dry vegetation becomes a very hot surface. During dry times, baseline temperatures of native vegetation increase and can produce a perceived decrease in relative urban heat.

Mitigating Urban Heat: Cooling Recommendations

Greening mechanisms

1. **Increase tree canopy cover**

   Trees should be located to shade existing impervious surfaces, oriented to provide shading during the hottest parts of the day, and along streets to provide shading of road and footpath surfaces.

2. **Non-tree ground plantings**

   Non-tree plantings (e.g. shrubs and grasses) are important considerations where it is not feasible to plant a tree. Alternatively, non-tree plantings combined with tree plantings can have substantial benefits to cooling, aesthetics, stormwater management, and biodiversity.

3. **Increase irrigation of open spaces**

   Dry grass or bare ground can result in major heat islands. Maintaining such areas as irrigated, healthy growing green cover will be an important future strategy, especially in areas where tree planting is not practical or feasible.

4. **Green walls and roofs**

   Green walls and roofs can complement tree planting actions and provide cooling benefits where it is not feasible to plant a tree. Such green infrastructure can be applied to new developments and also retrofitted to existing structures.

5. **Revitalising disused infrastructure and vacant lots**

   Derelict spaces and disused infrastructure, such as unimproved lots, spaces beside railway corridors, and abandoned buildings, can provide substantial cooling benefits if revitalised for greening purposes. As well as cooling benefits, revitalising such areas can also provide benefits for community and biodiversity.

Non- greening mechanisms

6. **Lighter 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.

7. **Materials selection**

   The selection of material will encourage cooler environments. This is especially important in new developments. For example, permeable paving allows rainfall to permeate the ground and facilitates water access to nearby plantings, leading to healthy plants and improved environment cooling. Materials that should actively be avoided include unshaded rubber soft fall surfaces, such as those commonly used in playgrounds; these materials can be deceptively hot.

8. **Water**

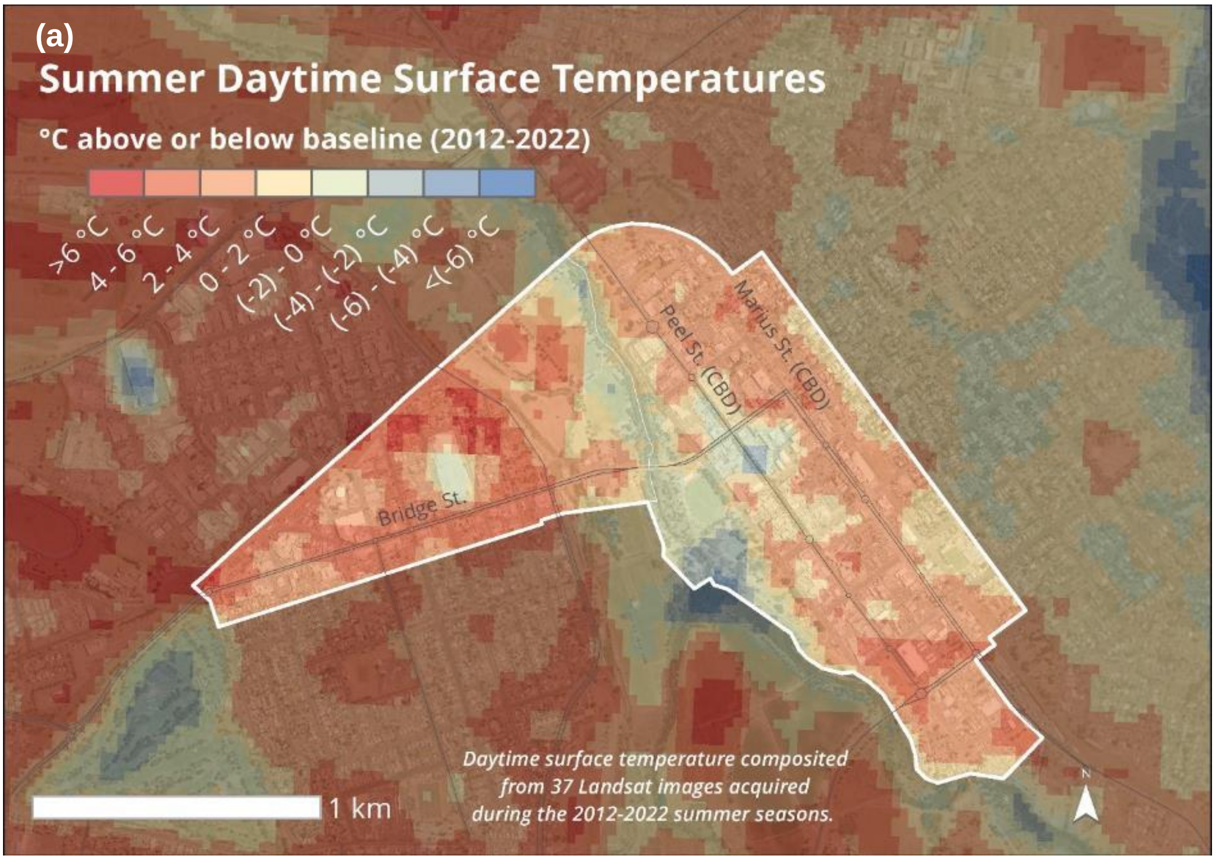
   Installing water features such ponds, fountains, pools, sprinklers, and misting systems can significantly cool urban environments, especially when combined with other cooling mechanisms. For example, studies conducted in western Sydney showed that temperatures were up to 10°C cooler adjacent to water features, and the combined effect of water features and cool coatings can reduce cooling needs by 29-43%.

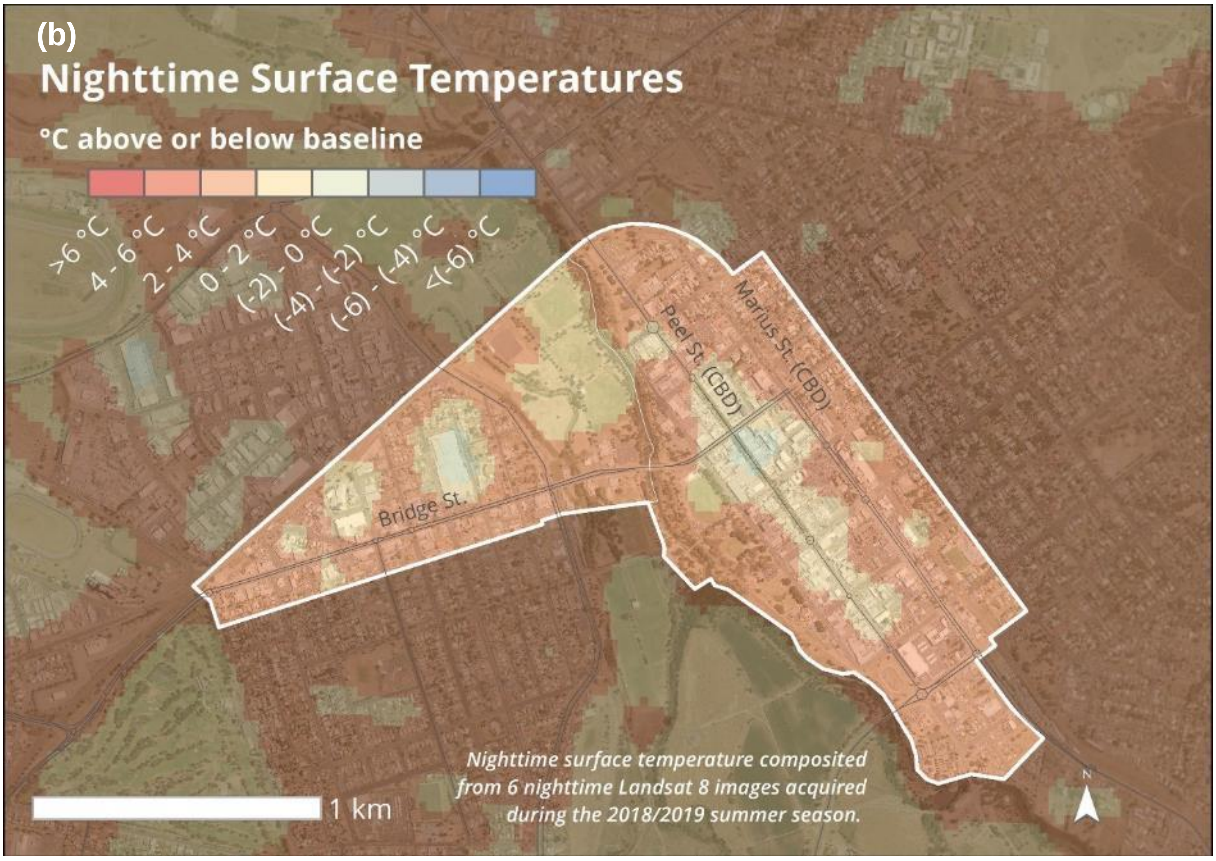
9. **Urban design**

   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.

10. **Water sensitive urban design (WSUD)**

    WSUD treatments can provide direct and indirect cooling by capturing, storing, and distributing water where it falls, rather than diverting it directly to waterways. WSUD can also allow for increased success of plantings by providing a supplementary water resource and can also directly involve plantings (e.g. wetlands) which help to increase overall green cover and local cooling.





Urban heat maps for Tamworth study area showing (a) daytime heat and (b) nighttime heat.

Contents

1 Introduction

1.1 Context

Extreme heat causes more mortality than any other natural hazard and extreme heat events are likely to increase in coming decades (Coates, et al., 2014; Vicedo-Cabrera, et al., 2021). In response, local councils around Australia have invested in understanding the location and severity of urban heat islands (UHIs) and the land use features that influence their development. UHIs represent parts of the urban landscape where heat accumulates to a greater extent than other areas. The conversion of green space to built 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, economy, and environment. The presence of urban heat islands will be further exacerbated by climate change induced temperature rises and continued urban expansion and in-fill development.

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 and subsequent mitigation actions.

1.2 Objectives

Tamworth Urban Heat Island project aimed to:

- Map surface daytime and night-time tempertaures during 2012-2022 to understand the spatial patterns and trends of urban heat in the Tamworth inner urban area;
- Inform land use and population planning, urban design and built form, place making and infrastucture strategies
- Increase resilience to a changing climate, within the context of population growth, land use decision-making, place making and increasing urban development.

The findings from the Tamworth Urban Heat Island Report will contribute to the review of Council’s Local Environment Plan. The Report will also contribute to the implemention of the following strategic work:

- Tamworth Regional Blueprint 100[1];
- Transport strategy;
- Public domain planning; and
- Place activation and night-time economy.

1.3 Study area

Tamworth Regional Council identified two areas of interest: CBD Precinct and Bridge Street Precinct (Figure 1). All results are focused specifically on these two precincts with precinct-level results referring explicitly to either precinct, and overall results calculated using the combined boundaries of these two precincts.

[1] https://www.tamworth.nsw.gov.au/about/policies-plans-and-regulations/blueprint-100

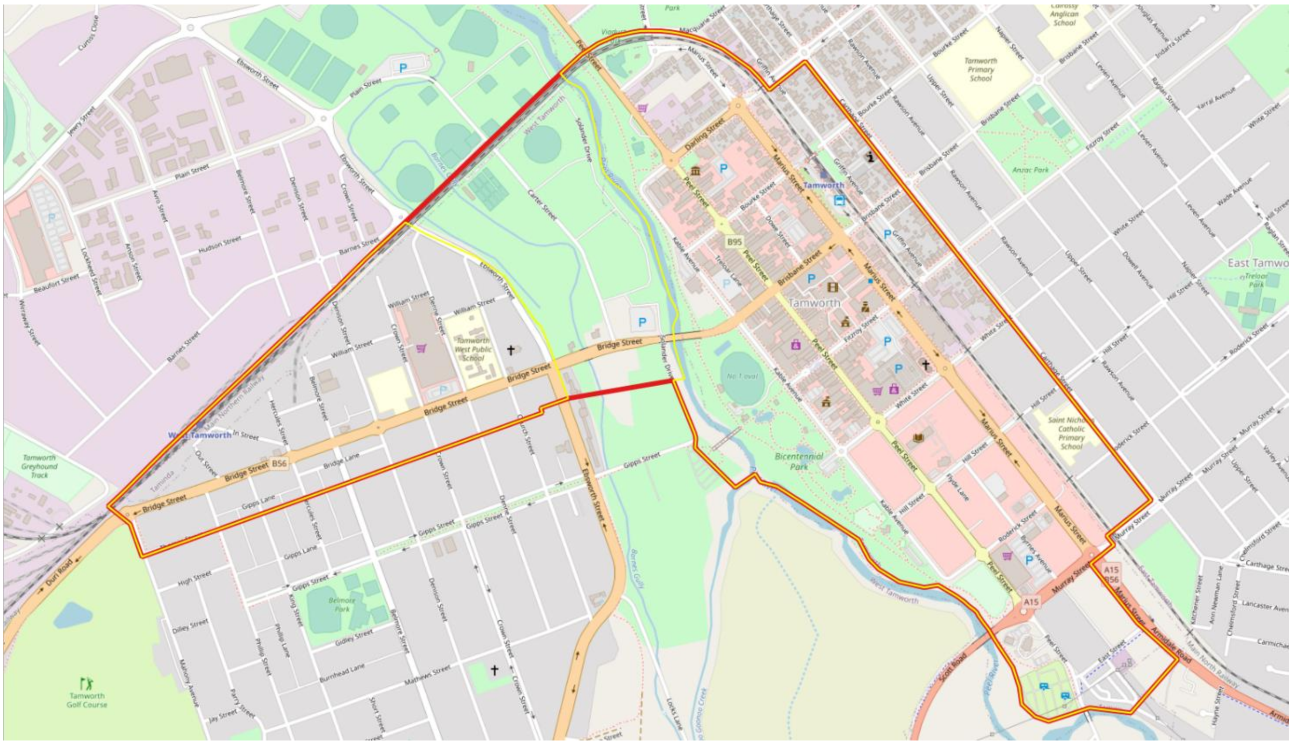


Figure 1. Study area (red outline) encapsulating CBD precinct east of the river and Bridge Street precinct west of the river (yellow outlines).

2 Approach and Method

This study assessed the distribution and trends of urban heat by measuring daytime and night-time surface temperatures over the last decade (2012-2022) across two adjacent precincts: CBD and Bridge Street (Figure 1). Using satellite data, clear and hot summertime thermal images were collected over the last decade to provide a robust understanding of daytime heat islands. Similarly, clear and hot night-time thermal images were collected during the 2019 summer season[2] to provide a robust understanding of night-time heat islands. The composited thermal datasets were analysed to assess the distribution of heat islands, and localised hot and cool areas within those precincts, as well as to explore trends in urban heat over time.

The results of this study are intended to identify general heat islands with limited localised insights due to the scale of the study area and the resolution of satellite data being used. To explore the thermal patterns over the study area, this report utilises the following data and analyses:

- a daytime satellite surface temperature dataset composited from 2012-2022 thermal images, to provide direct assessment of daytime surface temperature patterns and magnitudes;
- a night-time satellite surface temperature dataset composited from 2019 thermal images, to provide direct assessment of night-time surface temperature patterns and magnitudes;
- two daytime satellite surface temperature datasets composited from: (1) 2012-2017; and (2) 2018-2022 thermal images, to provide an assessment of the surface temperature change over time;

To understand the patterns of urban heat under during extreme heat events, a series of three land surface temperature maps were generated. These maps represent relative surface temperatures in degrees Celsius (ºC). Surface temperature, or skin temperature, measures 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 Data acquisition

Land surface temperature datasets were acquired from the Landsat satellite constellation: platforms 7, 8, and 9. Landsat 8 provided data coverage for most of the time period of interest, with Landsat 9 adding additional coverage since its launch in 2021, and Landsat 7 providing supplemental data preceeding the launch of Landsat 8 in 2013. Landsat data provides 30 metre by 30 metre resolution (100 m resampled to 30 m) thermal data. The freely available Landsat data was post-processed using geospatial software (Erdas Imagine, ArcGIS, and 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 and over time. 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. Futhermore, daytime Landsat overpass over the Tamworth region occurs around 11:50 am, generally one to two hours before peak temperautre and has a 16 day revisit cycle capturing only six to eight images during each summer season and adjacement months (defined as November – March, inclusive for this study).

Urban heat assessments require warm, clear, and calm weather conditions to sufficiently resolve thermal patterns in the urban landscape. The Tamworth region experiences many such days during the summer season allowing for numerous suitable dataset captures during the study time period. Specifically, from the ten most recent summer seasons, 37 suitable datasets were identifed that corresponded to peak air temperatures above 25°C as observed at the Tamworth Airport BOM station. Night-time data was more scarce as acquisitions only occur by researcher request. As such, only 6 images were suitable, all collected during the 2019 summer season.

[2] 2019 imagery was the only suitable imagery available during the last decade.

In addition to meeting hot and clear criteria, haze from bushfire smoke also complicated data selection as light haze is often transparent enough to pass image quality cloud-filters but is reflective enough to alter the signal received at the satellite sensor. As part of the data selection process, scenes believed to be affected by haze were also removed.

2.2 Analysis

All daytime thermal datasets were processed into relative surface temperatures (°C above or below baseline temperatures) and aggregated to provide three composite thermal maps:

1. 10-year: 2012-2022;
2. 5-year: 2012-2017; and
3. 5-year: 2018-2022.

All night-time thermal datasets were processed into relative surface temperatures (°C above or below baseline temperatures) and aggregated to provide a single composite thermal map for the 2019-2020 summer season.

From these datasets, the average relative surface temperature value was calculated for the two precincts of interest and the combined area (both precincts) as a whole, as defined by council-provided boundary datasets.

Satellite data processing

Landsat Satellite data was downloaded from the Earth Explorer website[3]. These data were processed according to best practices established in the Landsat Users Handbooks (7, 8, and 9) to produce land surface temperature datasets in absolute degrees Celsius. To account for variations in meteorological conditions from day-to-day and year-to-year, absolute temperature data were converted into relative temperature data, by subtracting a baseline temperature from the absolute temperature. A baseline temperature is the estimated *natural* temperature that would be expected absent of anthropocentric development. Heat islands, therefore, are defined as areas of excess heat accumulation above the baseline (natural) temperature.

The baseline temperature was established within each Landsat scene using the method developed by CSIRO (Devereux & Caccetta, 2017) where nearby areas of native vegetation are used to represent the natural baseline temperature. Native vegetation areas nearby the study region were determined using the National Vegetation Information System[4] (NVIS) and the baseline temperature was calculated as the mean temperature for all native vegetation areas within the Landsat image scene. This baseline temperature was subtracted from the absolute temperatures in the surface temperature map to provide a relative temperature value for each 30 x 30 m area, presented as degrees Celsius above or below baseline temperature.

To calculate the 10-year and 5-year surface temperature maps, all relative surface temperature maps from a given summer season were averaged together to generate an annual relative surface heat map representing a typical hot day for that year. These yearly averages were then used as the input in calculating the 10-year, and the 5-year maps, thereby accounting for some years having more data captures than others and to ensure each year had equal influence on the aggregated heat maps.

2.3 Study Limitations

Satellite-acquired thermal data is highly useful for identifying difference in thermal performance at landscape scales. However, the coarseness of this data means that attributing specific warming or cooling values to specific features below the resolution of the data (100m x 100m) is not appropriate. All surface temperature values represent the aggregated surface temperature of all surfaces within an individual pixel, such that the values of each pixel reflect the surface temperature of all features within the 100m x 100m area making it difficult to discern which surface is driving a particular heat value.

[3] https://earthexplorer.usgs.gov/

[4] All NVIS defined areas except those defined as *cleared, non-native vegetation, buildings and, unknown/no data*.

As described in section 3.1.1. the baseline temperature is susceptible to changing climatological conditions, namely precipitation. While efforts have been made to account for these influences, the imprecision of baseline temperature assessments induces some uncertainty in single timepoint assessments. The use of multiple timepoints (37 timepoints in the 10-year map) minimises this uncertainty.

This study provides an illustrative examination of broad patterns of urban surface heat. Further analyses of the areas identified as heat islands and cool islands, including higher resolution thermal data should be considered. Additionally, although surface temperature is the dominant influence on air temperature and thermal comfort, heat is transferred to humans through air in terms of thermal comfort. Impacts on liveability, health, and well-being should be explored in the context of air temperature and thermal comfort to ensure peoples experiences are best represented.

3 Tamworth Urban Heat Results

Urban heat results are presented as relative surface temperatures in terms of degrees Celsius above or below baseline temperatures, signifying the degrees of anthropocentric urban heat accumulation, known as an urban heat island effect.

3.1 Day surface temperatures

Analysis of the 10-year hot day average surface temperature map identifies the study area as measuring 2.54°C above baseline temperature (Figure 2, Table 1). This result classifies the study area as an urban heat island, defined as any area more than 2°C warmer than the natural baseline temperature, but not a severe urban heat island (which is any area warmer than 4°C above baseline temperature). Within this area, there is significant variation with some locations being up to 4°C cooler, specifically surrounding the confluence of the Peel River and Goonoo Goonoo Creek, while other locations are up to 8°C warmer, specifically within the Bridge Street Precinct over the residential areas between Denne and Church Streets, and along the railway in West Tamworth.

There is a divergence between the two precincts with the Bridge Street Precinct averaging 3.35°C above the baseline temperature, a full 1.3°C warmer than the CBD Precinct in the 10-year daytime heat map (Table 1). This difference is visible in the surface temperature map with the hottest surfaces concentrating in the western precinct while the coolest surfaces occur in the eastern precinct (Figure 2).

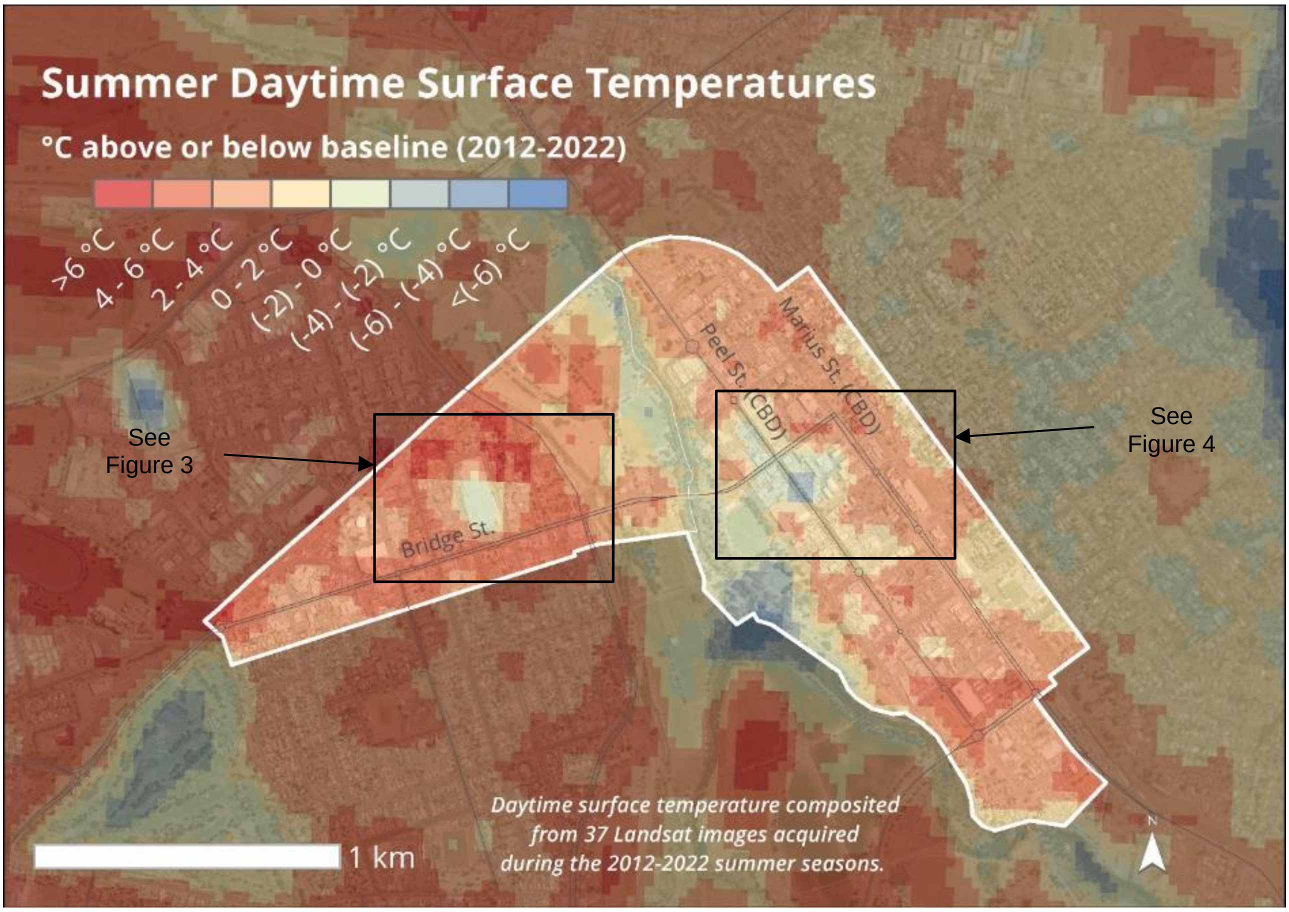


Figure 2. Ten-year daytime surface temperature map (2012-2022), with key cool spots indicated (see Figures 3 and 4).

Table 1. Relative surface temperature results.

Image	Number of scenes	Whole Study Area UHI Effect (°C)	CBD Precinct UHI Effect (°C)	Bridge Street Precinct UHI Effect (°C)	Precinct Difference (°C)
Daytime 10-Year (2012-2022)	37	**2.54**	2.05	3.35	+ 1.30
Daytime 5-Year (2012-2017)	21	**2.64**	2.19	3.38	+ 1.19
Daytime 5-Year (2018-2022)	16	**2.44**	1.91	3.32	+ 1.41
Night-time 1-year (2019)	6	**2.17**	2.25	2.03	- 0.22

Water tends to be the coolest surface within the area of interest with Peel River and its surrounds (including the Riverside Sporting Complex and Bicentennial Park). This provides a cool band through the CBD Precinct (Figure 2). Healthy green vegetation also appears to provide local cooling. Additional cooling within this area is driven by expansive white roofed buildings. These tend to be highly reflective surfaces and often measure much cooler than their surrounding areas, as illustrated by Tamworth Shopping World (Figure 3).

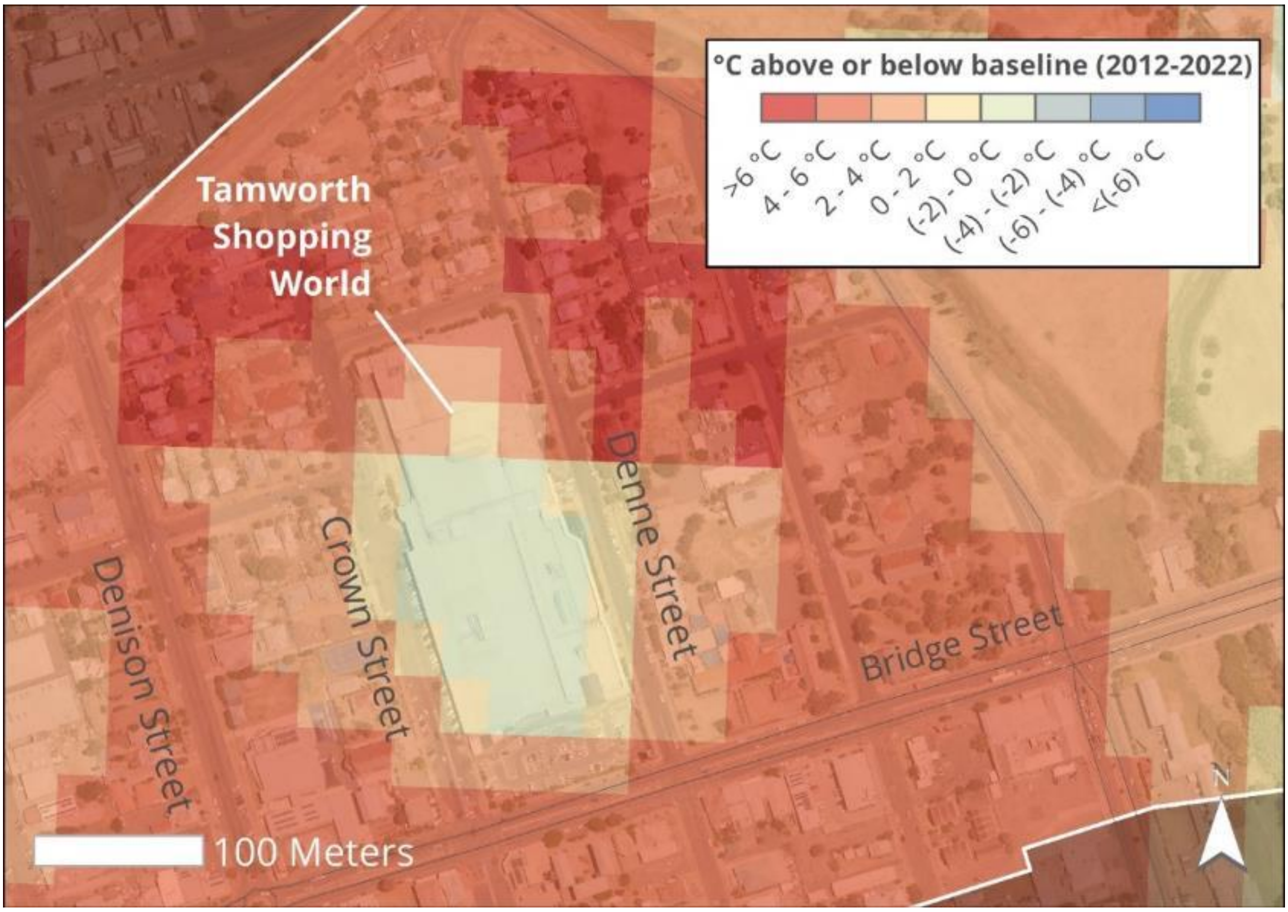


Figure 3. Cool spot around Tamworth Shopping World, Bridge Street Precinct.

These cooling forces appear to converge along Peel Street core area, between the crossroads of White and Bourke Streets (Figure 4). This area is predominately covered with white roofs and the road itself is largely obscured by numerous robust street trees forming a green tunnel through this area. As a result, nearly the entirety of Peel Street core area falls below the urban heat island threshold, with some areas measuring more than 2°C below baseline temperatures.

By contrast, Marius Street – a parallel street with large expanses of exposed bitumen, few trees, and many dark roofs – is several degrees warmer (Figure 4). Generally, barren, paved, and residential areas within the downtown area are within urban heat islands. Large swaths of bitumen, dark roofed areas, and non-irrigated vegetated areas are among the warmest surface types across the area.

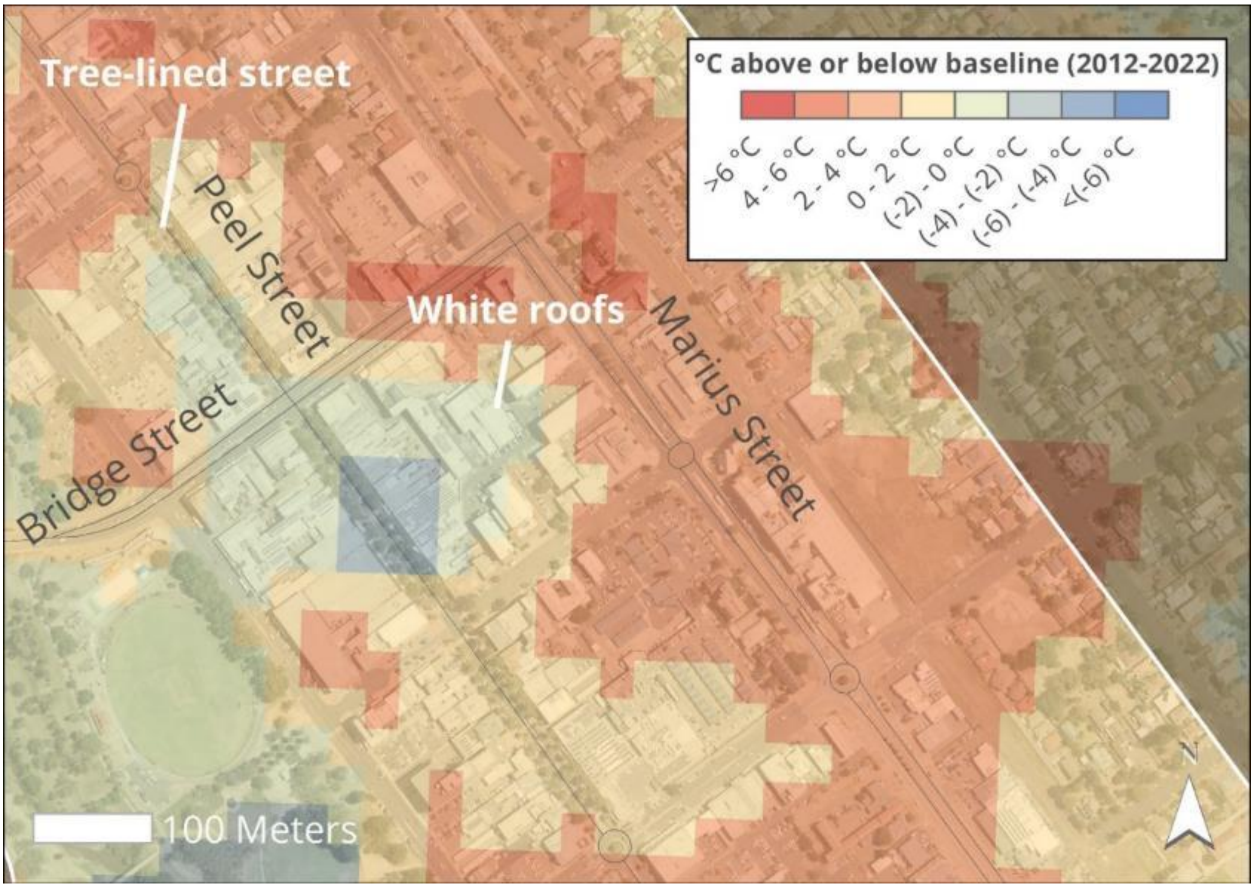


Figure 4. Cool spot along Peel Street, CBD precinct.

3.2 Night surface temperatures

Daytime heat islands are the most relatable to the way we experience heat from day-to-day; however, night-time heat islands, or elevated minimum temperatures, can have a greater impact on heat-related mortality (Laaidi, et al., 2012). The night-time surface temperature map, acquired during the 2019/2020 summer season, identifies some similar patterns to the daytime temperature maps with daytime warm areas continuing to be warm into the night (Figure 5). Similarly, the cool areas over Tamworth Shopping World, and Peel Street remain cool into the night. However, the areas along the Peel River switch from a net-cooling influence to a slight net-warming influence, a pattern documented in similar studies (Seed Consulting Services, EnDev Geographic, Monash University, 2017).

Water has a high degree of thermal inertia (or specific-heat) which means it is slow to warm but also slow to cool. Comparatively, air is very quick to lose its heat after sunset. As night-time Landsat data collection occurs around 11pm, most surfaces have released their heat whereas water has still retained most of its heat. Relative to the surrounding landscapes, water then appears to be warmer than it does during the day.

Overall, the study are remains in a heat island even during night-time conditions, measuring 2.17°C above baseline temperature (Table 1). Interestingly, the difference between the two precinct's reverses in the night-time heat map with the Bridge Street Precinct being 0.22°C cooler than the CBD Precinct, as the Peel River, which cools the CBD Precinct during the day, now warms the CBD Precinct at night. In general, the patterns of night-time heat are more evenly distributed, and variations are more muted than during the daytime heat maps.

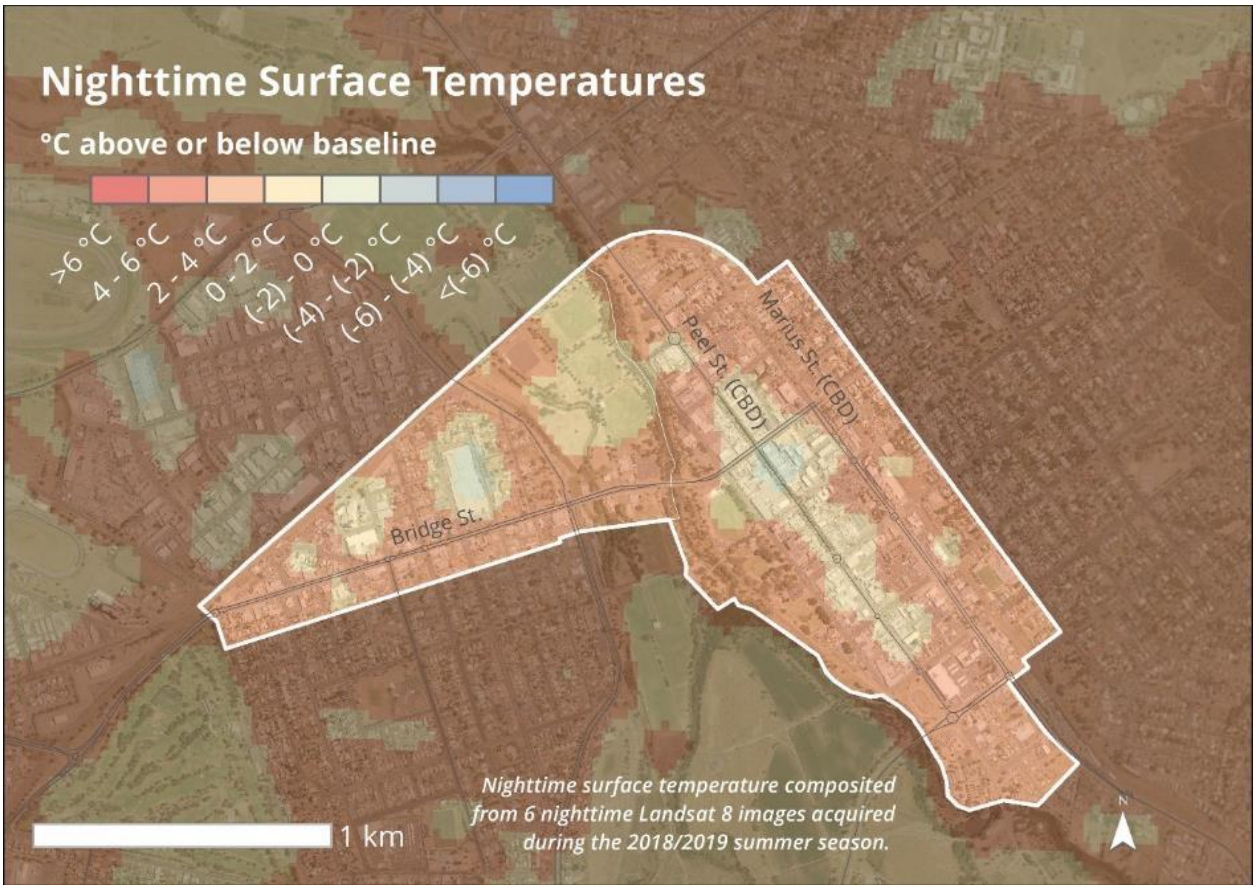


Figure 5. Night-time relative surface temperature map (2019-2020).

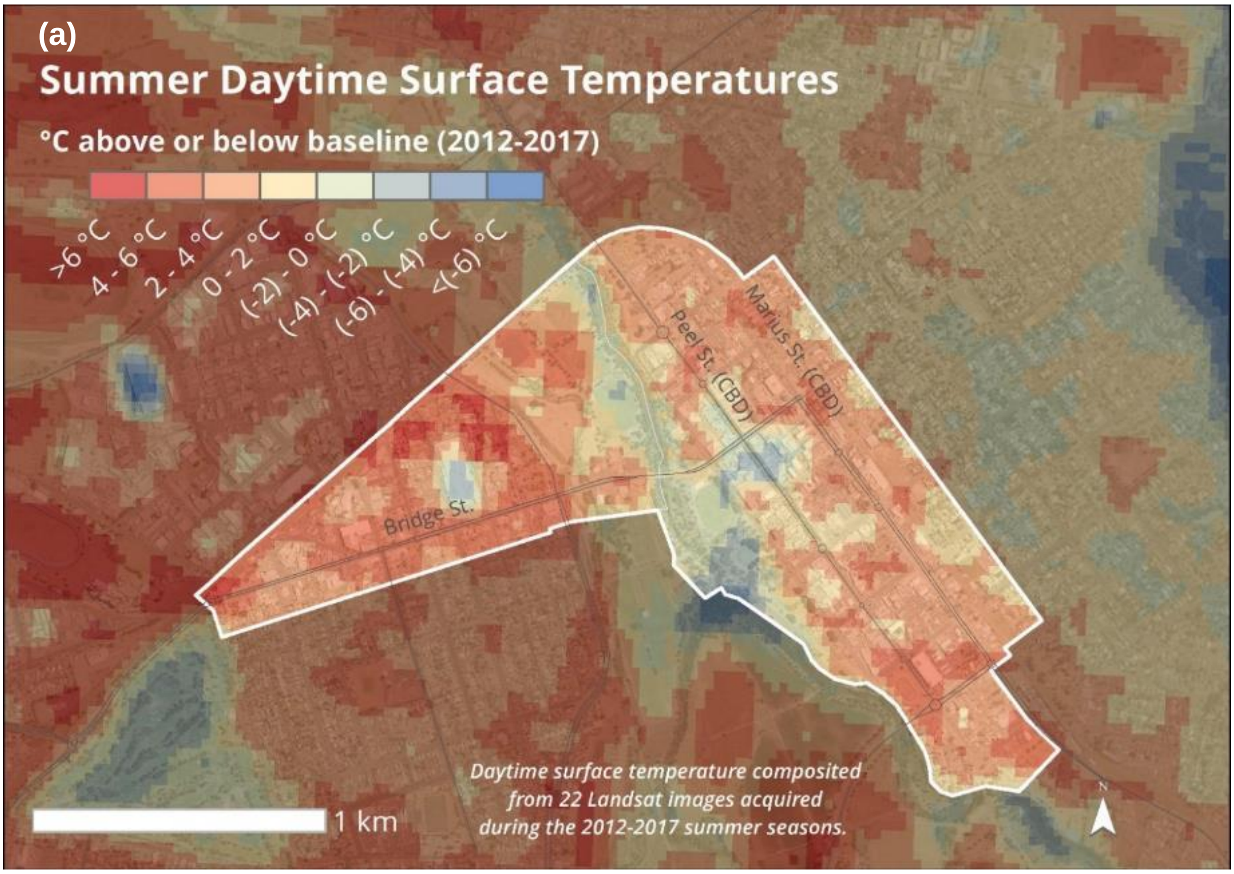
3.3 Change over time

To explore the trends in Tamworth's urban heat over time, the 10-years of satellite data were re-analysed in two 5-year increments: 2012-2017 and 2018-2022. Each of these 5-year relative surface temperature maps presents a similar, but slightly different thermal picture of Tamworth's downtown area and the two precincts. Within the 2012-2017 5-year temperature map (Figure 6a), the overall study area was located within a similar, but slightly warmer (2.64°C) urban heat island. In contrast, the Bridge Street Precinct heat island (3.35°C) was still warmer (by 1.2°C) than the CBD precinct (Table 1).

This reflects very similar conditions to those displayed in the 10-year map. The residential areas north of Tamworth Shopping World remain the hottest areas, whilst areas along Peel Street and near the rivers' confluence remain the coolest.

By contrast, the 2018-2022 5-year surface temperature map presents slightly more muted patterns of urban heat, mainly illustrated by the lessening in intensity of very cool areas (Figure 6b). Residential areas north of Tamworth Shopping World remain the hottest in the area, but the cool islands are slightly less pronounced, particularly apparent along Peel Street which lacks the deep blue areas in the 2018-2022 map. As a result, the latter time period (2018-2022) recorded a minor decrease in temperature (0.2°C cooler) than the preceding 5-year period, averaging 2.44°C above baseline temperature. This apparent cooling is in contrast to most urban heat trends across Australia and globally. Further analysis reveals this to be a product of strong seasonal precipitation anomalies during this time period, specifically in 2017-2018 and 2018-2019 summer seasons.

Non-irrigated vegetation and barren areas are one of the most thermally dynamic surface covers in the Australian landscape. Healthy vegetation reliably provides a strong cooling signal whereas dry vegetation provides a strong warming signal. This water sensitivity can create strongly divergent temperature signals dependent upon naturally occurring precipitation. The 2017-2018 and 2018-2019 summer seasons both experienced substantial drought conditions with both seasons receiving less than 50% of average summer rainfall as measured since 1992 (BOM Tamworth AWS). The drought conditions significantly raised the surface temperature of the natural vegetation areas used to establish the baseline temperatures. As a result, decreased precipitation led to increased baseline temperature, which slightly decreased apparent urban heat island magnitudes during these periods (See Annex 3 for more discussion). Overall, the slight decrease in relative urban heat island magnitude during the 2018-2022 time period is likely to be a product of precipitation anomalies, but further investigation into this relationship and effect may bare consideration for future planning decisions. Multi-year thermal assessments, as presented here, are less sensitive to the influence seasonal anomalies and therefore provide a more robust assessment of urban heat.



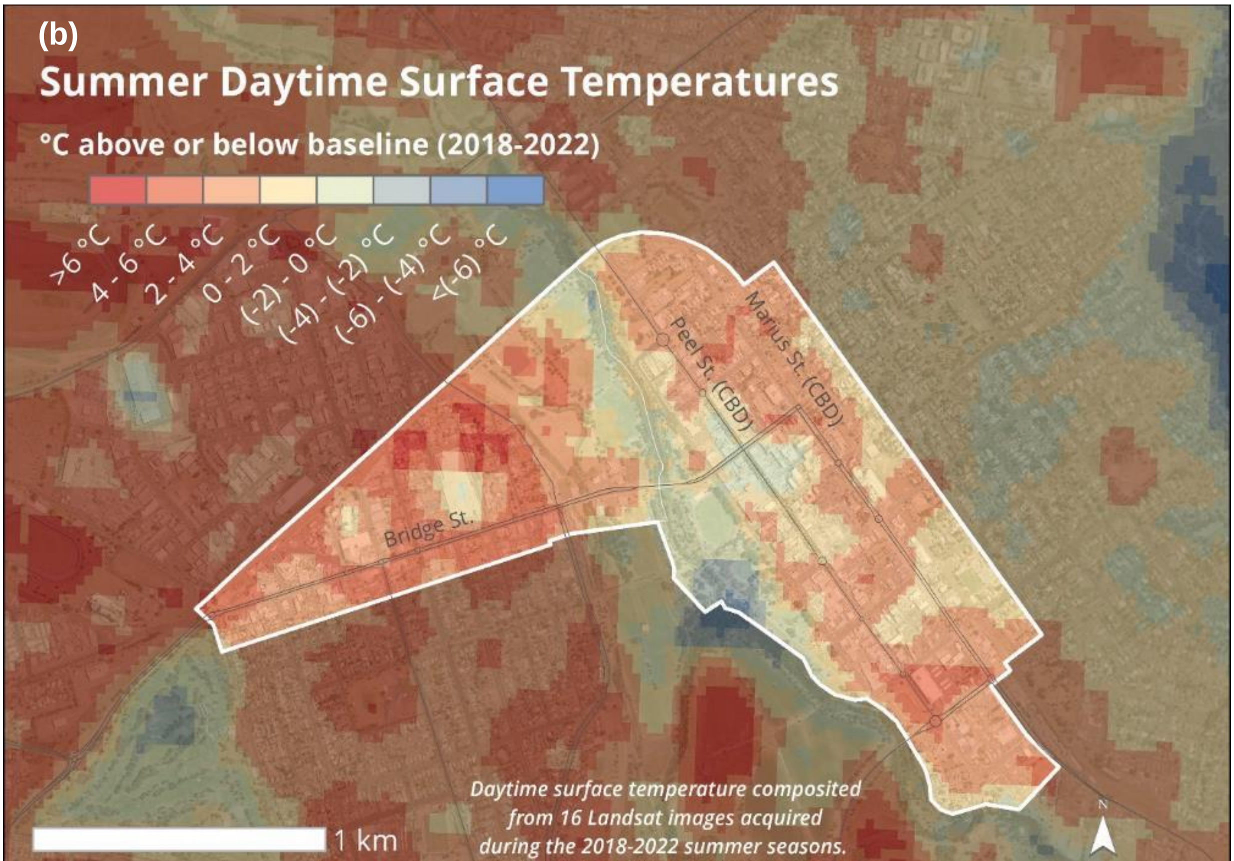


Figure 6. Multi-year averaged daytime relative surface temperature maps for (a) 2012-2017 and (b) 2018-2022.

3.4 Key findings

- The Tamworth study area is located in a daytime urban heat island measuring 2.54°C warmer than the baseline temperature, which although classified as a heat island (i.e. >2°C above baseline) it is not considered a severe urban heat island (i.e. >4°C above baseline).
- The Tamworth study area also experiences a night-time urban heat island, measuring 2.03°C warmer than the baseline temperature.
- The Bridge Street Precinct experiences a stronger heat island effect, measuring 1.3°C warmer than CBD Precinct.
- The hottest areas are found within the Bridge Street Precinct, in the residential areas near the Tamworth Shopping World and the adjoining railroad corridor.
- The coolest areas are found in:
    - CBD Precinct - along the tree-lined Peel Street corridor;
    - Along the Peel River; and
    - Bridge Street Precinct - directly over Tamworth Shopping World
- Residential areas, barren ground, and exposed bitumen are generally the hottest surfaces in the study area.
- Vegetated areas, predominately white roofed areas, and water-adjacent areas are generally the coolest surfaces in the study area.
- Water bodies, such as the Peel River, provide cooling during the day but are a relatively warm surface during night-time on account of high thermal inertia and slowly releasing heat throughout the night.
- In times of drought, dry vegetation becomes a very hot surface. During dry times, baseline temperatures of native vegetation increase and can produce a perceived decrease in relative urban heat. Multi-year thermal assessments are more robust as they are less sensitive to the influence of seasonal anomalies.

4 Mitigating Urban Heat: Cooling Recommendations

The cooling effect of vegetation and waterways was evident in the study area. The hottest landscapes were found to be residential areas, bare ground or non-irrigated vegetation, and exposed bitumen. Comparatively, vegetated and irrigated areas, shaded surfaces, white roofs, and water-adjacent areas all tend to be cooler. Although the river and vegetation provide some protection, poor design in the future could off-set these cooling benefits leading to extreme urban heat islands despite river and shade-related cooling.

Increasing tree canopy cover has many benefits. It can further cool the landscape and increase shade and thermal comfort for pedestrians (e.g. increased walkability of urban areas). Thermal comfort is a measure that considers how the body perceives heat and includes measures of humidity, solar radiation, and wind to calculate the apparent temperature. Proximity to water lowers temperature; however, trees are more effective at improving thermal comfort.

Irrigation is also a major factor in some of the cooler surfaces in the selected urban areas. Irrigation-driven cooling may not be resistant to future conditions as water availability may become an issue and may not constitute a resilient cooling option. Installation of infrastructure that will help to water-proof the region should be considered as a priority option to support increased plantings and long-term cooling (see Section 5.2).

The following sections provide greening and non-greening management considerations for Tamworth to help mitigate urban heat now and into the future. Whilst a combination of management actions will be important, the selection of cooling mechanisms for application in different contexts will best be informed through more refined heat mapping, which will enable for local-scale drivers of heat to be clearly identified and appropriate mitigation actions applied.

4.1 Greening cooling mechanisms

Increasing vegetation cover 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[5]. Trees and other green spaces must be prioritised and viewed as critical urban infrastructure. There are numerous approaches and applications for increasing greening. The choice of approach/es is highly context specific and will be influenced by factors such as: the driver/s 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 urban heat islands.

1. Increase tree canopy cover

Planting and protecting trees to grow canopy cover into the future is by far the urban greening mechanism receiving the highest global focus and action, given the myriad of environmental, social, and economic benefits provided by urban trees (Heart Foundation, 2013; Ulmer, 2016). 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 tree plantings needed 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 near buildings and oriented to provide shading during the hottest parts of the day, and along streets to provide shading of road and footpath surfaces. For example, tree-lined streets in East Adelaide were found to be more than 8°C cooler than exposed bitumen, and trees themselves were found to be 15°C cooler than artificial turf (Seed Consulting Services, EnDev Geographic, Monash University, 2017).

[5] Evapotranspiration = evaporation (i.e. transformation of soil and surface water to water vapor) + 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.

2. Non-tree ground plantings

Increasing coverage of irrigated plantings within the urban landscape will be an important consideration for mitigating urban heat. Non-tree plantings (e.g. shrubs and grasses) will be especially important considerations where it is not feasible to plant a tree. Alternatively, non-tree plantings combined with tree plantings can have substantial benefits not just to cooling, but also aesthetics, stormwater management, and biodiversity.

3. Increase irrigation of open spaces

Dry grass or bare ground can result in major heat islands. Maintaining such areas as irrigated, healthy growing 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.

4. Green walls and roofs

Green walls and roofs are an increasingly popular approach to complement tree planting actions and also provide cooling benefits where it is not feasible to plant a tree. A key benefit of such green infrastructure is that they can be applied to new developments and also 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 (Al-Kayiem, et al., 2020; Nugroho, 2020; Hao & Lin, 2019).

5. Revitalising disused infrastructure and vacant lots

Derelict spaces and disused infrastructure, such as unimproved lots, spaces beside railway corridors, and abandoned buildings, can provide substantial cooling benefits if revitalised for greening purposes. As well as cooling benefits, revitalising such areas can also provide benefits for community and biodiversity. Examples from other cities include: Madrid's *Madrid + Natural*[6], Melbourne's *Green Your Laneway*[7], NYC's *The High Line*[8], and Paris' *Coulée verte René-Dumont* (or *Promenade Plantée*)[9].

4.2 Non-greening cooling mechanisms

6. Lighter 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. NASA, for example, reported that on a hot New York summer day, white roofs can be up to 23°C cooler than black 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°C.

7. Materials selection

The selection of material will encourage cooler environments. This is especially important in new developments. For example, permeable paving 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

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

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

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

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

stormwater systems as happens with traditional non-permeable surfaces (Ferguson, 2012). Permeable paving has the added benefit of facilitating water access to nearby plantings leading to healthy plants and improved environmental cooling. Materials that should be actively avoided include, for example, unshaded rubber soft-fall surfaces, such as those commonly used in playgrounds; these materials can be deceptively hot, measuring 8°C warmer than irrigated grass (Seed Consulting Services, EnDev Geographic, Monash University, 2018).

8. 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 temperatures were up to 10°C 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°C (Sydney Water Corporation, 2017).

9. Urban design

For new and ongoing developments, it is important to consider the impacts of urban design on airflow and urban heat. 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.

10. Water sensitive urban design (WSUD)

Installation (including retrofitting) of WSUD should be considered a high priority in dry climate settlements such as Tamworth where access to, or cost of, water for plantings can be a limiting factor. Whilst some WSUD treatments would provide direct cooling in their own right (e.g. wetlands), all treatments will indirectly support cooling by capturing, storing, and distributing water where it falls, rather than diverting it directly to waterways. This would allow for increased success and financial viability of increased plantings by providing a supplementary water resource. WSUD treatments will also directly involve plantings which will help to increase overall green cover and local cooling. Treatments should also provide additional benefits such as improved quality and decreased quantity and flow rate of stormwater run-off.

WSUD treatments and associated infrastructure that may be considered for new developments, road upgrades, and retrofitting of streetscapes within Tamworth include, but are not limited to:

- rainwater gardens;
- swales;
- pervious paving;
- constructed wetlands; and
- stormwater harvesting systems.

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6 Annex A. Landsat Imagery Dates

Daytime Landsat Imagery			
Landsat Platfo	Summer Seasc	Image Date	BOM Max Daily Air Temperature (ºC)
LC09	21/22	14-2-2022	31.30
LC08	21/22	5-1-2022	34.30
LC08	20/21	3-2-2021	30.30
LC08	20/21	18-1-2021	26.80
LC08	20/21	15-11-2020	34.20
LC08	19/20	20-3-2020	31.00
LC08	19/20	17-2-2020	27.70
LC08	19/20	1-2-2020	38.60
LC08	19/20	31-12-2019	38.60
LC08	19/20	15-12-2019	36.90
LC08	19/20	13-11-2019	27.40
LC08	18/19	2-3-2019	31.80
LC08	18/19	14-2-2019	30.50
LC08	18/19	28-12-2018	36.60
LC08	18/19	10-11-2018	25.90
LC08	17/18	31-3-2018	33.00
LC08	16/17	24-2-2017	37.40
LC08	16/17	8-2-2017	34.70
LC08	16/17	7-1-2017	31.90
LC08	16/17	22-12-2016	34.00
LC08	16/17	20-11-2016	34.50
LC08	16/17	4-11-2016	27.70
LC08	15/16	25-3-2016	30.90
LC08	15/16	22-2-2016	35.30
LC08	15/16	6-2-2016	30.00
LC08	15/16	4-12-2015	30.00
LC08	15/16	18-11-2015	31.90
LC08	14/15	23-3-2015	31.20
LC08	14/15	3-2-2015	26.40
LC08	14/15	18-1-2015	33.10
LC08	13/14	31-1-2014	37.60
LC08	13/14	15-1-2014	37.90
LC08	13/14	12-11-2013	26.60
LE07	13/14	4-11-2013	27.20
LE07	12/13	4-1-2013	36.30
LE07	12/13	3-12-2012	29.00
LE07	12/13	1-11-2012	33.60

Night-time Landsat Imagery			
Landsat Platfor	Summer Seaso	Image Date	BOM Max Daily Air Temperature (ºC)
LC08	19/20	1-27-2020	34.4
LC08	19/20	1-20-2020	35.2
LC08	19/20	1-11-2020	34.3
LC08	19/20	1-4-2020	41.7
LC08	19/20	12-26-2019	36.5
LC08	19/20	12-03-2019	28.7

7 Annex B. Establishing thermal baselines in warm, arid climates

Relative surface temperatures are sensitive to baseline (natural) temperatures, with warmer baseline temperatures occasionally leading to apparent decreases in urban heat islands. This is attributable to the fact that dry, natural vegetation has a strong sensitivity to precipitation changes and corresponding vegetation health affects surface temperature via changes in transpiration and shading. During years of very low precipitation (Figure 7 - orange bars), baseline temperatures of natively vegetated areas increase (red line), creating a decrease in relative urban surface temperatures (yellow line). This affect can entirely mask the urban heat island effect (see 18/19 summer season). Longitudinal studies engaging multiple years of thermal data can provide more robust results, as well as incorporating meteorological data to ensure the timepoint in question is representative of the broader climatological conditions.

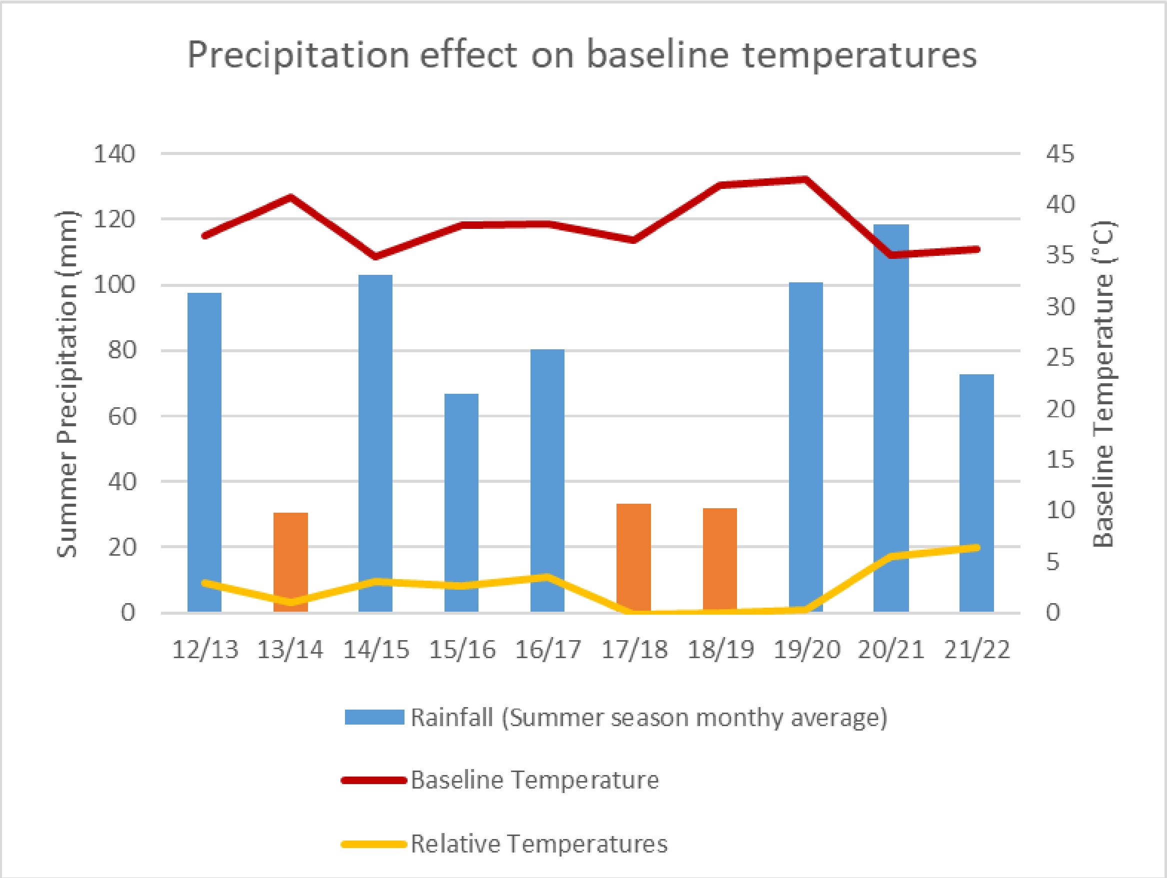

Figure 7. Relationships between precipitation anomalies, baseline temperatures, and relative urban surface temperatures.