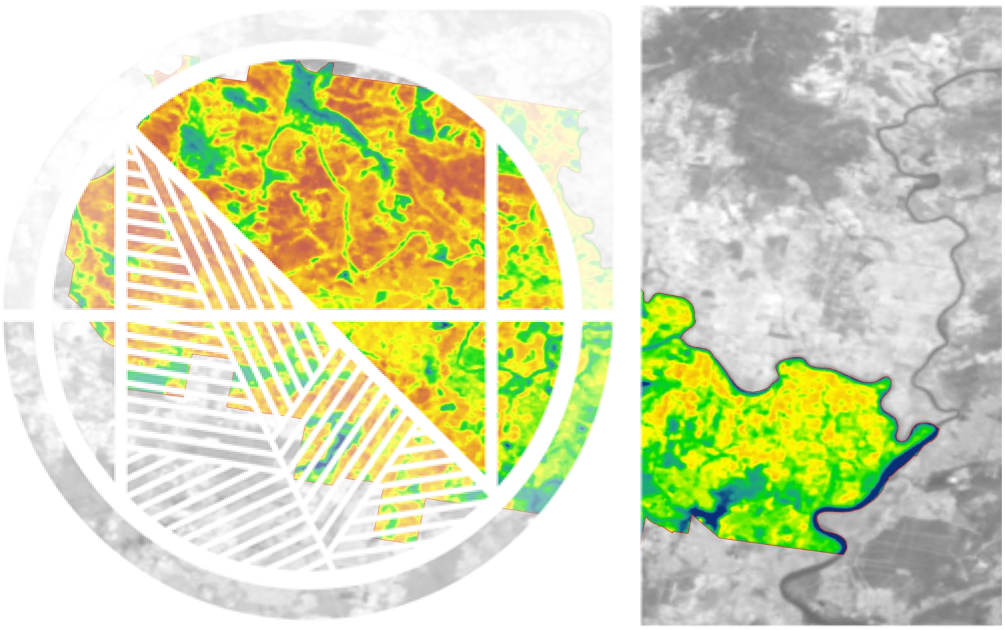
Final report

Maitland urban heat island assessment

March 2022

Project Number: 21-137



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Document verification

Project Title:	Maitland urban heat island assessment
Project Number:	21-137
Project File Name:	21-137_Maitland Urban Heat Island Assessment Report_Final.V1.0

Revision	Date	Prepared by	Reviewed by	Approved by
Draft V1.0	19/09/2021	Rebecca Sims	Christy Englezakis	Christy Englezakis
Final Draft V2.0	2/12/2021	Rebecca Sims	Christy Englezakis	Christy Englezakis
Final V1.0	15/03/2022	Rebecca Sims	Beth Kramer	Beth Kramer
	[Enter the date]			

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Acronyms and abbreviations

ABS	Australian Bureau of Statistics
AEST	Australian Eastern Standard Time
BOM	Australian Bureau of Meteorology
DAAC	Distributed Active Archive Centre
DST	Daylight Savings Time
EE	Earth Explorer
EROS	Earth Resources Observation and Science
GCP	General Community Data Packs
GIS	Geographic Information System
ha	hectares
HRPV	heat-related population vulnerability
IoT	Internet of Things
IRSD	Index of Relative Socio-economic Disadvantage
km	kilometres
LGA	local government area
LST	land surface temperature
LiDaR	Light Detection and Ranging
LEP	Local Environment Plan 2011
LZN	land zoning
m	metres
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
RGB	Red Green Blue spectral bands
SA1	Statistical Area Level 1
SEIFA	Socio-Economic Indexes for Areas
SUHI	surface urban heat island
USGS	United States Geological Survey
TIRS	thermal infrared sensor
UHI	urban heat island
ULST	urban land surface temperature

Executive summary

Background

Maitland City Council (Council) has undertaken this urban heat mapping project to identify priority suburbs within the local government area (LGA) and inform targeted initiatives to mitigate the heat island effect. These measures will integrate with the Council's development of an interconnected 'green and blue' network across the LGA, that will support improved community well-being, connectivity, biodiversity and air quality.

The 'urban heat island' (UHI) phenomenon refers to temperature differences caused by urbanisation (Taha 1997). Urban areas become significantly warmer than surrounding rural areas when there is less green cover and more hard surfaces. This happens because buildings and paved surfaces absorb and store solar radiation during the day and then release it slowly back into the environment at night. As a result, the UHI effect is typically most evident at night. Inappropriate building and street design and layout, as well as increased building density and height, can trap warm air, further reducing cooling at night thereby exacerbating heat build-up.

Heat islands can contribute to poor air quality, magnify the impacts of extreme heat events and put people's health at higher risk. Identifying hot spots within a city can help focus interventions where they are most needed during heat waves.

The primary objective of this study was to produce a baseline dataset identifying priority suburbs within the LGA for urban heat management initiatives and provide a starting point for future detailed investigation. Specifically, the investigation sought to establish a basic understanding of summer-time heat distribution across the LGA and to determine if and where a surface heat island may exist in the urban zone. Furthermore, to facilitate focus of mitigation actions, where possible communities with highest potential heat-related vulnerability occurring within the hottest neighbourhoods were identified.

Methods

To prepare a baseline urban heat mapping layer that considers land use, percentage impervious area, vegetation cover and historical thermal imagery (e.g., Landsat 8 Thermal Infrared bands 10 and 11), the following workflow was adopted:

- Generation of daytime and night-time land surface temperature (LST) maps for individual days/nights in summer using moderate resolution (30m pixel size) Landsat 8 thermal infrared data and coarser resolution MODIS satellite imagery
- Identification of the hottest areas in metropolitan Maitland and assessment of the contribution of land-use type and other built and natural characteristics in determining these patterns
- Development of a simple vulnerability index to identify residential areas where high LST coincides with high populations of potentially heat-sensitive residents.

Key Findings

- The study revealed that the Maitland LGA heats up significantly in summertime, with recorded surface temperatures reaching 40.5°C at 09:44 (DST) on 8 December 2019 (based on Landsat 8 TIR imagery) (Figure 3-2).

- Suburbs experiencing highest mean LSTs were Mount Dee (36.2°C), Windemere (36.2°C), Anambah (35.8°C), Luskintyre (35.7°C), Melville (35.5°C), Gosforth (35.1°C) and Lochinvar (35.1°C) (Appendix B).
- Suburbs with the lowest mean LSTs were Ashtonfield (29.7°C), Thornton (30.0°C), Woodberry (30.4°C), Pitnacree (31.1°C) Morpeth (31.2°C), East Maitland (31.3°C), Metford (31.5°C), Millers Forest (31.5°C) and Tenambit (31.6°C) (Appendix B).
- This study confirms that Maitland does indeed have a heat island at night within its urban zone that is about 3.7°C warmer in the summer than surrounding rural areas (based on night-time MODIS LST measurements at 23:45 in the evening (DST) on 9 December 2019).
- Suburbs exhibiting the surface heat island effect most strongly were across large parts of East Maitland, Rutherford, Maitland, Pitnacree, Horseshoe Bend, Metford and Ashtonfield. The SUHI effect was identified in areas exhibiting high daytime LST's which corresponded with a high night-time LST, resulting in moderate LST differences as can be seen in Figure 3-6 (yellow shades).
- Land-uses which exhibited highest day-time temperatures included aerodrome, residential, neighbourhood centre, business development, infrastructure and industrial land-uses (Figure 3-8).
- Of these land-uses with highest mean daytime LST's, those also coupled with an apparent heat lag at night-time included residential, industrial, infrastructure and business development (ascertained through visual inspection of the difference between day- and night-time LST's calculated from the MODIS image outputs, see Figure 3-6).
- A strong negative correlation was identified between % tree canopy cover and LST, indicating that increasing tree canopy cover has a significant cooling influence on surface temperatures (Figure 3-9).
- Dense forest stands were the most temperature stable, experiencing the smallest variation in temperature throughout the day.

Neighbourhoods with high heat exposure combined with high population vulnerability were located in Aberglasslyn, Rutherford, Gillieston Heights, Oakhampton, South Maitland, Maitland and Largs (Figure 3-22). These neighbourhoods are characterised as being located within the 40% hottest areas within the LGA and, as indicated by their heat-related population vulnerability (HRPV) score ≥ 3, also support the 80th percentile or top 20% of children aged 0-4 years, older people aged over 65 years, people requiring disability assistance and low-income households, earmarking them for highest priority heat mitigation actions.

Recommendations

Recommendations are provided regarding:

- Focussing mitigation actions within priority communities
- Reducing loss of existing tree canopy cover, especially dense mature forest communities
- Increasing tree canopy cover through strategic planting schemes
- Reducing the UHI-inducing impact of building materials used
- Undertaking ongoing monitoring and analysis of LST and street-level air temperature

Recommendations for strategic planning include:

- Development of a Street and Park Tree Masterplan

- Integration of the urban heat mapping into Council's spatial data for consideration when assessing development in or near hot spots
- Consideration of amendments to the Maitland Development Control Plan to increase protection for, and enhancement of, vegetation across the LGA as well as provide guidance on materiality and permeability
- Ensure that land use planning and the City's strategic framework for future development embodies a 'no worsening' scenario in respect of urban heat effects
- Consideration of strict landscaping thresholds
- Conduct an audit of road reserves (consider the data generated by NGH in the canopy mapping exercise, as well as ground-truthing surveys) to identify areas for the integration of green, permeable and reflective surfaces. This might include street tree planting, bio-swales, permeable and/or light-coloured road surfaces and footpaths.
- Identification of opportunities to retrofit existing stormwater infrastructure, such as basins, channels and drains, with green infrastructure.
- Adoption of a measurable target to reduce urban heat. Targets can relate to canopy cover and/or setting of benchmarks for heat indicators such as heat stress and micro-climates. Elegendawy and Davies (2019) note that the lack of a target generally results in less effective implementation of planning strategies.

1. Introduction

1.1 Project background

As one of the fastest growing inland cities in Australia, Maitland's natural areas are under considerable pressure from land clearing for urbanisation. This, combined with extensive historical clearing for forestry, agriculture and development, has led to a significant loss of vegetation cover; analysis of recent LiDAR data (NGH 2021) has revealed that only 15.6% of the City's tree canopy cover over 3m height remains.

The Maitland community has identified the protection and enhancement of the environment as a key priority. One reason for this is concern about urban heat, particularly in new suburbs with minimal urban canopy, which are more susceptible to the urban heat island effect. In response, Maitland City Council (Council) has undertaken this urban heat mapping project to identify priority suburbs within the local government area (LGA) and inform targeted initiatives to mitigate the heat island effect. These measures will integrate with the Council's development of an interconnected 'green and blue' network across the LGA, that will support improved connectivity, biodiversity and air quality.

1.1.1 The urban heat island phenomenon

The 'urban heat island' (UHI) phenomenon refers to temperature differences caused by urbanisation (Taha 1997). Urban areas become significantly warmer than surrounding rural areas when there is less green cover and more hard surfaces. This happens because buildings and paved surfaces absorb and store solar radiation during the day and then release it slowly back into the environment at night. As a result, the UHI effect is typically most evident at night. Inappropriate building and street design and layout, as well as increased building density and height, can trap warm air, further reducing cooling at night thereby exacerbating heat build-up. In addition, impervious surfaces allow surface water to wash away after rain, with the result that it is not available in soil for evaporative cooling. Furthermore, urban areas typically have low vegetation cover meaning that these areas experience less of the cooling benefit of shade and evapotranspiration provided by natural green cover.

Figure 1-1 illustrates how some areas are hotter than others because of the variable distribution of heat-absorbing buildings and pavements, whereas other land-cover types remain cooler due to tree canopy and water. For example, in the heat island diagram urban parks, ponds and residential areas are cooler than built up areas Figure 1-1.

Heat islands can contribute to poor air quality, magnify the impacts of extreme heat events and put people's health at higher risk (Gamble et al. 2013; Zhang et al. 2016; Vaidyanathan et al. 2020).

Extreme heat events have caused more mortalities over the past 100 years in Australia than any other natural hazard (Steffen et al. 2014).

Identifying hot spots within a city can help focus interventions where they are most needed during heat waves.

Without intervention, it is predicted that the heat island effect is likely to strengthen in the future as the structure, spatial extent and population density of urban areas change and grow (Hibbard et al. 2017).

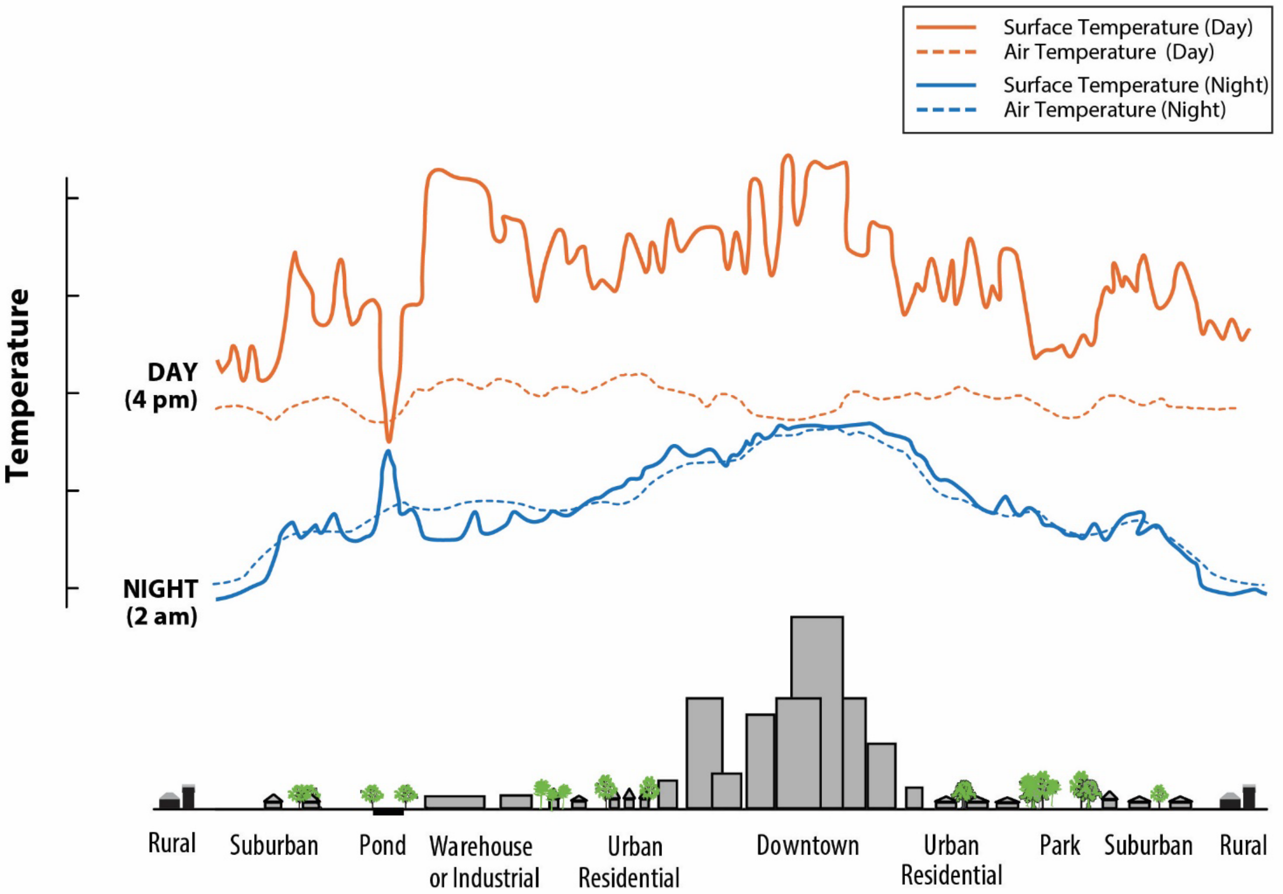


Figure 1-1 Heat island effect diagram (US EPA 2021 https://www.epa.gov/heatislands/learn-about-heat-islands#_ftn1)

1.2 Figure Heat island effect diagram (US EPA 2021 https://www.epa.gov/heatislands/learn-about-heat-islands#_ftn1)Project objective

The primary objective of this study was to produce a baseline dataset identifying priority suburbs within the LGA for urban heat management initiatives and provide a starting point for future detailed investigation. Specifically, the investigation sought to provide a basic understanding of summer-time heat distribution across the LGA and to determine if and where a surface heat island may exist in the urban zone. Potentially heat-vulnerable communities within Maitland, and identification of which of those communities occurred within the hottest suburbs, was also undertaken where possible, to focus mitigation actions.

1.2.1 Project scope

The following scope of work was implemented to achieve Council's project objective:

1. Produce a map of summer-time land surface temperature to identify hottest areas within the Maitland LGA.
2. Determine the presence of a surface urban heat island within the urban zone.
3. Investigate the influence of land-use and tree canopy cover on urban LST
4. Develop a simple, heat-related, population vulnerability index.
5. Identify communities with highest heat-related health risk.

6. Identify priority suburbs within the LGA for urban heat management initiatives.

2. Methods

2.1 Data acquisition & review

To prepare a baseline urban heat mapping layer that considers land use, percentage impervious area, vegetation cover and historical thermal imagery (e.g., Landsat 8 Thermal Infrared bands 10 and 11), we adopted the following workflow:

- Generation of daytime and night-time land surface temperature (LST) maps for individual days/nights in summer using moderate resolution (30m pixel size) Landsat 8 thermal infrared data and coarser resolution MODIS satellite imagery
- Identification of the hottest areas in metropolitan Maitland and assessment of the contribution of land-use type and other built and natural characteristics in determining these patterns
- Development of a simple vulnerability index to identify residential areas where high LST coincides with high populations of potentially heat-sensitive residents.

To achieve this, multiple datasets were acquired from numerous sources, including the City of Maitland, United States Geological Survey (USGS) Earth Resources Observation and Science (EROS) Centre, Australian Bureau of Meteorology (BOM) and the Australian Bureau of Statistics (ABS). All data used in this project were subject to stringent quality control procedures before their application to analysis (e.g., assessment of temporal, spatial, geometric and attribute content). For a complete list of data and what each dataset was used for, refer to Table 2-1. Details regarding the acquisition, review and processing of each dataset is discussed further within each of the relevant method sections below.

Table 2-1 Data list with sources and task application

Dataset	Filename	Source	Used for task items		
			LST & UHI mapping	Effect of land-use	Heat vulnerability index
Landsat 8 Bands 10 & 11	LC08_L1TP_089083_20191208_20200825_02_T1	USGS EROS 2021	√		√
MODIS satellite imagery	MOD11A1 V6.1	NASA DAAC 2021	√		
BOM observed temperatures	IDCJAC0010_061428_1800_Data	BOM 2021	√		√
BSA demographic data and socio-economic indices (e.g., age, SEIFA scores, household income, etc)	2016 Census GCP All Geographies for NSW Data Pack	ABS 2021		√	√
LiDaR-derived tree canopy	BR02718_Maitland_TreeCanopy_Above2m	City of Maitland 2021		√	√
Aug 2020 Aerial photography (R, G, B	WMS via MetroMaps	City of Maitland 2021	√	√	

Dataset	Filename	Source	Used for task items		
bands only)					
May 2021 Aerial photography (R, G, B bands only)	WMS via MetroMaps	City of Maitland 2021	√	√	
Updated Maitland Native Vegetation mapping 2020-21	Maitland Native Vegetation mapping 2020-21	City of Maitland 2021		√	√
Land zoning	LZN	City of Maitland 2021		√	√
Maitland Local Environmental Plan 2011	FLD & URA	City of Maitland 2021		√	
Future development areas	Future development	City of Maitland 2021		√	
Land tenure/ownership	Cadastre	City of Maitland 2021		√	
Suburbs	Suburbs	City of Maitland 2021		√	√
LGA boundary	Maitland_LGA	City of Maitland 2021	√	√	√
Protected estate (i.e., National parks and nature reserves)	Parks	City of Maitland 2021		√	
Council open space	Crown_Council_Land	City of Maitland 2021		√	
Private/Voluntary conservation properties	Environmental_Projects	City of Maitland 2021		√	
iTree Canopy-derived impervious surface estimates	Impervious surface estimates	City of Maitland 2021		√	

2.2 Calculation of land surface temperatures (LST)

Satellite thermal infrared imagery is commonly used to estimate land surface temperature (LST) and has been widely adopted for assessing urban heat in Australian cities (Coutts et al. 2016; Deilami et al. 2016). For this study, two types of thermal remote sensing imagery were used:

- Landsat 8: The Landsat 8 Thermal Infrared Sensor (TIRS) captures data over the Maitland region at 08:44 EST (09:44 DST). The TIRS Thermal bands have a spatial resolution of 100m x 100m resampled to 30m to match the multispectral bands.
- MODIS: MODIS imagery is collected twice daily, once in the morning (at approximately 10:15 EST or 11:15 DST) and again in the evening (at approximately 22:45 EST or 23:45 DST). While MODIS LST data has a relatively coarse spatial resolution of 1km x 1km, the more frequent revisit time makes it useful for studying the relationship between daytime and night-time urban heat trends, an important aspect of determining the presence of UHI's.

2.2.1 Summer daytime LST using Landsat 8

To determine the most appropriate time period (i.e., most informative year and time of year based on local temperatures experienced) which could provide the best representation of surface urban heat island effects within the Maitland LGA, daily maximum temperatures (collected at Maitland Airport) were sourced from the BOM Climate Data Online site for the past four years (2018-2021). Evaluation of the data revealed that highest daily maximum temperatures were observed throughout the months of November, December, January, February and March, with the hottest days occurring predominantly in the months of December, January and February. Comparing maximum daily temperatures of the past three summer seasons (i.e., December to February for 2018-2019; 2019-2020; and 2020-2021) it was found that the summer of 2019-2020 experienced the hottest maximum daily temperature for each of the months (Table 2-2).

Table 2-2 Comparison of maximum daily temperatures across three summers

Year	2018	2019	2019	2019	2020	2020	2020	2021	2021
Month	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb
Max T_{max} of the month (^0C)	39.1	42.6	40.4	44.2	45.1	44.3	36.1	38	33.2

Based on these findings, Landsat 8 imagery was reviewed focussing within these three summer periods. Using the USGS EROS Earth Explorer (EE) user interface, an online search and ordering tool, all Landsat 8 Level 1 scene(s) available for the Maitland region during the specified summer months were reviewed for image quality and degree of cloud cover. Out of 17 available daytime images, only two scenes were sufficiently cloud-free for reliable LST analysis. These scenes were acquired on 8 December 2019 and 10 February 2021, respectively. Due to the 2019 December date falling within a cluster of hotter days than the 2020 February date (31.4°C, 30.4°C & 34.5°C on 07,08 and 09 December 2019, respectively, as compared to 22°C, 30.5°C and 32°C, respectively for 9, 10 and 11 February 2020, respectively), it was decided that the 2019 image would be more suitable for investigating urban heat effects.

At the time of the analysis, night-time imagery acquired by the Landsat 8 sensor was not available for download via the ordering tool. It was subsequently established that Landsat 8 night-time imagery is available by special order via the USGS EROS site, however this information was attained after analysis had been completed for the current study. Therefore, only day-time imagery Landsat imagery was used to investigate finer scale urban heat effects. MODIS imagery was used for daytime and night-time LST comparisons (see Section 2.2.2).

Following atmospheric and other routine correction of the data, an appropriate image processing method was selected to digitally analyse Band 10 (TIRS-1) and Band 11 (TIRS-2). Due to calibration uncertainty in Band 11 created by stray light entering the sensors, Band 11 was determined to be unsuitable for use. For this reason, a mono-window algorithm method which utilises Band 10 only, was applied (Rongali et al. 2018).

The resultant LST map was used for further analysis to understand the spatial distribution of land surface temperatures in summer, and particularly to identify hot spots of concern within the urban zone.

As vegetation coverage has a significant influence on the Land Surface Temperature (LST) distribution, a map of vegetation ‘greenness’ was also produced to provide some insight into the distribution of vegetated vs non-vegetated surfaces across the LGA. For this purpose, the Normalised Difference Vegetation Index (NDVI) was used. Developed by Rouse et al. (1974) it is one of the most commonly applied vegetation indices and is an indicator of photosynthetic activity or plant 'greenness'. Based on the principle that well-nourished, living plants absorb red light and reflect near-infrared light, while stressed or dead vegetation absorbs comparatively less red light than healthy vegetation, the index can also be used to measure stress in vegetation. The index was calculated using the red and near infrared multispectral bands captured by the Landsat 8 satellite.

2.2.2 Identification of surface urban heat island (SUHI)

Daytime and night-time LST images were sourced using the National Aeronautics and Space Administration (NASA) Earth Data Search tool. Unlike Landsat, there is a processed MODIS LST product available which is analysis-ready (i.e., atmospheric correction and conversion of raw reflectance measurements to surface temperature values is already applied to the data). For this study, the MOD11A1 v6.1 product was used, which only required reprojection and conversion from degrees Kelvin to degrees Celsius.

In order to determine whether a surface urban heat island (SUHI) exists within Maitland City, day- and night-time scenes for the 9 December 2019 were visually compared and a temperature difference map was created by calculating the difference between daytime and night-time temperatures.

2.2.3 Examination of spatial collinearity trends within the LST data

A trend of increasing LST was visibly evident within the LST data extending from east to west across the LGA. To determine whether the trend was statistically significant, a Moran's I test was used to identify the presence or absence of spatial collinearity within the LST data. Correlation analyses were carried out between mean LST within each suburb and the following variables to establish which factor had any significant influence on the observed LST trend:

- Proximity to the coast – to ascertain whether proximity to the coast has any significant influence on mean suburb LST, the distance of each suburb centroid from the coast was calculated and correlated against mean LST of the suburb
- Elevation – the 1 second STRM-derived elevation was used to calculate mean elevation within each suburb.

The results of these tests were used to facilitate interpretation of the results of all subsequent investigations undertaken to determine which built features are influencing urban heat within Maitland LGA.

2.2.4 Identification of urban hotspots

To identify where the hottest locations within the Maitland urban zone are, the December 2019 Landsat 8 LST layer was clipped to the MCC-supplied urban zone layer and analysed to identify unusually hot areas. The urban zone layer was derived from land zoning and therefore is only indicative of future uses. For the purposes of this study, hot spots were defined as LST greater than the mean LST within the urban zone.

LST within the urban zone is referred to as urban land surface temperature (ULST) to help distinguish between LSTs discussed in relation to the urban zone alone as opposed to the entire LGA.

While mean ULST across the entire urban zone was 33°C (based on Landsat 8 imagery at 09:44 DST on 8 December 2019), due to coastal effects causing significantly cooler conditions in the eastern section of the LGA compared to those in the western section (see Section 3.1.1), the urban zone was divided into three regions, namely eastern, central and western, and a separate mean ULST was calculated for each. Hotspots were identified in each region by comparing local ULSTs against their region-specific mean ULST.

2.3 Influence of natural and built urban features on urban heat

Landscape features such as land use, percent canopy cover, percent impervious surface, dwelling density and dominant dwelling structure can influence ULST. To assess the contribution that these land cover characteristics have in determining patterns of high daytime ULST distribution, natural and built features including the following were analysed in relation to the above ULST mapping:

- Land use – mean LST was calculated for each land-used type across the whole Maitland LGA to determine which land-uses are associated with highest and lowest LST's (land-use was determined using the Maitland Land Zone mapping layer; LST was based on the December 2019 Landsat 8-derived LST)
- Percentage tree canopy cover – focussing on the Maitland urban zone, a correlative analysis was carried out between mean ULST (based on the Landsat 8-derived LST) and percent tree canopy cover (based on the Maitland 2021 LiDaR-derived tree canopy layer) within each land-use type
- Percentage impervious surface cover – a correlation analysis was carried out between estimates of % impervious surface cover by suburb, determined using the online iTree Canopy tool in the Maitland Vegetation Canopy Assessment (NGH 2021), and mean suburb LST to ascertain whether and how % impervious surface cover might impact LST. Impervious surface included roads, paving and all built structures (i.e., buildings, rooftops, etc).
- Gross dwelling density and dominant dwelling structure – focussing on the Maitland urban zone, gross private dwelling density (GPDD) and dominant dwelling structure were derived using ABS Census of Population and Housing data. Correlative analyses were carried out between GPDD and various ULST statistics (i.e., ULST mean, range, minimum and maximum within urban land-use zones), as well as between dominant dwelling structure and ULST statistics.

2.4 Assessment of population vulnerability

To identify neighbourhoods with high potential heat-related population vulnerability, first a potential heat-related population vulnerability (HRPV) index was developed based on a literature review which considered research identifying high-risk vulnerability parameters including:

- Population age – children aged 0-4 years and those over 65 years of age
- Level of special care and disability – people who require assistance with daily activities (disabilities)
- Low-income households – defined as the lowest 25% of household incomes in Maitland. For this purpose, an equivalised annual income of between $0 and $41,548 was applied.
- Ethnicity – in an Adelaide study, higher risk was noted for non-English speaking groups (i.e., people living in culturally and linguistically diverse communities), especially amongst older individuals with low English-speaking skills

- SEIFA score –the Index of Relative Socio-economic Disadvantage (IRSD), in particular, was considered. The IRSD is a general socio-economic index summarising a range of information about the economic and social conditions of people and households within the urban zone.

Data related to the above parameters were obtained from the 2016 ABS Census of Population and Housing. Individual and household data are aggregated by the ABS to the area of a Statistical Area Level 1 (SA1) which is the smallest area for which the majority of demographic and socioeconomic census data are available.

Research has shown that communities with highest heat-related health risk are the young (those who are either 4 years or younger), the old (those over 65 years of age), individuals requiring special disability assistance, as well as low-income households (Zhang et al. 2016). While ethnicity (ability to speak English) and SEIFA were both considered as potential predictors of heat-related health risk in communities, after evaluation of the data and testing predictability, both were deemed inappropriate for this study and were not included in the final calculation of HRPV scores.

To calculate the vulnerability scores, count data of individuals and households within each SA1 area were extracted from the 2016 Census GCP data pack for NSW (ABS 2021), for each of the chosen predictors of heat-related health risk identified above. A score of '1' was assigned to an SA1 for each predictor that exceeded the 80th percentile pertaining to that predicting factor.

For example, a score of '1' was assigned to an SA1 for each of the vulnerability factors where the count value relating to that factor exceeded the following threshold value within the SA1 area (these thresholds were determined by calculating the 80th percentile for each of the vulnerability factors), i.e.:

- If there were more than 39 children aged 0-4 years within an SA1 unit, a score of '1' was assigned
- If there were more than 84 people aged over 65 years within an SA1 unit, a score of '1' was assigned
- If there were more than 36 people requiring disability assistance within an SA1 unit, a score of '1' was assigned'
- If there were more than 18 low-income households within an SA1 unit, a score of '1' was assigned.

An SA1 exceeding the threshold (i.e., in the top 20%) for all four population vulnerability factors would achieve an aggregated score of '4' which is the maximum score attainable, whereas an SA1 achieving 80th percentile thresholds for 2 or 3 factors would receive a total vulnerability score of '2' and '3' respectively, and so on.
The heat-related vulnerability assessment was carried out for the entire LGA.

2.5 Identification of priority communities for action

Heat-related health risk may be greatest when populations with high heat-related vulnerability are living within the hottest neighbourhoods. On this basis, a GIS overlay analysis was carried out using both the aggregated HRPV score and the 20% and 40% hottest SA's (based on the mean LST of each SA1 within Maitland LGA) to identify the high-risk communities in relation to hotter areas within the LGA.

3. Results

3.1 Distribution of greenness and temperature

3.1.1 Summer day-time heat distribution across the LGA

Based on the Landsat 8 multispectral imagery captured on 8 December 2019, the map of NDVI vegetation greenness (Figure 3-1) showed irrigated fields and forests as having the strongest greenness values (shown as dark blue and greens), with native forests having higher NDVI responses than urban forests, the latter being more moderate (showing as yellow in Figure 3-1). Paddocks, grasslands and non-irrigated crop areas showed a mixture of moderate to moderately high NDVI responses. Urban areas, quarries and development sites had extremely low greenness indices, indicating very little or an absence of vegetation.

The map of daytime LST for 8 December 2019 at 09:44 (DST) (Figure 3-2) reveals cooler temperatures in the eastern half of the LGA, most notably across the south-eastern suburbs, while warmer temperatures appear more prevalent in the western region and urban areas. This observation that the eastern parts of the LGA are cooler than the western parts was statistically confirmed by the Moran I test which revealed that the apparent trend of increasing LST from east to west across the LGA was significant. Furthermore, a strong positive correlation ($r = 0.7680$) was identified between the distance of the suburb centroid from the coast and the mean suburb LST. This statistically verifies that the proximity to the coast has a cooling or moderating effect on the eastern half of the LGA, the influence of which diminishes westwards. The correlation between mean elevation and LST was much weaker ($r = 0.3922$).

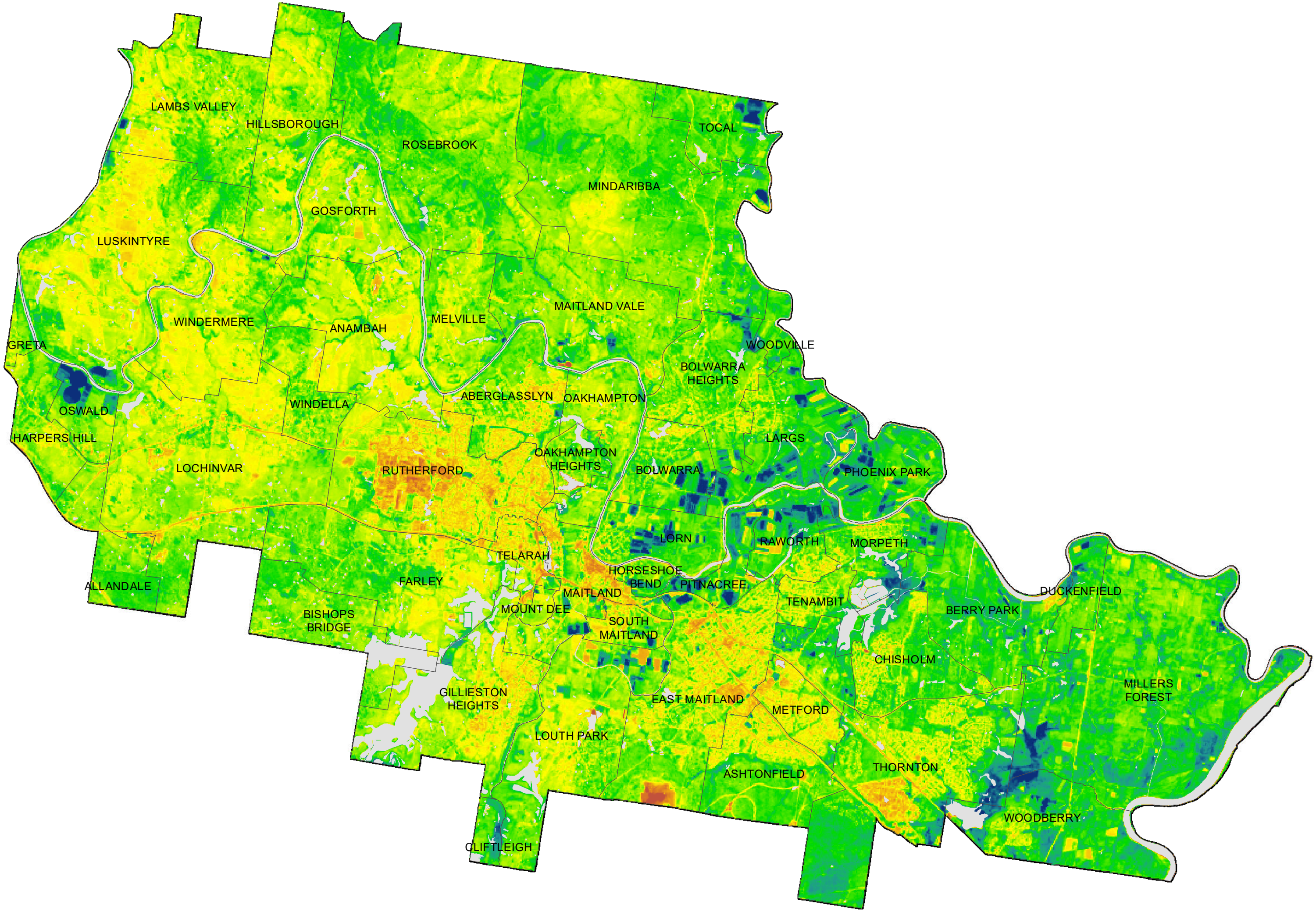
Features such as forests and waterbodies presented the coolest areas within both the eastern and western regions when compared with other landcover types in the local area; in places exhibiting comparative temperatures of at least 6°C lower than immediately adjacent hotter areas.

In general, there is a negative correlation between LST and NDVI in Maitland, with LST increasing as vegetation greenness decreases (Figure 3-1 and Figure 3-2). However, it is important to be aware that other factors, such as proximity to coastal effects (as demonstrated above), vegetation-cover and type, topography, terrain, rainfall, wind, water bodies, soil moisture and presence of rock outcrops may also influence LST.

Suburbs with the lowest mean LSTs were Ashtonfield (29.7°C), Thornton (30.0°C), Woodberry (30.4°C), Pitnacree (31.1°C) Morpeth (31.2°C), East Maitland (31.3°C), Metford (31.5°C), Millers Forest (31.5°C) and Tenambit (31.6°C). Suburbs experiencing highest mean LSTs were Mount Dee (36.2°C), Windemere (36.2°C), Anambah (35.8°C), Luskintyre (35.7°C), Melville (35.5°C), Gosforth (35.1°C) and Lochinvar (35.1°C). Mean LSTs for all suburbs within the LGA are graphically compared in Figure 3-3.

A detailed list of NDVI and LST statistics (including mean, standard deviation, maximum, minimum and range for both NDVI and LST) are provided for all suburbs in Appendix A and Appendix B, respectively.

Figure 3-1 Vegetation greenness index (NDVI) for Maitland on 8 December 2019, based on Landsat 8 multispectral satellite imagery



Surburb boundary
Masked waterways & waterbodies

NDVI
High greenness
Low greenness

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Ref: 21-137 Fig Landsat NDVI 9Dec2019
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

NGH

0 0.5 1 2 Km

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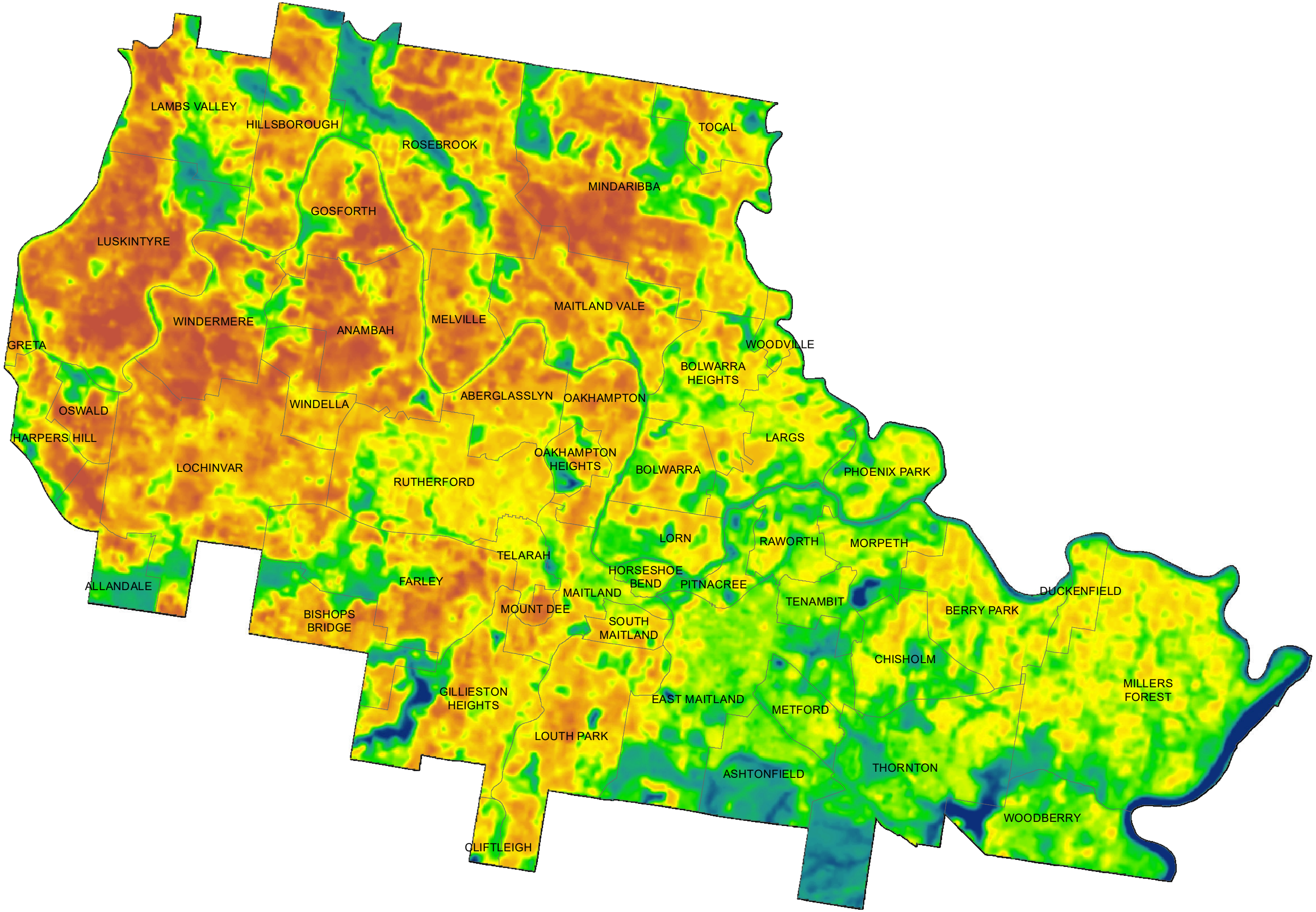
Figure 3-2 Summer day-time land surface temperature (LST) for Maitland on 8 December 2019, based on Landsat 8 thermal infrared imagery (at 09:44 DST)



Surburb boundary

Land Surface Temperature (°C)

High Temp (MaxT 40.5°C)

Low T (MinT 22.6°C)

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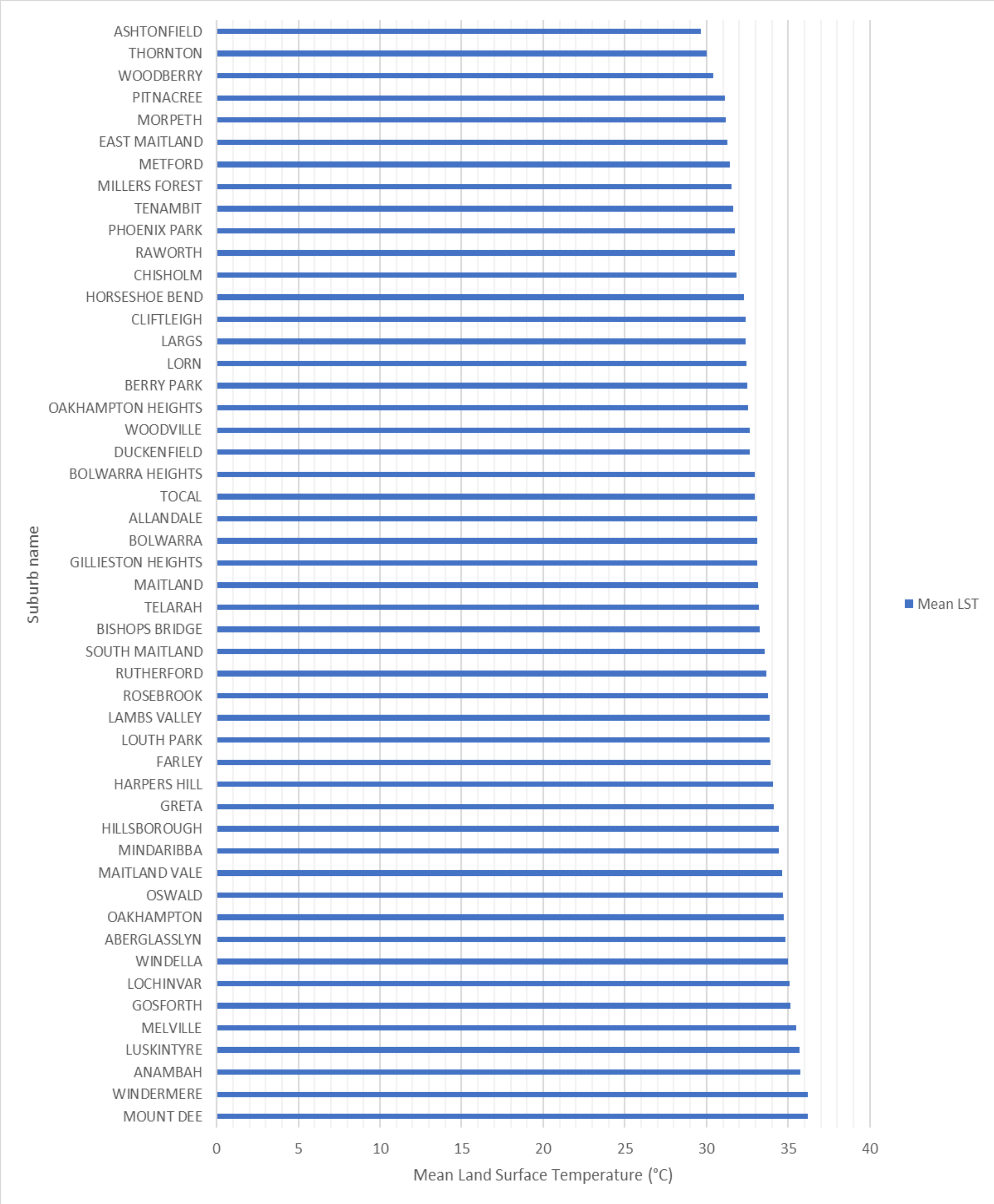


Figure 3-3 Mean land surface temperature (°C) for Maitland suburbs (based on Landsat 8 TIR imagery captured on 8 December 2019, 09:44 DST)

3.1.2 Identification of a surface urban heat island in Maitland LGA

Even with the relatively coarse scale of 1km x 1km pixel resolution, the MODIS thermal imagery showed clear daytime and night-time patterns in surface heat distribution across the LGA on 9 December 2019 (i.e., at 11:15 and 23:45 (DST), respectively). The coolest areas were evident in the forested areas (both in the northwest, south and southeast and around waterways, waterbodies and wetlands (Figure 3-4), while hotter areas were strongly evident across the rural western suburbs which are dominated by grasslands with minimal tree cover and lesser influence of the coastal cooling effect from the east. Temperature profiles in the urban areas were mixed, showing temperatures in the mid-ranges with hottest areas in the eastern half of Rutherford, Telarah, the south end of Bolwarra Heights and East Maitland.

As expected, no surface urban heat island effect was evident in the day-time map (Figure 3-4), which is consistent with similar findings from other cities.

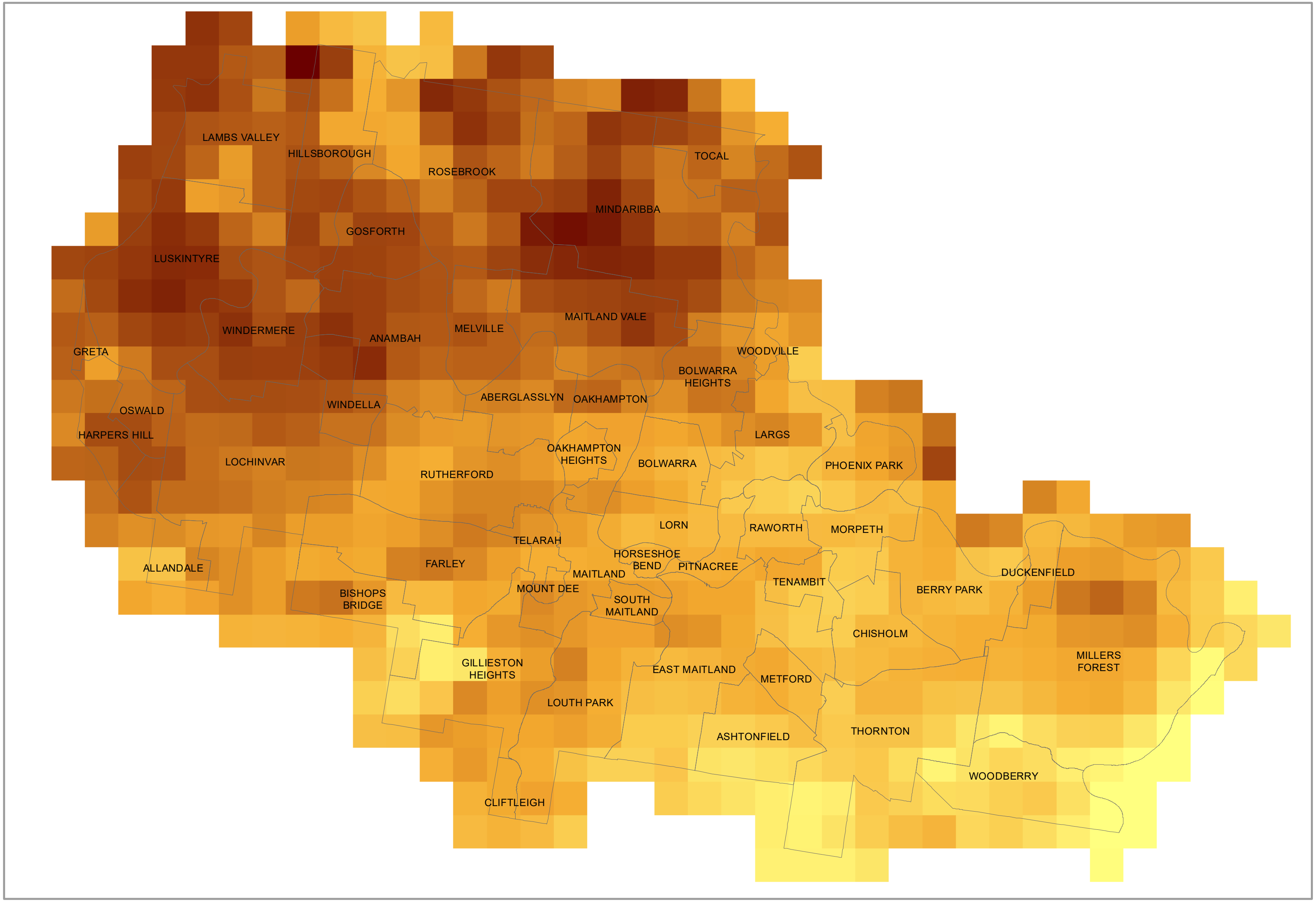
However, a persisting surface urban heat island was evident in the late evening (Figure 3-5). This phenomenon is caused by the tendency for man-made structures and surfaces (buildings and roads) to hold on to the heat absorbed during the daytime and then re-emit it slowly at night-time, preventing these areas from experiencing the same degree of cooling as the more natural land-cover types do in the rural and suburban areas. The night-time imagery in Figure 3-5 shows this effect, with the urban centres demonstrating warmer night-time LSTs, suggesting a lag in heat release. In contrast, the rural areas which are still dominated by ‘natural’ surfaces (e.g., grasslands and other vegetated surfaces) with a lower cover of built and impervious surfaces, show a greater ability to cool down. For example, in the western section of the LGA even those areas which exhibited greater daytime LSTs than some urban areas (e.g., Anambah, Gosforth, Windermere and Luskintyre), managed to achieve cooler temperatures than the urban areas at night-time.

The persisting SUHI effect is especially evident in the temperature difference map (Figure 3-6) as it highlights the effect within the urban areas (shown as light yellow). In the urban centres of the LGA, where the SUHI phenomenon is present, temperature differences between daytime and night-time are moderate to low, indicating that heat is not being released as effectively as in areas where more ‘natural’ land-cover types still dominate, such as rural areas.

By contrast, in areas where the night-time SUHI effect is absent or weak, the temperature differences between day- and night-time are more extreme (i.e., displayed as dark blue or red). In these areas there is either a very large difference between day- and night-time temperatures in the hottest rural areas (e.g. the western grasslands), which reach high LSTs in the daytime but are able to release the heat load at night (i.e. dark blue implies large temperature change), or there is a very small temperature change in the coolest day-time areas, and hence do not have a large heat store to release as they do not heat up as much during the day. For example, dark red pixels in Figure 3-6 imply virtually zero net change in LST between day- and night-time, these coincide with waterbodies or larger areas of dense forest. In Figure 3-6 waterbodies appeared as the most thermally stable land-cover type, meaning that the difference between daytime and night-time LSTs show the least change. Densely forested areas also tend to exhibit similar thermal stability (i.e., both their daytime and night-time LSTs tend to be lower and show small differences between night and day), however this is only evident in Figure 3-6 where the area of dense forest covers the majority of the MODIS pixel area. This latter point highlights the importance of taking into account the coarse spatial resolution of the MODIS imagery when interpreting the map output. The 1km x 1km represents the mean LST for all features within the pixel area. This can result in the LST ‘signal’ of smaller spatial features (such as forest patches which are smaller in size than the pixel area) not being accurately represented in the map.

The difference parameter should be less sensitive to collinear influences (such as coastal cooling effects or elevation), as the input values (i.e., daytime LST and night-time LST are influenced by the same spatial collinear influences). However, to fully understand all the factors influencing the observed results, further statistical exploration of the data needs to be undertaken.

Figure 3-4 Day-time land surface temperature (LST) for Maitland on 9 December 2019, based on MODIS thermal satellite imagery (approx. 11:15 DST)



Service Layer Credits:

Surburb boundary

Day-time LST (°C)

Highest T (Max T 50.6°C)

Lowest T (Min T 39.0°C)

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Ref: 21-137 Fig MODIS Day LST 9Dec2019
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

NGH

0 0.5 1 2 Km

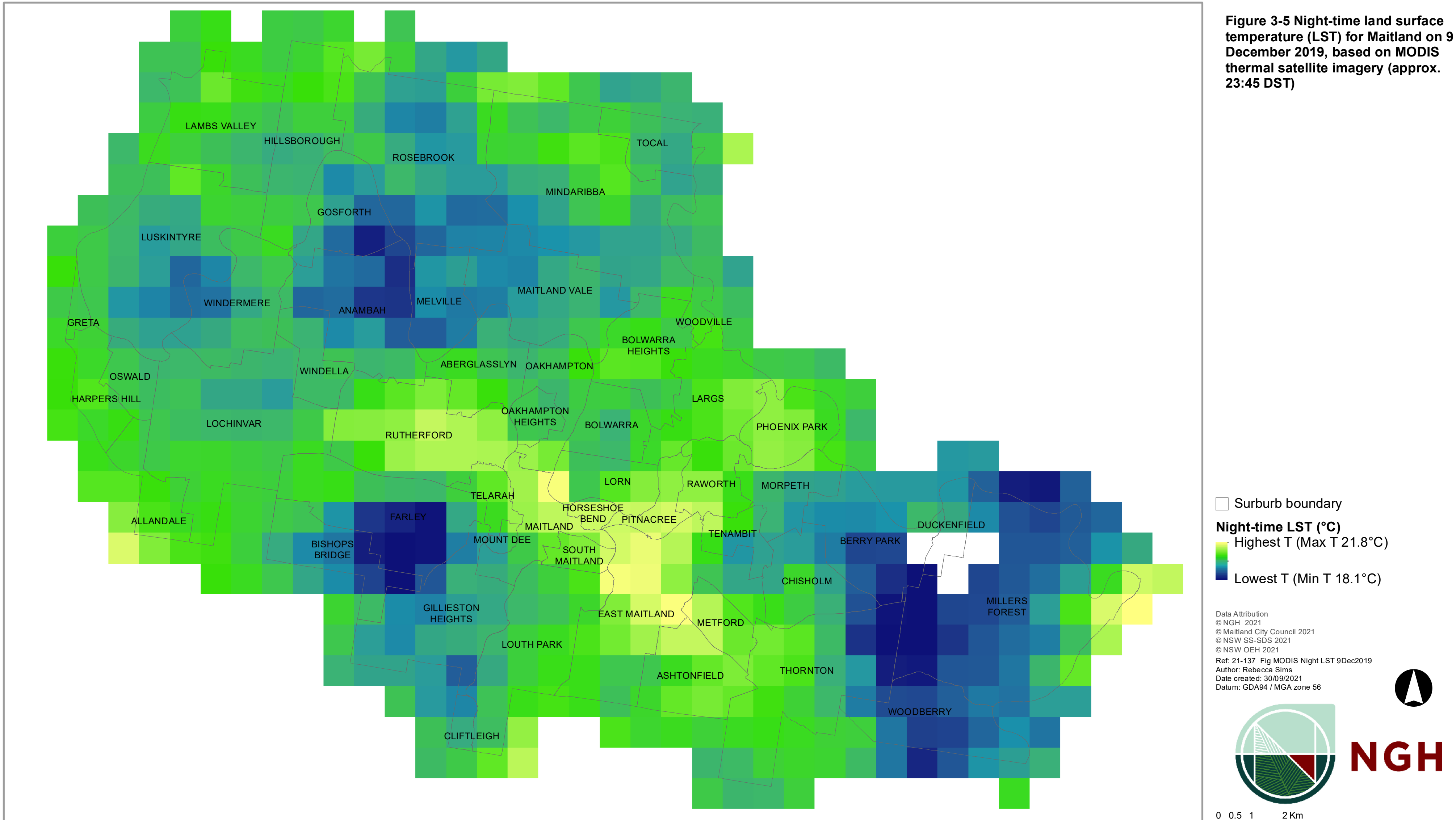

Figure 3-5 Night-time land surface temperature (LST) for Maitland on 9 December 2019, based on MODIS thermal satellite imagery (approx. 23:45 DST)

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Service Layer Credits:

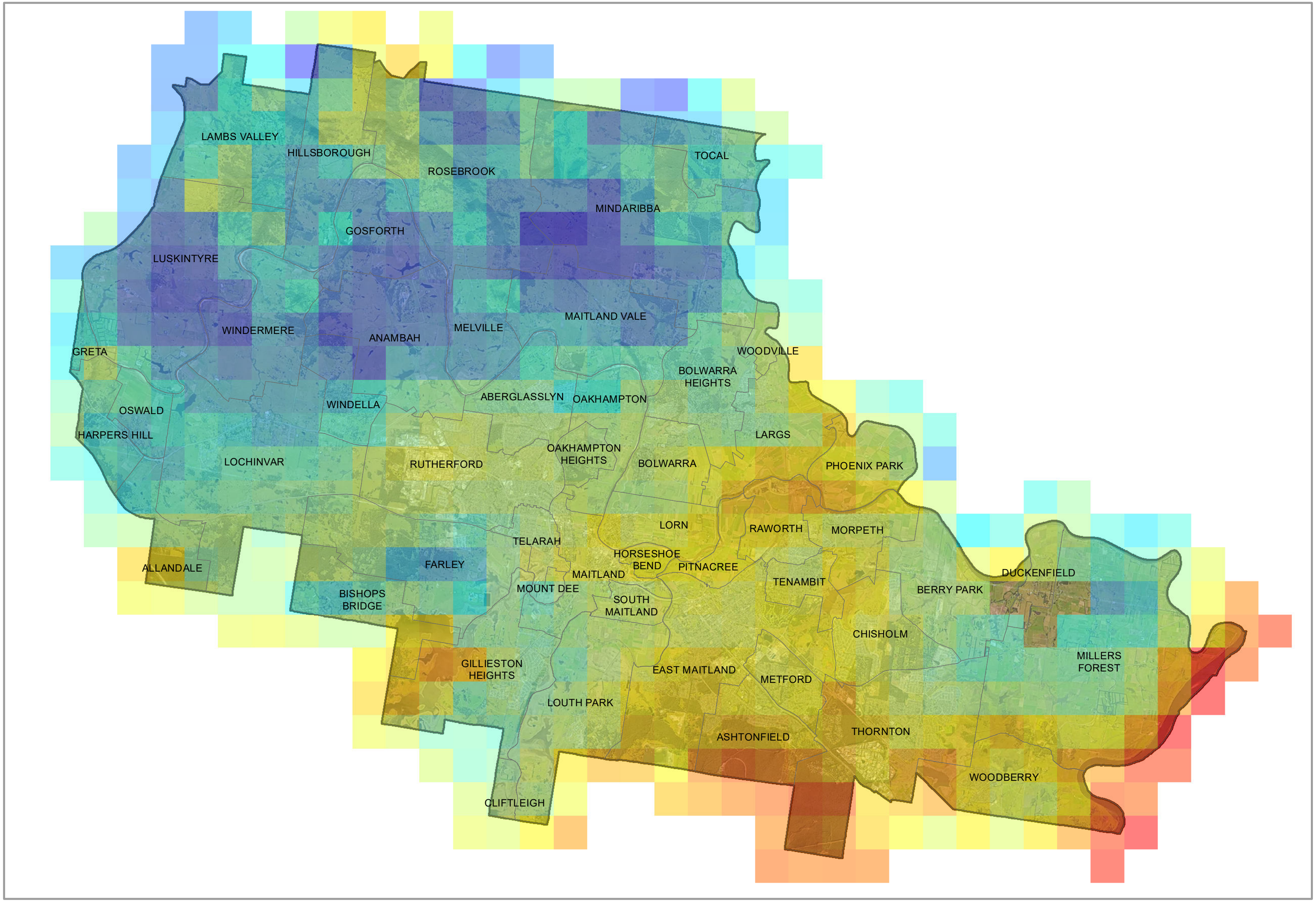

Figure 3-6 Difference in land surface temperature from day-time to night-time for Maitland on 9 December 2019, based on MODIS thermal satellite imagery (approx. 11:15 DST (day-time) & 23:45 DST (night-time), respectively)

Surburb boundary

Difference in LST between day-time & night-time

Highest difference

Lowest difference

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Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

NGH

0 0.5 1 2 Km

Service Layer Credits:

3.1.3 Identification of day-time hotspots within the urban zone

High daytime ULSTs, above the mean LST for the urban zone, or 'urban hotspots', were associated with numerous land-uses and cover types. Figure 3-7 highlights the locations and key land-uses associated with hotspots throughout the urban zone. This map displays the variance from the mean LST to indicate which areas exhibit above-average daytime LST and those with below-average LST. To assist with like-for-like comparison of LST variance between the cooler eastern and warmer western regions (caused by the cooling effect of coastal proximity on eastern suburb LSTs), three regions were defined and a separate mean LST calculated for each. These three regions, located within the eastern (mean LST of 32 °C), central (mean LST of 33°C) and western (mean LST of 35°C) sections of the urban zone are displayed within the inset map of Figure 3-7. The LST variations displayed for each region in the map are calculated against each region-specific mean LST.

While areas of above-mean temperature could be found in the urban zone of most suburbs, hotspots were hottest within the western sector (notably, Lochinvar, Windella, Anambah, Rutherford, Aberglasslyn, Oakhampton Heights, Gillieston Heights and Farley). As previously mentioned, these hotter conditions within the western areas appear to be due to a weaker influence of coastal cooling effects on these suburbs as their distance from the coast increases.

Hotspots within these suburbs were associated with the following land-uses (refer to Appendix D for example photos and corresponding LST responses for each land-use):

- Grassland: suburbs such as Lochinvar and Anambah have large areas of grassland, which have highest daytime ULSTs for the western region but low night-time ULSTs. These areas are zoned for 'general residential' use. Currently these areas cool down at night. When converted to urban residential landcover, they will be prone to develop persistent UHI's.
- Aerodrome: the Maitland airport produced a high mean ULST response above the mean for the western urban zone. This is likely due to a combination of the large impervious surface area of the runway, surrounded by an extensive open grass area. By necessity there is a low percentage tree canopy cover, which exacerbates the high surface temperatures in this area.
- Large lot residential: while these blocks are dominated by natural surfaces, they heat up in the daytime as the large lot residential properties as shown in Figure 3-7 are mostly grassed areas with very little tree canopy cover. However, these areas do show cooling at night, as can be seen in the night-time MODIS LST map (see Figure 3-6). Furthermore, large lots with tree-cover exhibited below-average LSTs.
- General residential: the general residential areas, both established and newly developed, all show strong above-median ULSTs. The newly developed areas and those with development in progress tend to exhibit higher ULSTs than the more established areas due to bare ground or low tree cover coupled with impervious surfaces.
- Industrial, commercial and business development centres: these land-uses demonstrate above-median ULSTs, largely due to a dominance of impervious surfaces and structures in the form of large rooftops and expansive parking lots with very little tree cover. These localities also exhibit persisting UHIs at night (as can be seen in the MODIS night-time LST map in Figure 3-6).
- Neighbourhood centres, local centres and mixed-use areas: many areas zoned as these land-uses exhibit above-mean LST 'hotspots' in Figure 3-7, indicating they heat up more than their local surroundings. This is likely due to the presence of large rooftops and parking lots, coupled with low percentage tree cover.

- Environmental living: the residential areas zoned as environmental living in the western urban areas experience a mixture of both below- and above-average ULSTs. This is the direct result of the land-cover type present in the area. Coolest areas occur in areas where dense tree canopy and/or waterbodies are present, whereas areas with no tree cover present the hottest areas. Within the eastern urban zones, areas zoned for environmental living all experience below-mean ULSTs. This is largely due the latter areas reaping the cooling benefits of both higher tree canopy cover, combined with coastal cooling effects. Comparative examples of both western and eastern regions can be seen in Appendix D.
- Sports fields and recreation areas: sports fields and grassed recreation areas with low tree canopy cover and/or large areas of impervious surface show up as hotspots in Figure 3-7. However, as can be seen in the example photos in Appendix D, as tree canopy cover increases, mean LSTs tend to decrease, suggesting that planting of peripheral trees could help reduce LSTs in the area.

While hotspots within the eastern urban areas are less intense than the western hotspots, they do still exhibit areas of above-median temperature (shown as yellow in Figure 3-7). These above-average LST areas are associated with the same land-use types as those described for the western areas. Additionally, within these suburbs (including Chisholm and Thornton), hotspots are particularly associated with newly developed residential areas and/or land cleared for development, or are under construction for new urban developments. These areas are characterised by a high density of impervious surfaces (rooftops, paving and roads) and an absence of tree cover.

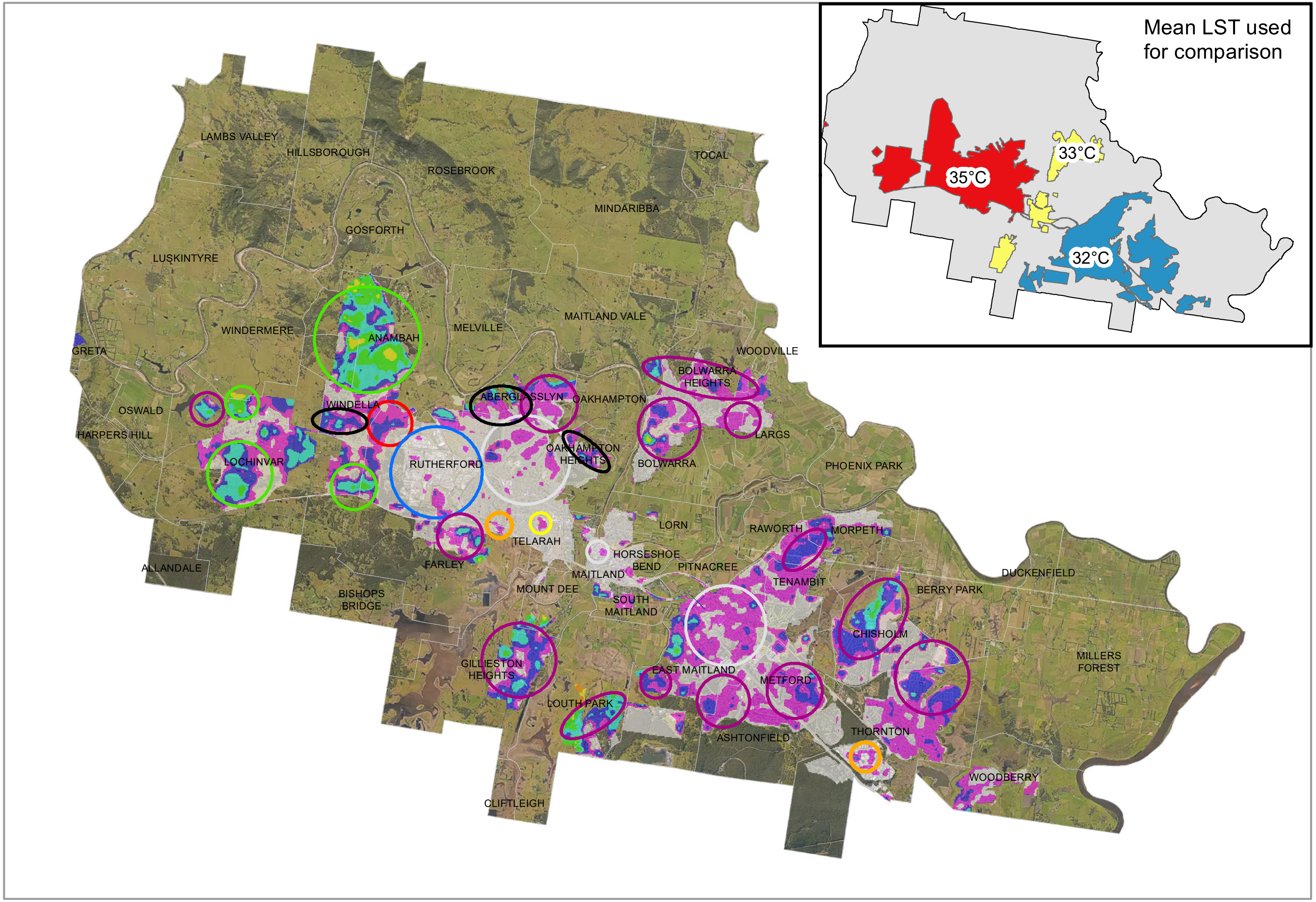

Figure 3-7 Urban hotspots with associated land-uses - departures from median urban LST (ULST) (32°C) within the urban zone (based on Landsat 8 TIR imagery captured 8 Dec 2019 at 09:44 DST)

Associated land-cover

- Airport
- Business centres - large rooftops & parkinglots
- Grasslands
- Industrial park
- Large lot residential with low tree cover
- New & established urban developments
- Sports fields
- Urban centres
- Surburb boundary

Hotspots (°C above mean ULST)

- Below mean
- 0.1 - 1
- 1.1 - 2
- 2.1 - 3
- 3.1 - 4
- 4.1 - 5
- 5.1 - 6
- 6.1 - 7.3

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Author: Rebecca Sims
Date created: 2/12/2021
Datum: GDA94 / MGA zone 56

0 0.5 1 2 Km

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3.2 Influence of land-use and vegetation on urban land surface temperature

3.2.1 Influence of land-use on ULST

Overall, there was a distinct difference in mean ULST between land-use types. 'Aerodrome' was the land-use with the hottest mean LST (35.2°C), almost 5.5°C hotter than the coolest land-use, which was 'Waste Management', with a ULST of 29.8°C. The lower ULST associated with 'Waste Management' is the result of a significant vegetated buffer area, which is larger in area than the landfill itself. In addition, there is a low percentage of impervious surface in the area.

'Large Lot Residential' (34.0°C) and 'General Residential' (33.4°C) had the second and third highest ULSTs respectively, while 'Environmental Living' (29.9°C) and 'Environmental Conservation' (30.8°C) were the second and third coolest land-uses, respectively.

Figure 3-8 summarises the mean LSTs associated with each land-use located within the urban zone. A detailed list of LST statistics (including mean LST, standard deviation, maximum-, minimum-LST and LST range) for each urban land-use can be found in Appendix C.

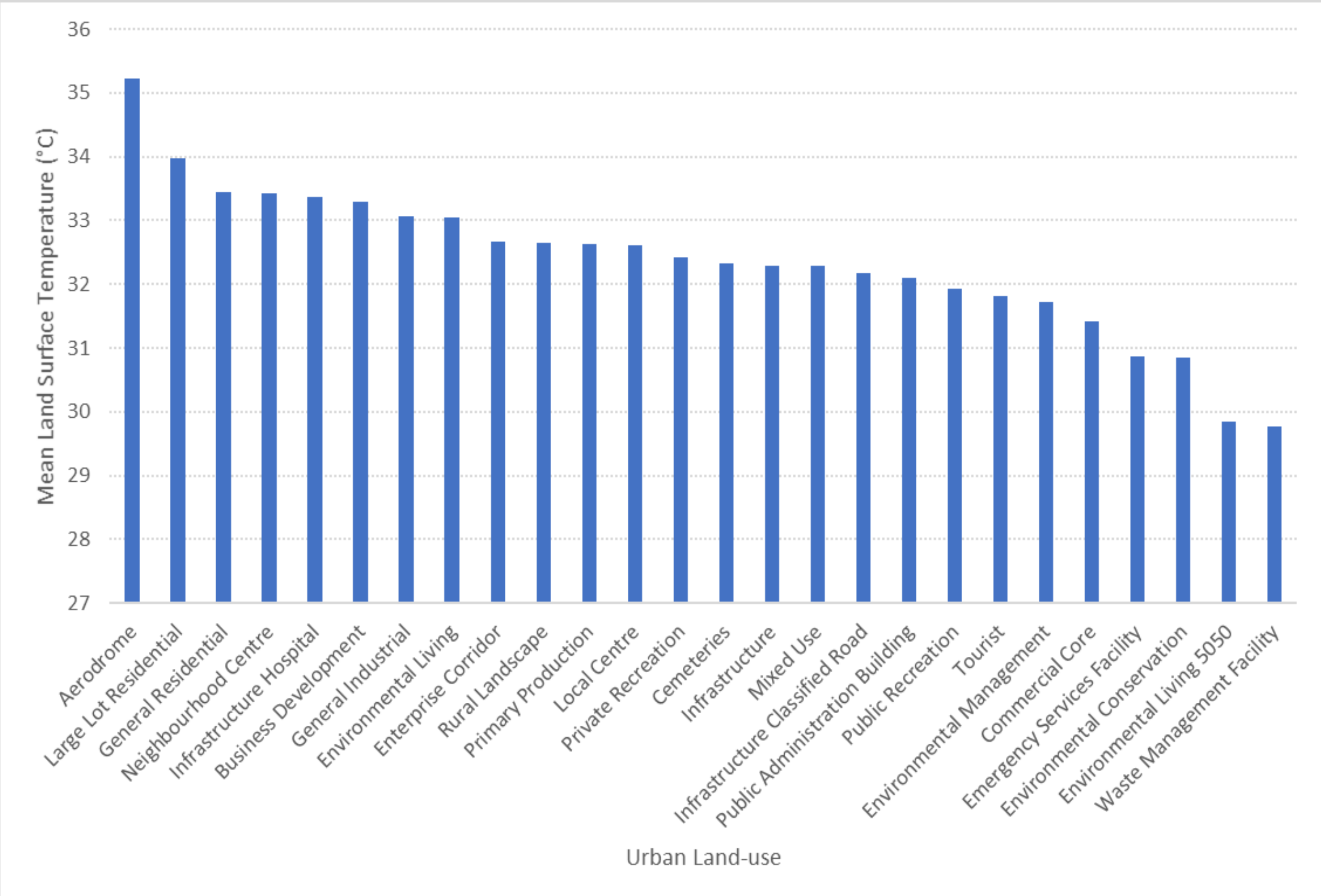


Figure 3-8 Mean land surface temperature (°C) for each Land-use Zone (based on Landsat 8 TIR imagery for 8 December 2019, 09:44 DST)

3.2.2 Influence of percentage tree canopy cover on urban land surface temperature

A correlative analysis between mean ULST and percent tree canopy cover within each land-use type revealed that there was a strong negative correlation between tree cover and temperature, statistically confirming that increasing tree canopy cover has a significant cooling influence on the mean ULST of land-uses (Figure 3-9). The combination plot in Figure 3-10 shows mean ULSTs and mean % tree canopy cover associated with each land-use, reflecting this correlation. In Figure 3-11 land-uses have been combined into broader land-use categories based of similar functionality, namely 'commercial', 'industrial', 'residential', 'non-urban', 'transport & services' and 'parks & recreation', with associated ULST and % tree canopy cover plotted together. The broader land-use groupings demonstrate the negative correlation of decreasing ULST with increasing % tree canopy even more strongly. The 'commercial' category showed a lower ULST due to a small dense stand of remnant forest on one commercial block which significantly reduced the overall mean ULST for the category as a whole, effectively demonstrating the strong degree of influence dense tree canopy has on reducing land surface temperature.

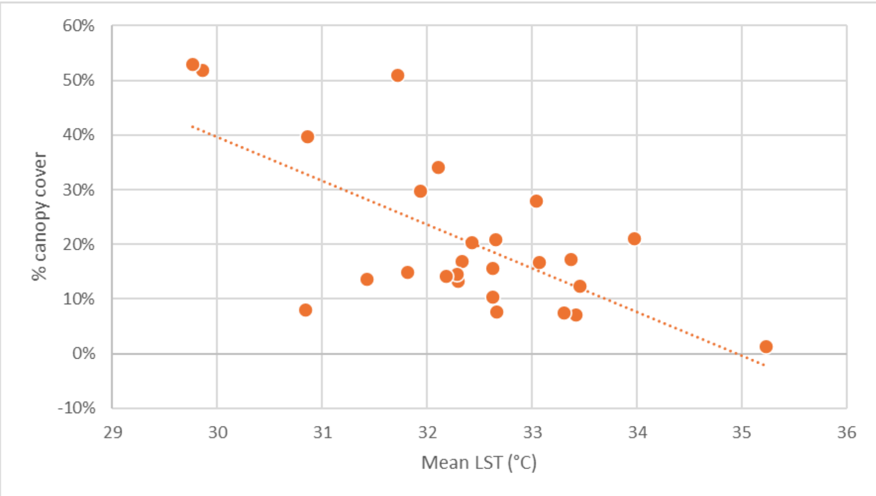


Figure 3-9 Correlation plot between ULST and % tree canopy cover showing a high negative correlation (r = -0.6831). The points represent mean ULST and percent tree canopy cover within each land-use type plotted against each other

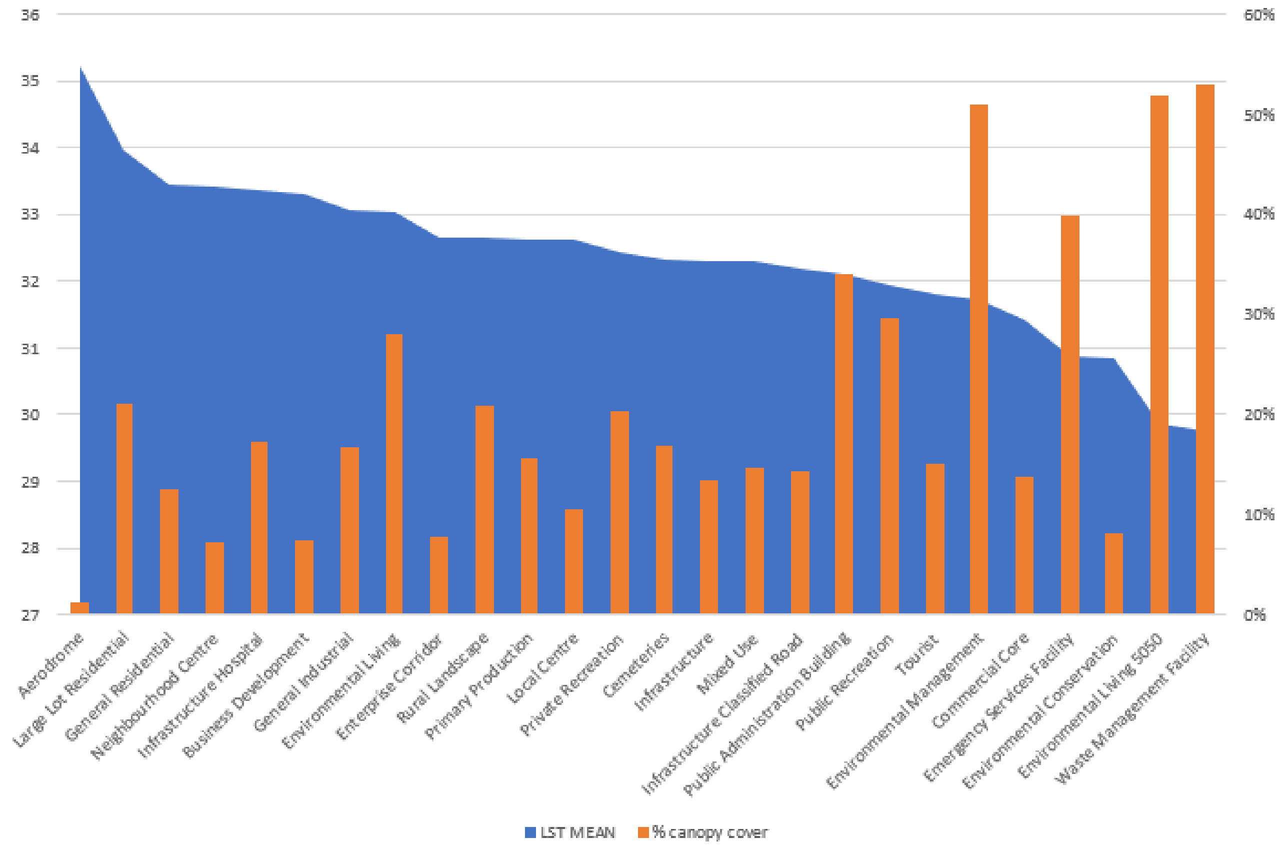


Figure 3-10 Combination plot of ULST related to each land-use type plotted against the % canopy associated with the land-use type. The plot shows how LST increases with decreasing % tree canopy cover

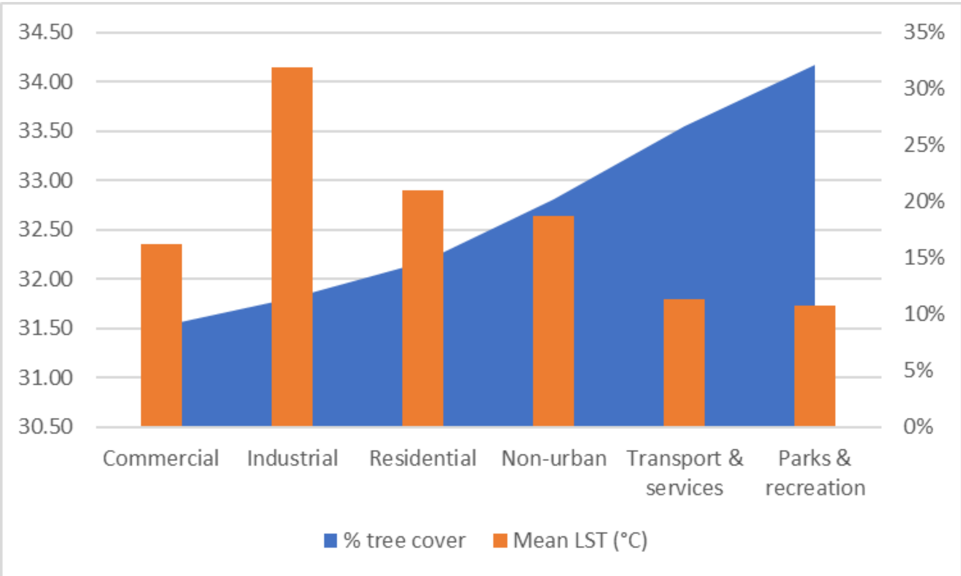


Figure 3-11 Combination plot showing ULST (left y axis) associated with broad land-use activities against percent tree canopy cover (right y axis)

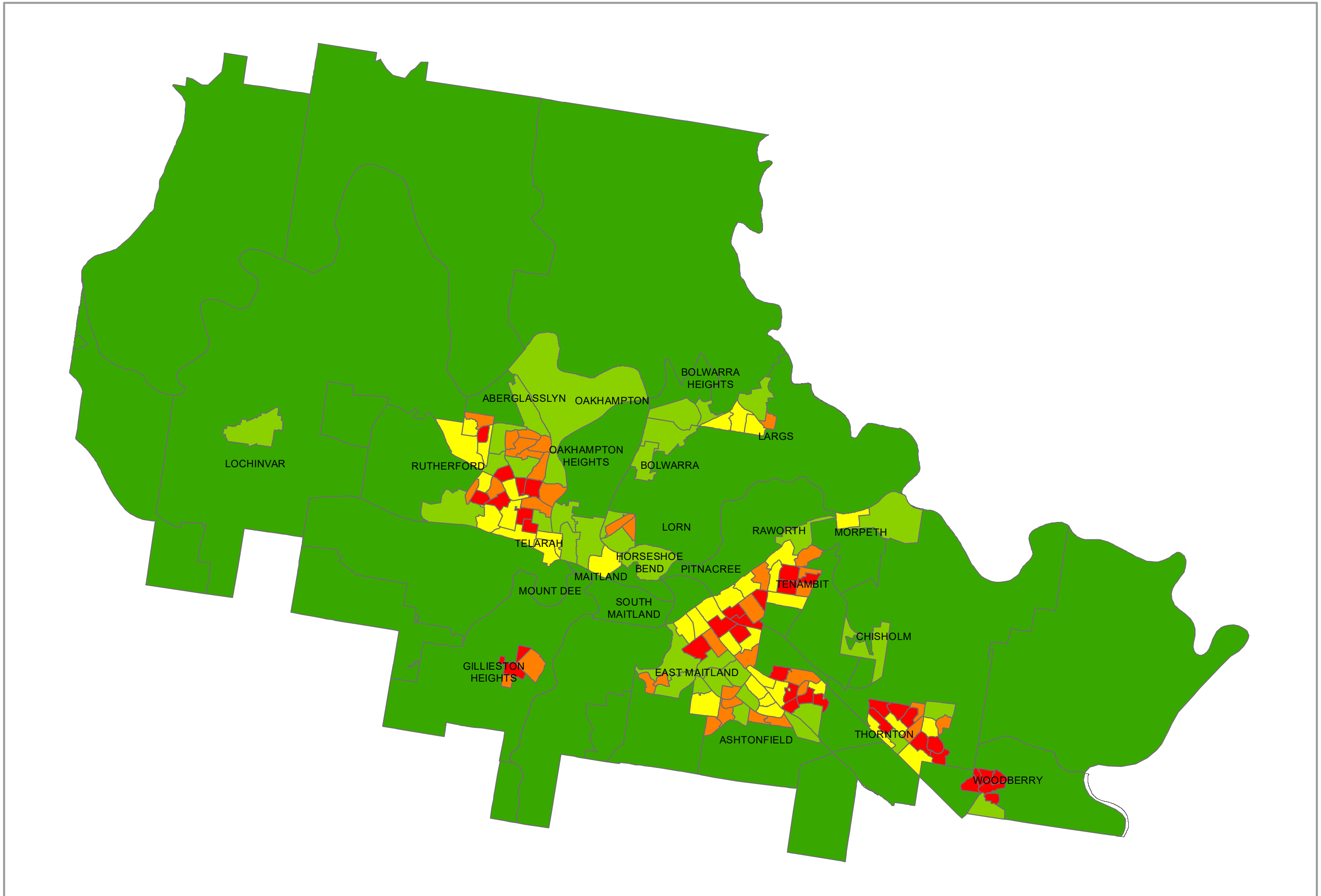
3.2.3 Influence of impervious surface on urban land surface temperature

Results derived from a correlative analysis between iTree Canopy-derived estimates of impervious surface and mean suburb LST were inconclusive. The scale of the input data (i.e., the use of generalised mean parameter values of both LST and impervious surface estimates across whole suburbs) was not appropriate for the scale of the analysis. The mean values do not adequately reflect the full range of value variability across whole suburbs, which is essential for detecting correlation between the feature types being considered (i.e., fairly fine-scale features such as roads and roof tops) and LST. It is recommended that the correlation analysis be repeated using high resolution spatial data, such as LiDAR-derived impervious surface cover, when it becomes available.

3.2.4 Influence of gross dwelling density and dominant dwelling structure on urban land surface temperature

Gross private dwelling density (GPDD) mapped by SA1 revealed that suburbs with highest dwelling density were Rutherford, East Maitland, Tenambit, Thornton, Gillieston Heights and Woodberry (Figure 3-12).

Figure 3-12 Gross private dwelling density displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Gross Private Dwelling Density (dwellings/km2) within SA1 areas

- 0 - 134
- 135 - 515
- 516 - 764
- 765 - 947
- 948 - 1561
- Surburb boundary

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0 0.5 1 2 Km

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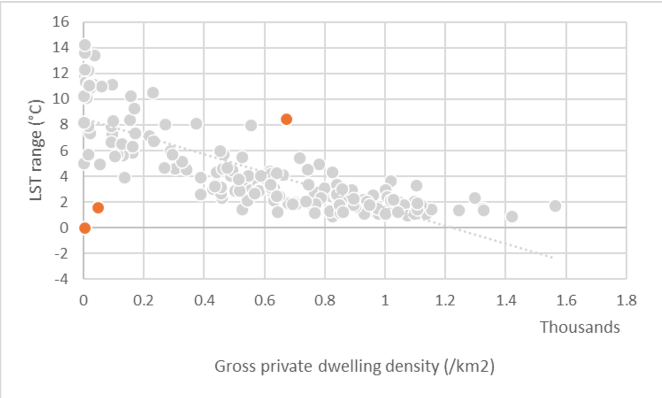
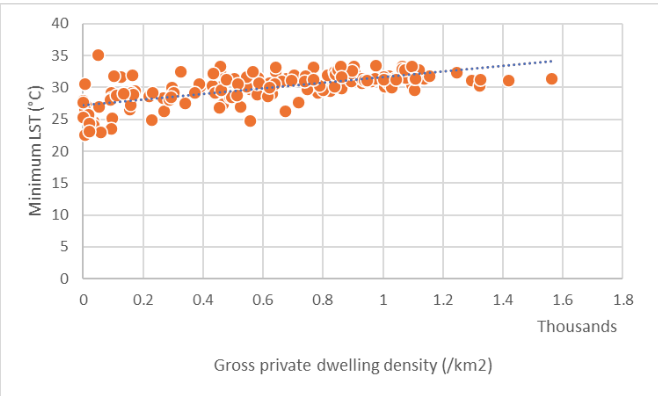
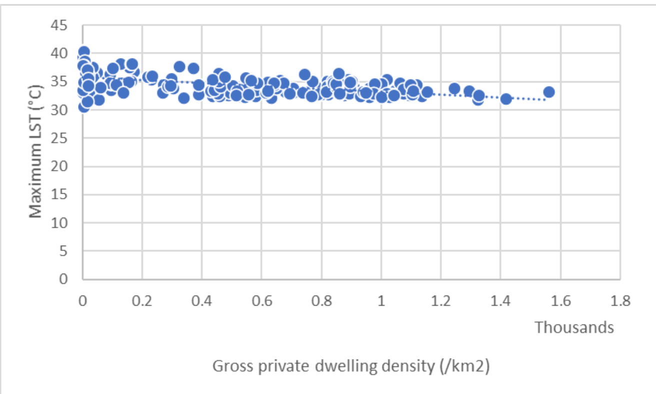
While correlative analysis between gross private dwelling density (GPDD) and mean ULST (by statistical area level 1 (SA1)) revealed no significant relationship, the analysis did however show a strong negative relationship between dwelling density and temperature range, as well as a strong positive correlation between dwelling density and minimum LST. While dwelling density was correlated with maximum ULST, there was no apparent positive or negative trend. These results suggest that areas with a lower gross dwelling density tend to have more variation in temperature across the neighbourhood (i.e., there are cool spots as well as hotspots present), but as the GPDD increases this temperature variation disappears until a point is reached where the neighbourhood is uniformly hot without any cooler 'refuges' (Figure 3-13A-C).



A



B



C

Figure 3-13 Statistical plots showing Gross Private Dwelling Density correlated with (A) LST range (r = -0.7888), (B) minimum LST (r = 0.7154), and (C) maximum LST (r = -0.5256) within SA1 areas

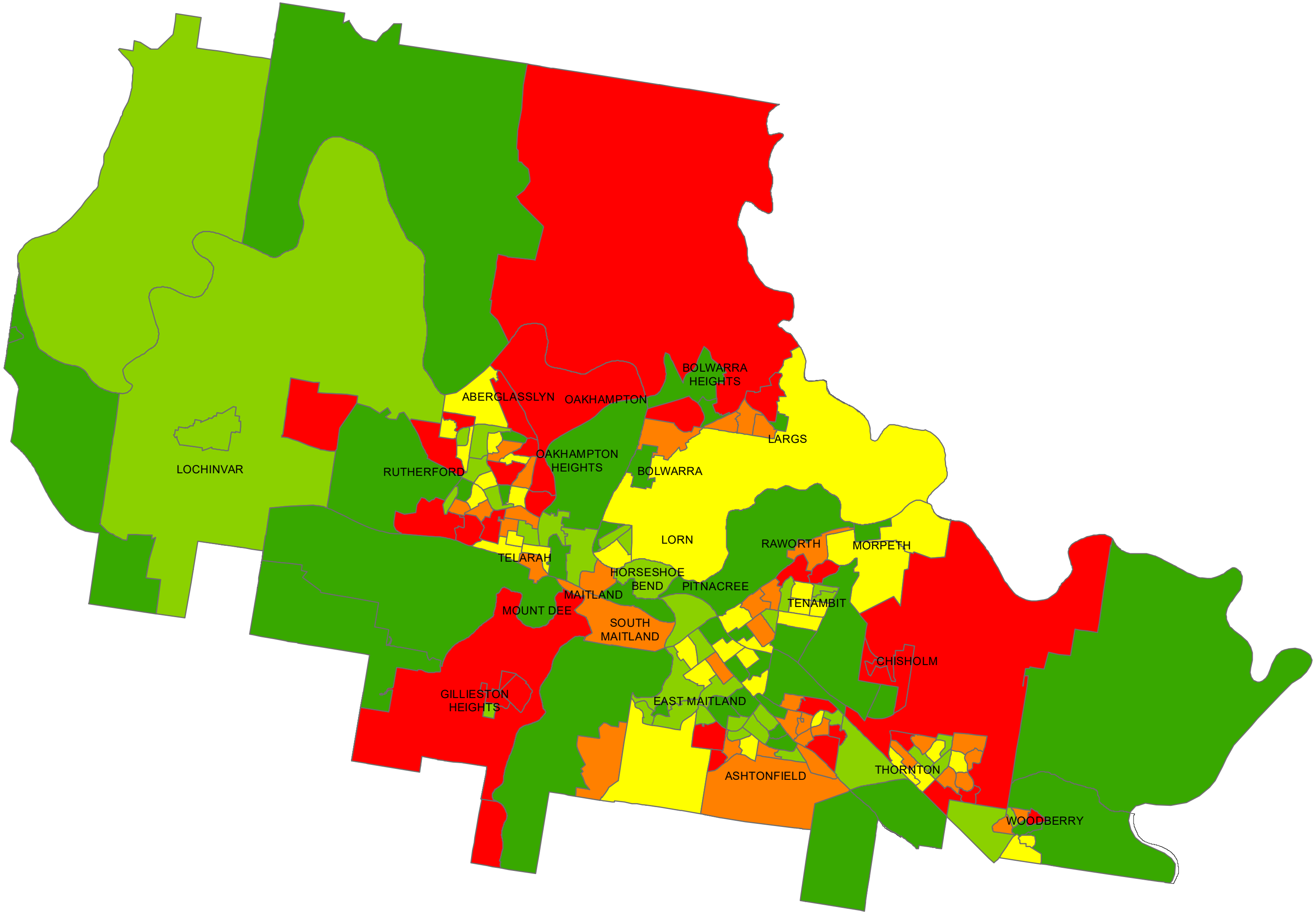
An examination of the effect dwelling structure has on urban land surface temperature revealed that of the five types of dwelling structure considered (i.e., separate house dwellings, semi-detached/terraced dwellings, flats/apartment buildings, other dwelling types and unoccupied dwellings), separate house dwellings were the dominant dwelling type within every neighbourhood. Due to the dominance of separate house dwellings across every neighbourhood in the Maitland LGA there is insufficient data to determine which dwelling structures create the strongest heating effect in the Maitland LGA. Data from other studies should be used to determine this.

3.3 Heat-related population vulnerability

An analysis of the distribution of vulnerability factors revealed there is not a high incidence of overlap between SA1 neighbourhoods with high numbers of young children (Figure 3-14) and those with high numbers of elderly (Figure 3-15). By contrast, there is a greater incidence of spatial overlap between SA1 neighbourhoods supporting the elderly and those requiring disability support services (Figure 3-16). This is largely due to both groups locating more towards the urban areas. Low-income groups are also primarily located within the urban zones (Figure 3-17). Highest population densities were located within SA1 neighbourhoods, in the urban zones of Rutherford, East Maitland, Tenambit, Thornton, Woodberry, Gillieston Heights and Ashtonfield (Figure 3-18).

The distribution of combined or aggregated HRPV scores are displayed in Figure 3-19, showing that neighbourhoods with highest heat vulnerability are located within Aberglasslyn, Rutherford, Gillieston Heights and Oakhampton which have neighbourhoods with scores of '4', and South and East Maitland, Woodberry, Maitland, Metford and Largs, which contain neighbourhoods which reach scores of '3'.

Figure 3-14 Number of children 0 - 4 years old displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Number of children 0-4 years by SA1

- 0 - 16
- 17 - 23
- 24 - 29
- 30 - 40
- 41 - 324
- Surburb boundary

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Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

0 0.5 1 2 Km

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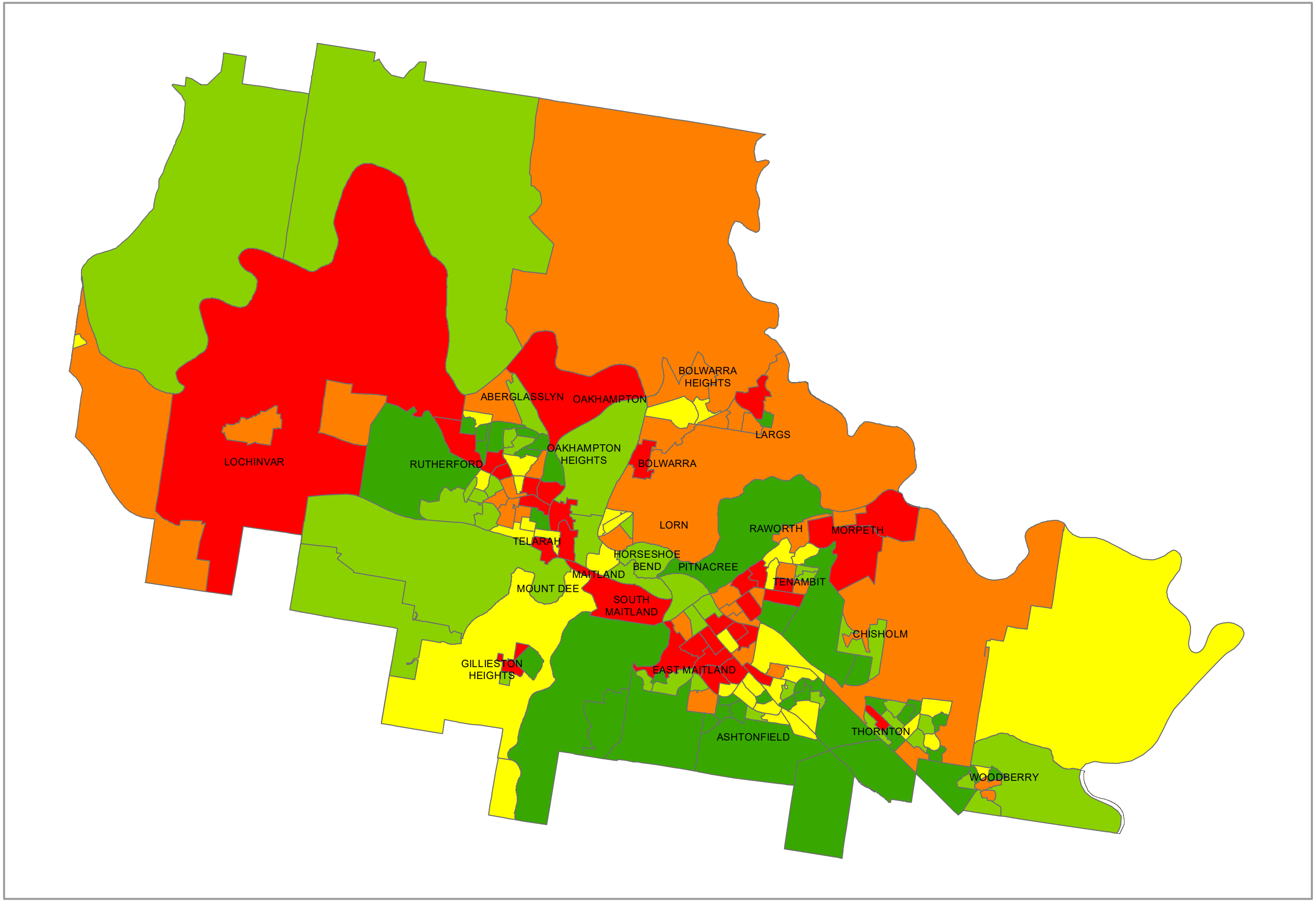
Figure 3-15 Number of over the age of 65 years old displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Number of people over the age of 65 years

- 0 - 32
- 33 - 50
- 51 - 66
- 67 - 84
- 85 - 308
- Surburb boundary

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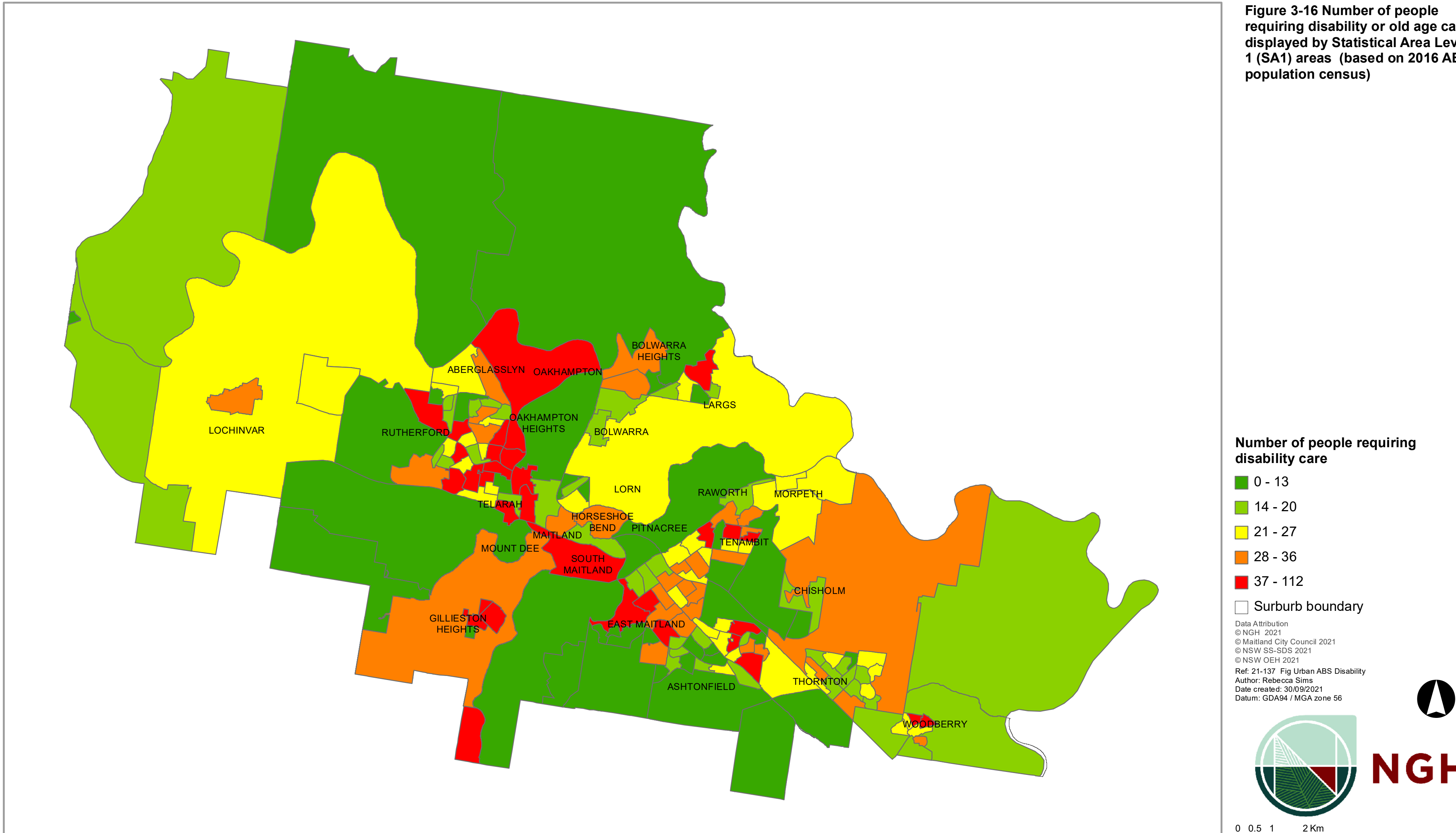
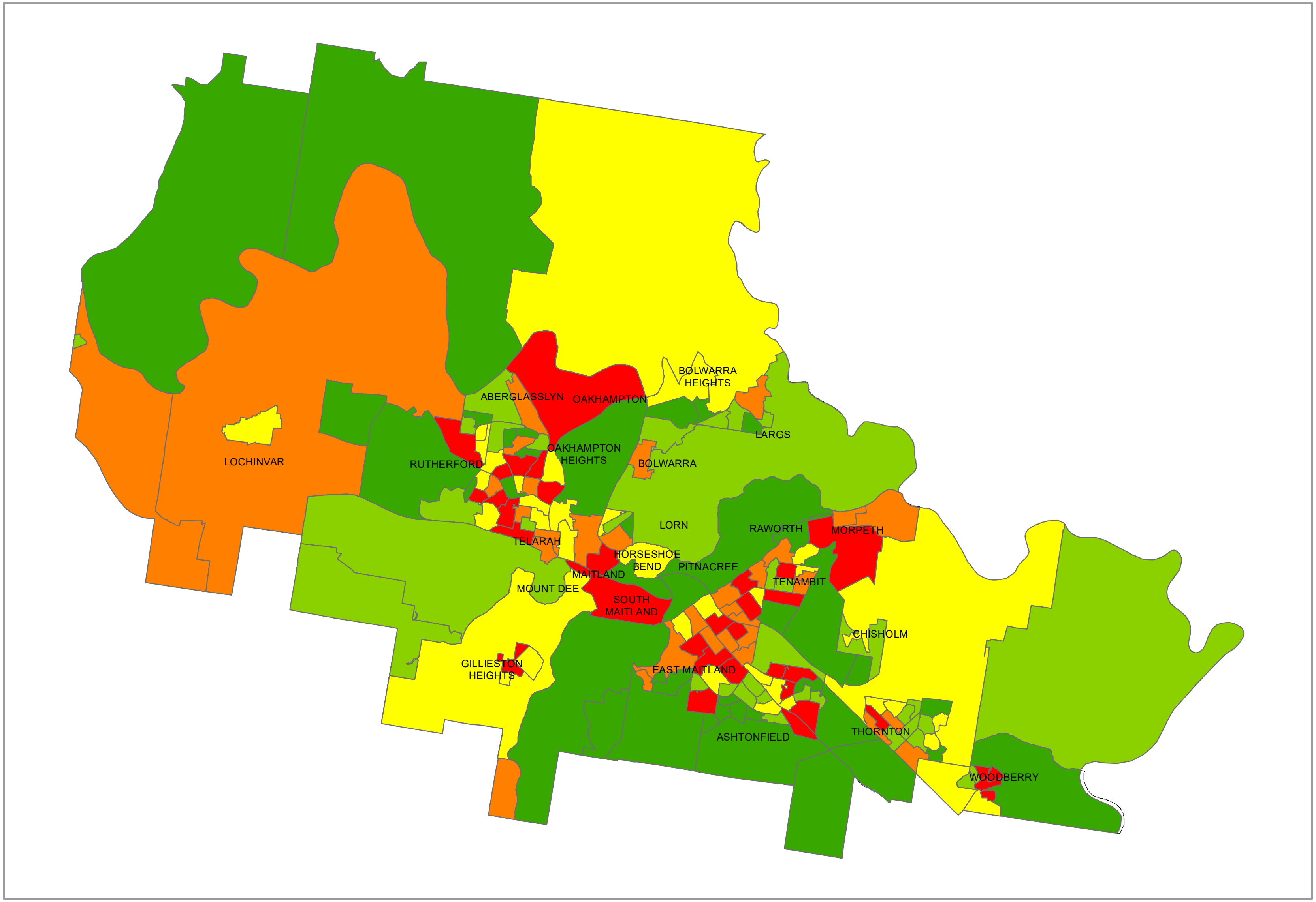
Service Layer Credits:

Figure 3-16 Number of people requiring disability or old age care displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Service Layer Credits:

Figure 3-17 Number of low income earners (earning <$799/week or <$41,548 p.a.) displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Number of low income earners by SA1

- 0 - 5
- 6 - 9
- 10 - 12
- 13 - 18
- 19 - 65
- Surburb boundary

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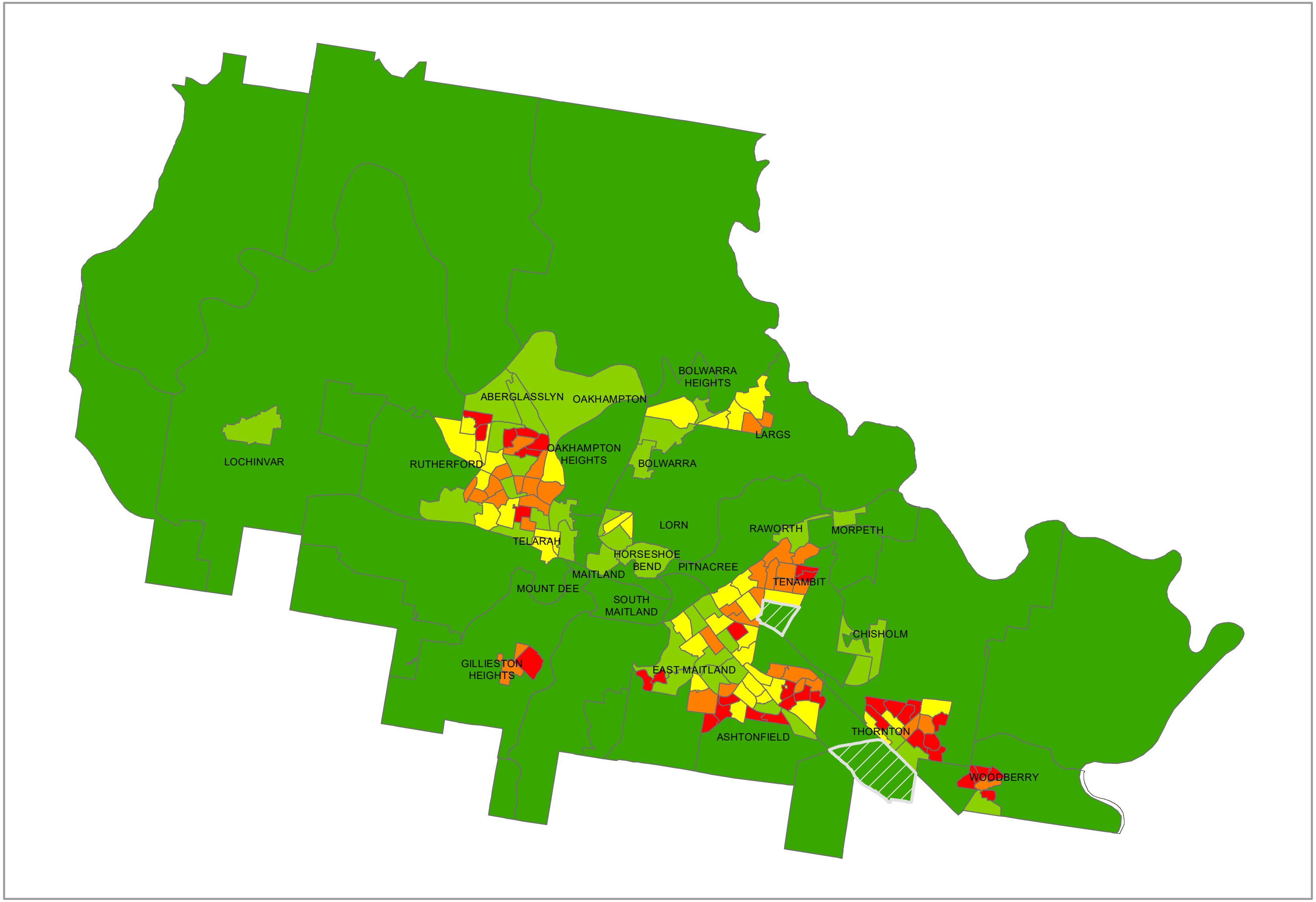
Ref: 21-137 Fig Urban ABS Low Income
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

NGH

0 0.5 1 2 Km

Service Layer Credits:

Figure 3-18 Population density (individuals/km2) displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Unoccupied SA1's

Population density (individuals/km2)

- 0 - 338
- 339 - 1264
- 1265 - 1892
- 1893 - 2449
- 2450 - 3800

Surburb boundary

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Ref: 21-137 Fig Urban ABS Population density
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

0 0.5 1 2 Km

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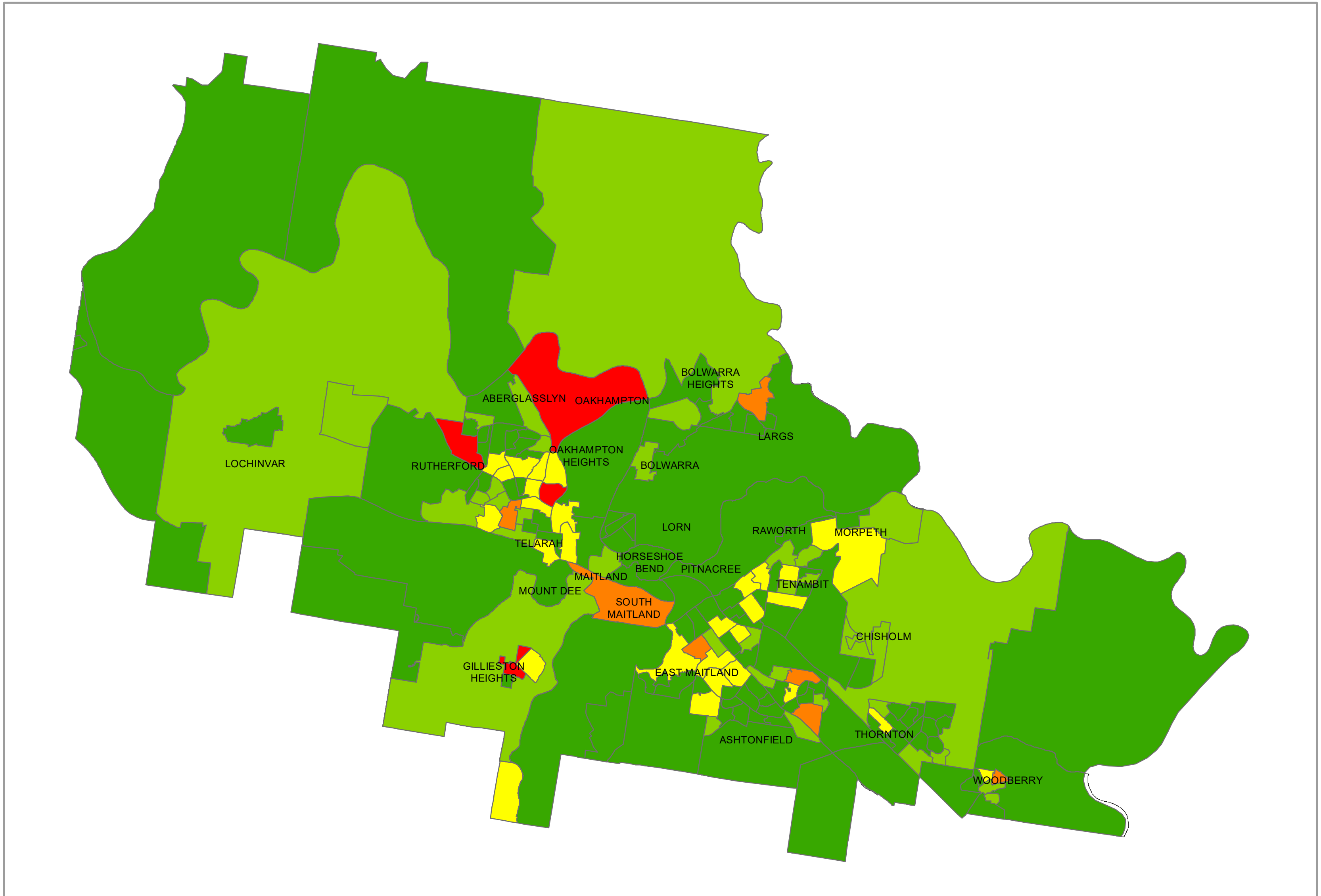
Service Layer Credits:

Figure 3-19 Heat-related vulnerability score displayed by Statistical Area Level 1 (SA1) areas (based on 2016 ABS population census)



Heat-related Vulnerability Score

- 0 - Lowest vulnerability
- 1
- 2
- 3
- 4 - Highest vulnerability
- Surburb boundary

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Ref: 21-137 Fig Urban Heat Score by SA1
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

NGH

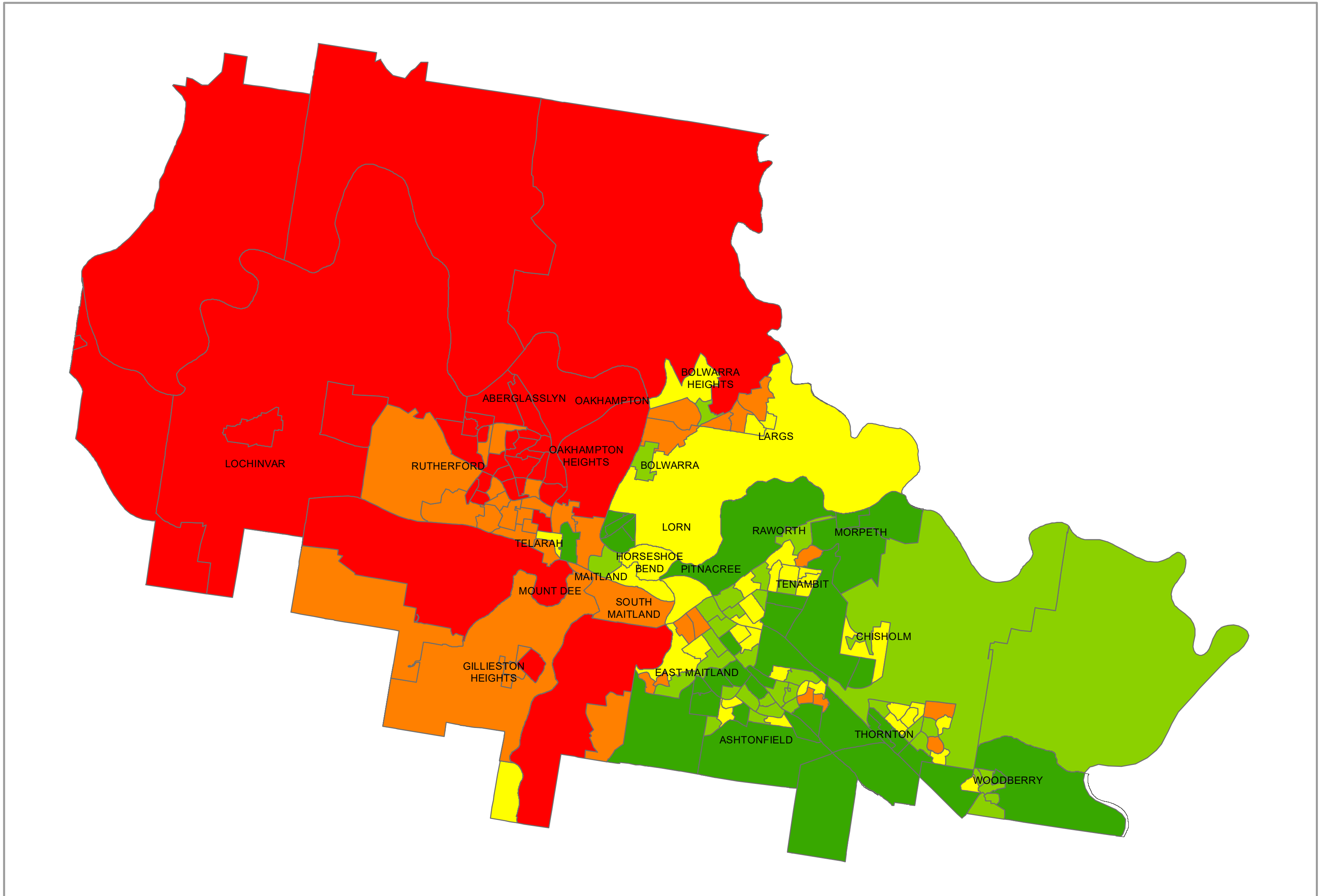
0 0.5 1 2 Km

Service Layer Credits:

3.4 Vulnerable populations in hot neighbourhoods

Mean LST mapped by SA1 areas shows that the 20% hottest neighbourhoods are primarily located within western suburbs of the LGA (Figure 3-20). When overlaid with the spatial locations of highest heat vulnerability scores, the most vulnerable populations within hot neighbourhoods become evident. Figure 3-21 shows HRPV scores within the 20% hottest neighbourhoods, while Figure 3-22 shows heat vulnerability scores within the 40% hottest neighbourhoods. Suburbs with communities with highest heat-related health risk are Aberglasslyn, Rutherford, Gillieston Heights and Oakhampton which occur within the 20% hottest neighbourhoods (Figure 3-21), and South Maitland, Maitland and Largs, which contain neighbourhoods which reach scores of ‘3’ occur within the 40% hottest neighbourhoods (Figure 3-22). Raworth and Metford each have SA1 neighbourhoods which score ‘1’ in this latter region too. Table 3-1 summarizes the mean LST, % tree canopy cover and maximum HRPV score occurring within each suburb.

Figure 3-20 Mean land surface temperatures for SA1's (displayed in 20th percentiles)



Mean LST (°C) by SA1

- 27.7 - 31.5
- 31.6 - 32.1
- 32.2 - 32.6
- 32.7 - 33.7
- 33.8 - 35.9
- Surburb boundary

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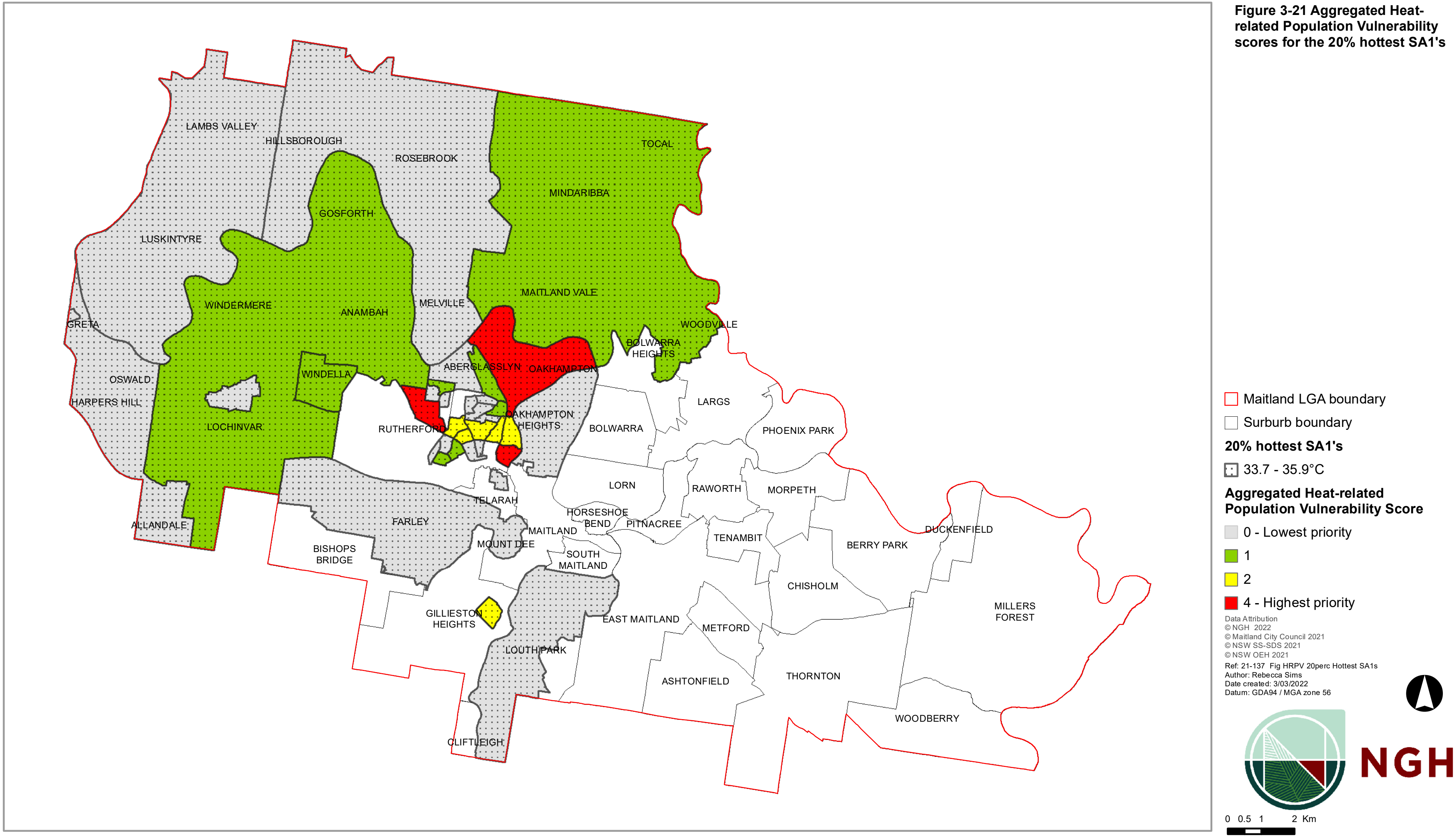
Ref: 21-137 Fig LST by SA1
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

NGH

0 0.5 1 2 Km

Service Layer Credits:

Figure 3-21 Aggregated Heat-related Population Vulnerability scores for the 20% hottest SA1's



Service Layer Credits:

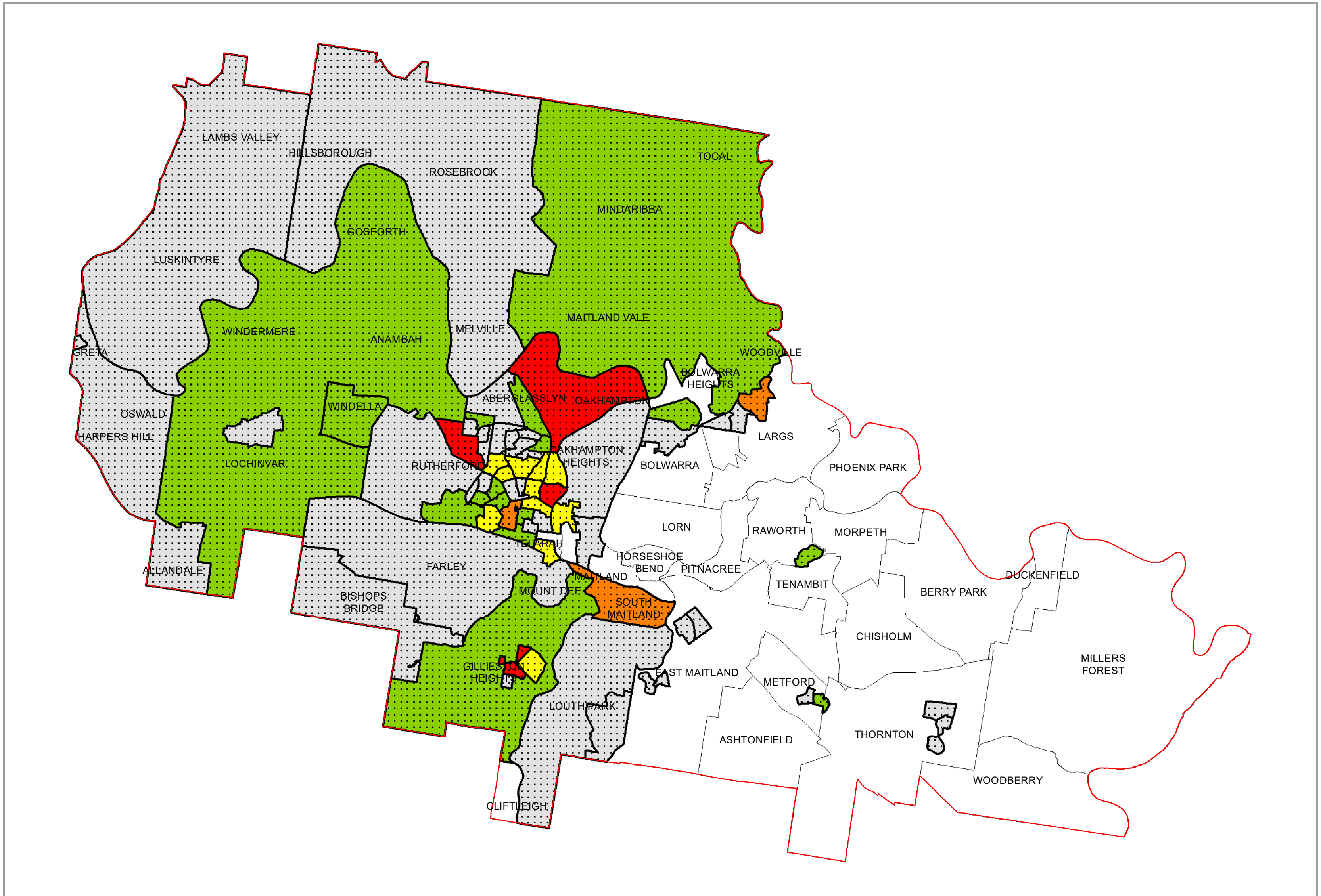


Figure 3-22 Aggregated Heat-related Population Vulnerability scores for the 40% hottest SA1's

Maitland LGA boundary

Surburb boundary

40% hottest SA1's

32.6 - 35.9 °C

Aggregated Heat-related Population Vulnerability Score

0 - Lowest priority

1

2

3

4 - Highest priority

Data Attribution
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Ref: 21-137 Fig HRPV 40perc Hottest SA1s
Author: Rebecca Sims
Date created: 30/09/2021
Datum: GDA94 / MGA zone 56

0 0.5 1 2 Km

Service Layer Credits:

Table 3-1 Summary of mean LST, % tree canopy cover and maximum HRPV score by suburb

Suburb name	Mean LST (°C)	% Tree Canopy Cover	Maximum HRPV Score
ABERGLASSLYN	34.83	11%	4
ALLANDALE	33.08	40%	0
ANAMBAH	35.76	9%	1
ASHTONFIELD	29.65	54%	1
BERRY PARK	32.51	5%	1
BISHOPS BRIDGE	33.25	23%	0
BOLWARRA	33.10	9%	1
BOLWARRA HEIGHTS	32.93	19%	1
CHISHOLM	31.86	19%	1
CLIFTLEIGH	32.41	1%	2
DUCKENFIELD	32.67	7%	1
EAST MAITLAND	31.25	26%	3
FARLEY	33.94	23%	0
GILLIESTON HEIGHTS	33.10	6%	4
GOSFORTH	35.13	16%	1
GRETA	34.14	26%	0
HARPERS HILL	34.10	26%	0
HILLSBOROUGH	34.41	19%	0
HORSESHOE BEND	32.30	9%	0
LAMBS VALLEY	33.85	30%	0
LARGS	32.41	6%	3
LOCHINVAR	35.08	12%	1
LORN	32.46	8%	0
LOUTH PARK	33.89	6%	0
LUSKINTYRE	35.70	13%	0
MAITLAND	33.15	11%	3
MAITLAND VALE	34.65	16%	1
MELVILLE	35.48	8%	0
METFORD	31.46	26%	3
MILLERS FOREST	31.52	4%	0
MINDARIBBA	34.43	23%	1
MORPETH	31.18	7%	2
MOUNT DEE	36.20	1%	0
OAKHAMPTON	34.75	6%	4
OAKHAMPTON HEIGHTS	32.55	23%	0
OSWALD	34.70	6%	0
PHOENIX PARK	31.73	2%	0
PITNACREE	31.12	3%	0
RAWORTH	31.73	6%	1
ROSEBROOK	33.77	28%	0
RUTHERFORD	33.64	14%	4
SOUTH MAITLAND	33.58	6%	3

TELARAH	33.21	10%	2
TENAMBIT	31.63	16%	2
THORNTON	30.03	38%	2
TOCAL	32.96	25%	1
WINDELLA	35.01	21%	1
WINDERMERE	36.18	11%	1
WOODBERRY	30.44	7%	3
WOODVILLE	32.66	2%	1

Scores of '3' and '4' indicate highest heat related vulnerability and, when coupled with high LST's, are of highest priority (highlighted in orange and red respectively), whereas scores of '1' and '2' indicate lower heat-related vulnerability (highlighted in green and yellow respectively). A score of '0' indicates lowest heat-related vulnerability, implying lowest priority for mitigation (highlighted in grey).

3.5 Limitations

1. The current analysis represents a snapshot in time as most data used in the analysis are time dependent. For example, the heat-related vulnerability criteria are based on 2016 ABS census data and all Land Surface Temperature and NDVI calculations are based on imagery captured in December 2019. It is therefore recommended that follow up analyses be carried out at regular intervals as and when these datasets are updated to ensure understanding of heat-related vulnerability is relevant to the most up-to-date population information.
2. There is a need for further research and ongoing data collection. For example, land-use zoning as used in the current study delineates future planned land-use and doesn't necessarily represent current land-use and land-cover. Analysis results could be improved for understanding of current conditions by repeating study of land use/cover impact on LST using the Australian Land Use and Management classification system. Ground-truthing and ongoing data collection is recommended as changes in land-cover from grassland to residential land-use will experience changes in daytime LSTs as well as corresponding increases in urban heat island effect. Land cover types like bare ground, dark paving and building materials typically develop high surface temperatures on hot days. However, over time their surface characteristics and consequently their associated surface temperatures will change. Ongoing monitoring could help determine the magnitude of this change over time.
3. Identifying the impact of topography and coastal impacts on observed LST. To facilitate reliable like-for-like comparisons of land-use and -cover LST responses between different regions within the LGA, it is necessary to further analyse and ascertain the impact of factors such as topography and coastal impacts on observed LST.
4. Difference between air temperature and land surface temperature. While land surface temperatures are useful for gauging level of exposure to urban heat, there is not always a direct relationship with air temperature. For example, land surface temperatures are most similar to near-ground air temperatures in the early morning, however LSTs become more variable later in the day and respond rapidly to shadow (e.g., due to passing cloud).

   Similarly, there can be a disconnect between rooftop temperatures on tall buildings and temperatures measured at street level. An effective framework for monitoring and measuring effects of urban heat should include a carefully considered network of air temperature monitoring stations.

5. Insufficient data granularity to determine impact of building types and construction material. For example, MODIS with its 100m x 100m cell size is too coarse-scale for discerning fine-scale LST trends. To improve our current understanding of persisting night-time SUHI's within the Maitland urban zone to a feature level on the ground, the night-time LST response should be re-analysed using night-time Landsat 8 imagery (available by special order through USGS EROS). Even higher definition can be achieved using drone-borne sensors. Drone technology not only allows for improvements in data resolution, but also allow for more frequency and flexible transect flyovers of hotspot areas.

4. Discussion

4.1 Patterns of day-time hotspots and night-time urban heat island

Analyses within the study revealed that the Maitland LGA heats up significantly in summertime, with recorded surface temperatures reaching 40.5°C at 09:44 (DST) on 8 December 2019 (based on Landsat 8 TIR imagery). While measured air temperatures did not get as high on the day (maximum air temperature measured at Maitland Airport reached 30.4°C), surface heat has the ability influence local microclimates within some built-up areas. Furthermore, highly urbanised landscapes featuring a high density of man-made structures and impervious surfaces have the ability to store much of this heat and are slow to release the heat at night-time, resulting in a phenomenon known as surface urban heat island (SUHI) effect.

This study confirms that Maitland does indeed have a heat island at night within its urban zone that is about 3.7°C warmer in the summer than surrounding rural areas (based on night-time MODIS LST measurements at 23:45 in the evening (DST) on 9 December 2019). Suburbs exhibiting this phenomenon most strongly at this time were East Maitland, Rutherford, Maitland, Horseshoe Bend, Pitnacree and parts of Metford and Ashtonfield. However, it should be remembered that as urbanisation continues to expand and natural land surfaces continue to transform into built ones, the extent of this effect is likely to similarly expand and, in some cases, intensify.

An examination of the influence of land-use on daytime LSTs within the urban zone revealed that two key land-cover characteristics affect surface temperature most strongly, namely, % tree canopy cover and extent/density of impervious surface. Land-uses which exhibited highest day-time temperatures with a corresponding heat lag at night-time were industrial, commercial and residential land-uses. A strong negative correlation was identified between % tree canopy cover and LST, indicating that increasing tree canopy cover has a significant cooling influence on surface temperatures. Tree canopy-dominated land-uses had the lowest day-time temperatures, as well as the lowest night-time temperatures. Dense forest stands were the most temperature stable, experiencing the smallest variation in temperature throughout the day.

In summary, key findings included:

- Areas with above-mean surface temperatures are characterised by large expanses of impervious surface cover (i.e., rooftops, paving, parking lots, dense road network) and few trees, common in commercial and industrial areas, car parks and new housing developments.
- Established residential areas with elevated LSTs were generally characterised by low tree canopy cover and higher dwelling densities.
- While the eastern urban suburbs are significantly cooler than the western urban areas due to cooling effects from the coast, comparisons within the eastern, central, and western regions show that the coolest areas in summer typically have dense tree canopy cover, have green irrigated vegetation and/or are near waterbodies (i.e., rivers, lakes, dams). Forested areas represented the most temperature stable land surface types.
- While grass-dominated land cover types (e.g., sports fields and open paddocks) experienced the highest daytime LSTs, they also experienced highest differences in day-night LST temperatures, indicating that these areas are not prone to urban heat island effect. Furthermore, these natural surfaces are able to absorb water, enabling them to provide an evaporative cooling effect through evapotranspiration. Visual comparisons between sports fields showed that those with tree canopy cover present were noticeably cooler than those without, suggesting that additional peripheral tree canopy should be

encouraged to ensure the thermal comfort, minimise UV exposure, etc. of people who use these spaces.

4.2 At-risk communities in hottest neighbourhoods

Heat-related health risk may be greatest when communities with high heat-related vulnerability are living in the hottest neighbourhoods. Neighbourhoods with high heat exposure combined with high population vulnerability were located in Aberglasslyn, Rutherford, Gillieston Heights, South Maitland, Telarah, Maitland and Largs. These neighbourhoods are characterised as being located within the 40% hottest areas within the LGA and, as indicated by their HRPV score ≥ 3, also support the 80th percentile or top 20% of children aged 0-4 years, older people aged over 65 years, people requiring disability assistance and low-income households, earmarking them for highest priority heat mitigation actions (Figure 3-22).

5. Recommendations based on study findings

5.1 Short-term recommendations

Undertaking ongoing monitoring of LST and street-level air temperature and research to address the aforementioned limitations

- While satellite-based measurement of LST is a low-cost means of identifying and prioritising neighbourhoods for heat mitigation actions, these methods rely on assumed relationships between LST and air temperature. An important next step is to verify and validate the findings of this project with field-based measurements. Based on what has been learned from the current study, such measurement could be targeted within day-time hotspot areas and persistent night-time SUHI areas, with priority given to neighbourhoods with high risk HRPV communities. Opportunities could be identified where installation of measurement sensors could be deployed in tandem with existing or proposed new MCC initiatives or projects (e.g., the LED street lighting role out may present an opportunity for deploying sensors to monitor street temperature). Other emerging technology innovations should also be considered such as identification, deployment, and utilisation of 'Internet of Things' (IoT) sensors to facilitate near real time measurement of temperature (ambient and surface) across the city.
- Establish an urban heat monitoring program using satellite thermal imagery and field measurements to evaluate heat mitigation actions
- Verify the relationship between surface and air temperatures through the day with field-based measurements
- Determine the level of air and land surface temperature reductions that can be achieved through the implementation of different combinations of urban heat mitigation strategies. Potentially this could be achieved through a literature review but would also require some practical application to test responses under local conditions.

Focus mitigation actions within priority communities:

- Priority areas for targeted urban heat mitigation actions have been identified. It is recommended that the baseline data in the form of the LST mapping, urban heat island mapping, NDVI mapping and LiDaR-based tree canopy mapping, along with the collated population information by neighbourhood be used to identify focussed actions which cater for the specific conditions within each neighbourhood. For example, understanding the land-uses present and the characteristics of those land-uses responsible for elevated LST in the area, as well as designing mitigation strategies focussing on the at-risk members of the community.

Reduce loss of existing tree canopy cover, especially dense mature forest communities:

- Urban development appears to be the biggest cause of tree canopy removal. Removal of dense tree canopy has the immediate effect of acutely increasing the LST of an area as it often results in bare ground with no canopy cover. The time and cost required to replace mature tree canopy is significant. It is therefore recommended that Council engage with developers to plan and design new residential neighbourhoods with the aim to maximising retention of existing tree cover. Forested corridors supporting dense mature canopy have the highest stabilising impact on temperature. Where appropriate, it would be beneficial to impose protection of such dense mature canopy as a condition of development approval.

Provide incentives for developing without removing all existing vegetation. Council could consider incentives for the retention of vegetation, such as:

- Reduced development application or subdivision fees for development that proposes a reduced yield in order to retain vegetation patches
- Lower percentage applied to the long service payments levy
- Reduced maintenance periods where areas of retained vegetation will be handed over to Council as part of an infrastructure contribution.

Increase tree canopy cover through strategic planting schemes:

- Research in China has shown that for every 10% increase in the green space ratio, the land surface temperature drops by 0.4°C, and per kilometre increase in the distance from the forest park, the land surface temperature increases by 0.15°C (Amani-Beni et al. 2019), confirming that careful and strategic design of green spaces within urban areas can provide significant cooling benefits. It is recommended that a spatial analysis be carried out which applies these research findings to understand the gaps in the current green space network and to identify strategic locations where improved green infrastructure might provide maximum cooling benefits to urban areas.
- Based on the findings of the Maitland Vegetation Assessment 2021 (NGH 2021) currently 7% of tree canopy is located on Council-controlled properties (434.7ha out of a total of 6,456.4ha). As Council-controlled properties cover a total area of 1,331.6ha, these spaces present an opportunity for increasing tree canopy cover to some degree. It is recommended that MCC maximise tree canopy cover on all Council-controlled properties, where practical, by planting appropriate native tree species.
- The road network represents an important opportunity in terms of providing green infrastructure to urban areas through streetscape planting. It is recommended that MCC develop and roll out a strategic street planting scheme which identifies appropriate native tree species to plant within selected road reserve areas and road verges to provide community shade and habitat and connectivity for local fauna species.
- New development plans could be encouraged to build ‘green hearts’ and/or ‘green corridors’ which ideally either retain mature canopy or alternatively incorporate a planting scheme which demonstrates a design which will be effective at providing cooling benefits (e.g., appropriate tree species, sufficient height and canopy span, planting density, undergrowth species, width of corridor)
- Consider offsets – when mature tree canopy is removed, it should be replaced elsewhere. As a last resort. when mature tree canopy is removed there will be a heating effect and it will take years to reduce the impact through tree planting. Offset mechanisms should extend to private development/lands and include financial mechanisms

Reduce the UHI-inducing impact of building materials used:

- It is recommended that a list of building materials, products and approaches which enhance cooling (i.e., reduce SUHI effect) be identified. Thereafter, it is recommended that MCC engage with the building industry to identify and or trial these ‘cooling’ materials and products, under local conditions.

- A project should be undertaken which identifies low-cost urban heat mitigation actions which can be incorporated as part of existing work programs
- The effectiveness and costs of a range of treatments should be evaluated or compiled from existing sources for potential future implementation to existing buildings and structures.

5.2 Strategic planning for transformational change

Strategic urban planning is essential to mitigating the UHI effect and should be targeted at reducing adverse heat effects at the local (suburb) level (Mohajeri et al 2021), as well as LGA-wide. This UHI analysis provides for the development and application of data-driven planning measures to mitigate urban heat at this scale.

It is critical that planning controls are implemented to avoid exacerbation of the UHI problem in the future, however measures should also encompass existing development and prioritise strategies and controls implemented by Council on public land. Controls that rely on private landholders are an important element in achieving change, however, require adequate enforcement and should be supported by education to encourage compliance.

Important strategic planning measures that may provide for targeted UHI mitigation include:

- Develop a Street and Park Tree Masterplan that specifies vegetation types and density for each suburb in the LGA, as well as a prioritised street tree planting program based on the data (i.e., 'where, when and what to plant'). Best practice examples of this approach include: City of Newcastle, Sunshine Coast Council and City of Sydney.
- Integrate the urban heat mapping into Council's spatial data for consideration when assessing development in or near hot spots. This would inform design considerations and the application of conditions specific to appropriate location of green space and standards for green infrastructure.
- Consider amendments to the Maitland Development Control Plan (DCP) that increase protections for, and enhancement of, vegetation across the LGA, such as:
  - In Part B - Environmental Guidelines:
    - performance criteria that require the maintenance of UHI mitigation and an acceptable solution requiring compensatory measures and/or plantings on a lot where a tree/s contributed to the urban canopy
    - broaden the definition of 'amenity' to encompass temperature and amend the acceptable solution for maintaining amenity to require compensatory measures where a tree/s contributed to the urban canopy/shade
    - consider including canopy trees in the definition of a *significant tree*, to ensure a permit is required for clearing.
  - Update Part C – Design Guidelines, to provide for green buildings (green roofs, communal terrace gardens and balcony plantings) and to require the use of building materials that reflect heat.
  - Amend Locality Plans (Part D) to incorporate urban heat considerations. Urban heat can be considered a constraint that warrants specific development outcomes, such as mitigation and 'no worsening'.
  - Designate areas with high 'greenness' and low heat related vulnerability scores as 'Special Precincts' under Part E (DCP), to provide for the application of additional requirements for vegetation protection and mitigation.

- Include a Desired Future Outcome for urban release areas (Part F, DCP) that requires development to consider the provision of shade and green infrastructure, as well as the use of heat resistant building materials/design. Urban heat mitigation could be a design consideration for these areas. Best practice examples are
- Require future development in suburbs with the heat-related vulnerability score of two or above, to incorporate densely planted areas, such as in multi-function corridors and open space areas.
- Require development proponents to meet an acceptable solution/performance criteria for mitigating (and no worsening of) urban heat.

- Consider the 'quarantining' of areas throughout the LGA from future high density subdivision development. Instead, provide for and/or incentivise in-fill development with integrated green infrastructure.
- Consider strict landscaping thresholds, for example, a certain area of open space is required per a specified gross floor area; or require that a minimum percentage of a subdividable area be allocated to green reserve area.
- Ensure that land use planning and the City's strategic framework for future development embodies a 'no worsening' scenario in respect of urban heat effects
- Consider the application of a fees and charges regime, including, for example, a Special Rate Variation for particular developments, for the purpose of urban canopy enhancement. The UHI data demonstrates a clear nexus between such development and a subsequent need for vegetation and enhancement in UHI suburbs. Tweed Shire Council is one example of where such a measure has been adopted for subdivision development.[1]
- Conduct an audit of road reserves (consider the data generated by NGH in the canopy mapping exercise, as well as ground-truthing surveys) to identify areas for the integration of green, permeable and reflective surfaces. This might include street tree planting, bio-swales, permeable and/or light-coloured road surfaces and footpaths.
- Identify opportunities to retrofit existing stormwater infrastructure, such as basins, channels and drains, with green infrastructure.
- Review funding mechanisms available for resourcing green infrastructure.
- Investigate development of a measurable target to reduce urban heat. Elegendawy and Davies (2019) note that the lack of a target generally results in less effective implementation of planning strategies. Targets might include, for example:
  - Increasing urban canopy cover, particularly within UHI suburbs. These should be set out in a Street and Park Tree Masterplan and/or Urban Canopy Strategy (or similar). For example, 50% canopy coverage on public land.
  - Temperature change in UHI areas, for example, reductions in median maximum temperature in localities where targeted greening measures are implemented, based on changes identified through heat mapping
  - Increases in the use of heat mitigating building materials in new development.
  - Improved functionality and useability of public open space, as well as increased use of green space
  - Changes in health indicators that correlate with heat impacts.
- Review best-practice examples of urban development design to mitigate the UHI effect. It is suggested that grid-pattern development, which is a common design adopted by

[1] Tweed Shire Council Kings Forest Special Rate Variation.

subdivision development proponents, increases the UHI effect, whilst a less-ordered development pattern mitigates against this effect (Chandler, 2018; Walls and Barrins, 2014).

6. Summation of recommendations

To assist with prioritisation of the recommendations detailed in the previous section, a summary of key points are outlined below.

Short Term Recommendations:

- Undertaking ongoing monitoring and analysis of LST and street-level air temperature
- and research to address the aforementioned limitation.
- Focussing mitigation actions within priority communities
- Reducing loss of existing tree canopy cover, especially dense mature forest communities.
- Increasing tree canopy cover through strategic planting schemes

Further research and policy recommendations:

- The mapping undertaken in this project indicate that URAs are in the hottest part of the LGA. Undertake research to develop specific planning controls, design tools and incentives to develop climate resilient suburbs considering the particular topographic and heat characteristics of these locations.
- Create guidance for community and developers on creating homes and subdivisions suitable for climate adaptation.
- Development of a Street and Park Tree Masterplan
- Integration of the urban heat mapping into Council's spatial data for consideration when assessing development in or near hot spots to ensure appropriate land use planning for climate adaptation.
- Consideration of amendments to the Maitland Development Control Plan (DCP) that increase protections for, and enhancement of, vegetation across the LGA
- Conduct an audit of road reserves (consider the data generated by NGH in the canopy mapping exercise, as well as ground-truthing surveys) to identify areas for the integration of green, permeable and reflective surfaces. This might include street tree planting, bio-swales, permeable and/or light-coloured road surfaces and footpaths.
- Identification of opportunities to retrofit existing stormwater infrastructure, such as basins, channels and drains, with green infrastructure.
- Review funding mechanisms available for resourcing green infrastructure.
- Investigate development of a measurable target to reduce urban heat (see Elegendawy and Davies (2019), WSROC Urban Heat Planning Toolkit)

7. References

Amani-Beni M, Biao Zhang B, Xie G & Shi Y. (2019) Impacts of Urban Green Landscape Patterns on Land Surface Temperature: Evidence from the Adjacent Area of Olympic Forest Park of Beijing, China. *Sustainability:* 11, 513.

Coutts AM, et al. (2016) Thermal infrared remote sensing of urban heat: Hotspots, vegetation, and an assessment of techniques for use in urban planning. *Remote Sensing of Environment* 186:637-651.

Deilami K, Kamruzzaman M, & Hayes JF (2016) Correlation or causality between land cover patterns and the urban heat island effect? Evidence from Brisbane, Australia. *Remote Sensing* 8(9):716.

Elegendawy, A. and Davies, P. (2019) The Urban Heat Island in Australian City Planning, Sate of Australian Cities Conference, 30 November – 5 December 2019, Perth, Western Australia

Gamble, J.L., B. J. Hurley, P.A. Schultz, W.S. Jaglom, N. Krishnan, and M. Harris. (2013) Climate Change and Older Americans: State of the Science. Environmental Health Perspectives 121(1): 15-22.

Hibbard, K.A., F.M. Hoffman, D. Huntzinger, and T.O. West. 2017. Changes in land cover and terrestrial biogeochemistry. In Climate Science Special Report: Fourth National Climate Assessment, Volume I [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC. pp. 277–302.

Mohajeri, N., Sanchez, J.P.R. and Javanroodi, K. (2021) Sustainable City Planning: A Data Driven Approach for Mitigating Urban Heat, *Frontiers in Built Environment*, 26 January 2021, doi.org/10.3389/fbuil.2020.519599

NGH Environmental. (2021) Maitland Vegetation Canopy Assessment. A report prepared for the Maitland City Council.

Rongali, G., Keshari, A.K., Gosain, AK. & Khosa, R. (2018) A Mono-Window Algorithm for Land Surface Temperature Estimation from Landsat 8 Thermal Infrared Sensor Data: A Case Study of the Beas River Basin, India. *Science & Technology*, 26(2): 829-840.

Rouse, J. W., Haas, R. H., Schell, J. A., and Deering, D. W. (1974) “Monitoring vegetation systems in the Great Plains with ERTS.” In Proceedings of the Third ERTS Symposium, 10–14 December 1973, Washington, DC (Greenbelt, MD:NASA), vol. SP–351, 309–317 pp.

Steffen W, Hughes L and Perkins S (2014). Heatwaves: hotter, longer, more often. Climate Council of Australia Limited. ISBN: 978-0-9924142-3-8 (web) © Climate Council of Australian Ltd 2014.

Taha, H (1997) Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat, *Energy and Buildings* 25, 99–103.

Vaidyanathan. A., J. Malilay, P. Schramm, and S. Saha. (2020) Heat-related deaths — United States, 2004–2018. Morbidity and Mortality Weekly Report 69(24):729–734.

Zhang Y, Nitschke M, Krackowizer A, Dear K, Pisaniello D, Tucker G, Shakib S & Bi P. (2016) Risk factors of direct heat-related hospital admissions during the 2009 heatwave in Adelaide, Australia: a matched case–control study. *BMJ Open* 2016;6:e010666.

Appendix A Normalised difference vegetation index (NDVI) statistics by suburb

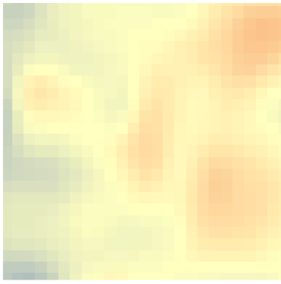
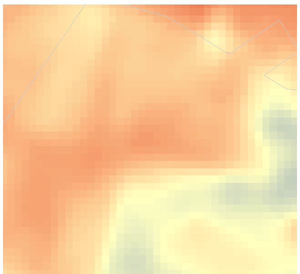
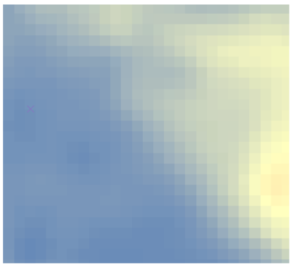
Appendix B Land surface temperature (LST) statistics by suburb

Appendix C Land surface temperature statistics and % tree canopy cover associated with land-uses within the urban zone

Appendix D Urban hotspots – examples and photos

Examples of features associated with above or below average land surface temperatures in Maitland urban zones and potential LST responses based on Landsat 8 thermal imagery for 8 February 2019 (9.45 AM DST). For each location, the thermal imagery (30m x 30m spatial resolution) is shown on the left and the associated aerial view is on the right using Metromaps May 2021 aerial photography. Red indicates higher temperatures, yellow is median and blue indicates lower temperatures.

D.1 Industrial, commercial and business development centres

<table>
<tr><td colspan="4">Both industrial areas and shopping centres typically have large expanses of roofing, paving, parking lots and very few trees for shade, often resulting in almost uniform high surface temperatures. The adoption of cool roofs and green cover could reduce land surface temperatures in these areas, but care is required to avoid glare when increasing reflectivity of surfaces.</td></tr>
<tr><td colspan="2">Rutherford industrial park has large expanses of roofing and paving resulting in very high daytime LSTs in summer. Adoption of ‘cooling’ building materials and increasing tree coverage in strategic locations can help mitigate some heat (as evidenced by the cooler signals associated with the trees present on the site image below)</td><td colspan="2">Maitland Airport has large areas of grass, impervious paving and rooftops which all result in high LST. Increasing tree cover around the parking area could help reduce daytime temperatures.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">As with industrial areas, business development areas also return high LST signals due to large roof expanses and impervious surface areas. In some cases, retrofitting roof tops with cool roofs and green cover could reduce temperatures in these areas. Materials should be trialled to ensure they do not exacerbate adverse conditions through reflectivity.</td><td colspan="2">Waste management was a land-use returning one of the lowest LST signals. Even though this site is located in the cooler eastern region of the LGA, the cooler conditions on-site can still be attributed to the large dense tree stand on-site and minimal impervious surfaces. Bare ground returned a higher heat signal.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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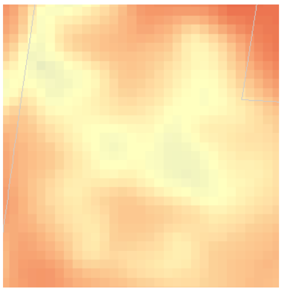
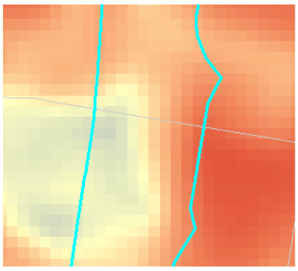
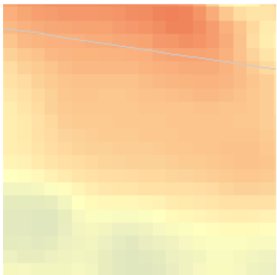
D.2 Residential – General, large lot, environmental living

LST's of residential areas are influenced by multiple factors, including but not limited to tree cover, dwelling density and structure, irrigation and proximity to water. Maitland LGA exhibits a gradient of decreasing temperature from west to east due to a cooling effect caused by coastal proximity in the east, with the result that similar landcover types in the east exhibit overall lower LST responses than in the west. All residential types with established tree canopy present showed lower LST's in the localised areas with tree canopy. Residential areas with a high proportion of roof cover (e.g., general residential and new residential developments) and low vegetation cover showed significant heating up in the day with comparatively lower release rate of stored solar heat at night, implying the presence of heat island effect in these areas.

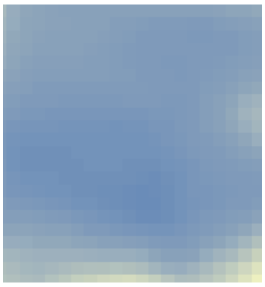
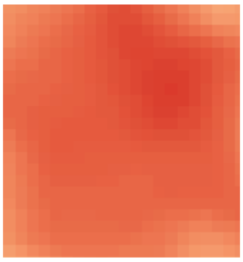
General residential (west) – uniform heating demonstrated across general residential areas. These areas also exhibited higher nigh time temperatures suggesting the presence of UHI effect.	General residential (east) – while overall maximum LST's were lower when compared with residential areas in the western areas, the eastern residential areas also exhibited higher daytime LST's with reduced rates of cooling at night suggesting the presence of UHI effect.
	
Large lot residential (west) with trees – larger residential lots tend to have larger grassy surface areas which heat up in the day but cool off rapidly at night. The example shown here shows the cooling effect caused by presence of tree canopy.	Large lot residential (west) few trees - the example below shows a proportion of grassed areas and low tree cover, with the result that daytime LST's are uniformly high. These areas showed cooler LST's at night. Cooler areas correspond to presence of canopy.
 	 
Environmental living (west) – in the west many of these areas were covered by grass, tree canopy and water. Grass areas showed high daytime LST but cooled rapidly at night; tree canopied areas had comparatively cooler daytime LST's; water had lowest LST.	Environmental living (east) – in the east daytime LST's overall were lower than west LGA. Areas zoned as environmental living in east LGA were characterised with high level of tree canopy which showed low LST response.

<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">New residential (west) – new residential areas are characterised large expanse of roofing and low to no tree canopy cover resulting in these areas being uniformly hot. These landcover types also showed reduced rate of cooling at night suggesting the presence of UHI effect. With time, these areas could potentially be cooled with once suitable tree canopy is established.</td><td colspan="2">New residential (east) – similarly, new residential areas in the east showed uniform heating, however the overall maximum LST's experienced in the daytime were lower than the western areas due to coastal cooling effects. Reduced cooling at night suggests these newer residential developments are prone to UHI effect.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

D.3 Sports fields

<table>
<tr><td colspan="4">Surface temperatures in playing fields can be highly variable depending on the playing surface, soil moisture and presence of tree canopy cover.</td></tr>
<tr><td colspan="2">Sports field (west) few trees showing higher day time LST's. The grass surfaces cooled showed cooling at night, implying there is no UHI effect caused.</td><td colspan="2">Sports field (central) with some trees. Cooler LST's are evident in the presence of tree canopy. While the grassy areas heat up significantly during the day, but they also cool down at night.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Sports field (central) with few trees and high impervious surface cover resulting in elevated daytime LST's.</td><td colspan="2">Sports field (central) with peripheral trees, showing the cooling effect in the presence of tree canopy cover.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

D.4 Natural land cover types

<table>
<tr><td colspan="4">Maitland LGA has numerous important ecological communities, including woodlands and forests, which support a range of threatened flora and fauna species. Natural landcover types dominated by tree canopy also have the effect of reducing daytime LST's and are thermally stable throughout the day. Dense tree canopy has a cooling effect on LST during the day through evapotranspiration. Air temperatures can also benefit from the cooling effects of tree canopy through shading and evapotranspiration.</td></tr>
<tr><td colspan="2">Forest (west) – with the exception of waterbodies, native forest cover in the west exhibited some of the lowest daytime LST of all landcovers in the western section of the LGA.</td><td colspan="2">Forest (east) – dense, intact, native forest in the eastern regions showed some of the lowest daytime LST's with little variation throughout the day. Forests in the east exhibited slightly lower LST's than the west, probably due to the cooling effect of coastal proximity to the east of the LGA.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Grassland (west) – grasslands in the western region exhibit extremely high LST's during the day, but cool off rapidly overnight.</td><td colspan="2">Grassland (east) – grass-dominated landcover in the east tend to be paddocks and cultivated croplands, some of which are irrigated. LST's associated with grassland in the eastern regions were elevated during daytime, but max LST's were lower compared to the west, possibly due to the moderating effects of coastal proximity, as well as evaporation effects from higher moisture content due to irrigation, higher water table and flooding from nearby waterways.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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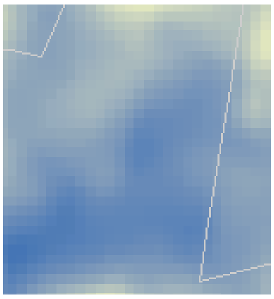
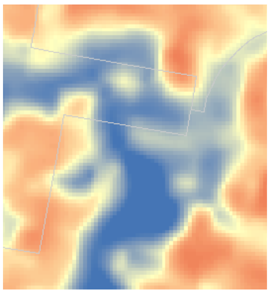
D.5 Wetlands and lakes/dams

<table>
<tr><td colspan="4">Presence of waterbodies, like dams, lakes and rivers, as well as water saturation, like wetlands and irrigation, can provide cooling benefits on hot days through evaporation. In addition, wetlands and irrigation also supports evapotranspiration. Waterbodies maintain relatively constant temperatures throughout the day- and night-time.</td></tr>
<tr><td colspan="2">Wetland – wetlands maintain constant temperatures throughout the day due to both evaporation and evapotranspiration</td><td colspan="2">Waterbody - Large waterbodies like dams, lakes and rivers can provide cooling benefits on hot days through evaporation</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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