Department of Spatial Sciences

Urban Forest Mapping and Analysis: The Development of Urban Heat Islands in the City of Melville Due to Changing Land Use Types

Luke Ellison

This project report is presented for the Degree of Bachelor of Surveying of Curtin University

November 2017

ABSTRACT

The City of Melville requests that a study be undertaken to confirm or deny the existence of Urban Heat Islands within their precinct. This project utilises shapefiles, High-Resolution aerial imagery, Low-Resolution satellite imagery, as well as thermal imagery to determine how Urban Heat Islands may occur in the City of Melville, and quantify their severity.

This report will summarise the data and methods used throughout the process, as well as a summary of results and evaluation. Suggestions for future studies will also be provided.

ACKNOWLEDGEMENTS

I would like to acknowledge the following people for their help and guidance throughout this project.

Petra Helmholz, Department of Spatial Sciences
Ashraf Dewan, Department of Spatial Sciences
Ashty Saleem, Department of Spatial Sciences
Janine Ahola, City of Melville

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1. 1 Motivation

A growing population in every province of the world, there has been great discussion around the topic of global warming. While there is debate from all sides of the spectrum, there are analytical steps that can be undertaken to show the direct cause of increasing temperature in urban environments.

Urban Heat Islands are a direct result of the urbanisation of flora based area's and regions. Urban Heat Islands (UHI) describe regions where there has been a significant temperature change, in regions of development, when compared to temperatures in non-developed regions in the nearby surrounds. These UHI are influenced by the type of development that has been undertaken in the regions of interest. These types of development fall under different types of Land Cover/Land Use (LCLU) designations.

1. 2 Objectives

This project is aimed at identifying Urban Heat Islands in three Areas of Interest (AOI) in the City of Melville. Through Identifying these UHI we can estimate the heat difference between three different Land Cover/Land Use designations.

These designations of LCLU are as follows:

- Industrial
- Residential
- Flora/Vegetation

After calculating the estimated temperature change between LCLU types, we can apply these findings to Landsat images and Aerial Imagery from the past to show the growth of Urban Heat Islands over time, from 1953 through to 2016.

1. 3 Structure

This report will adhere to the following structure:

- Introduction
- Related Work
- Background
- Methodology
- Study Areas (Areas of Interest)
- Results
- Conclusion

2 BACKGROUND

2. 1 Previous Urban Heat Island Studies

There have been multiple journal articles published in recent years on the topic of Urban Heat Islands, many just taking place on small scale projects in suburbs of cities around the globe. The studies I chose to focus on as reference for my project took place in Bahrain, Xiamen City (China), and Chicago (USA). This provides results based on different climates, and environment variability. This way trends can be identified between studies, and similarities in results can be assumed to be consistent.

The Bahrain study was conducted in order to confirm that studies in other Gulf Cooperation Council Countries (GCCC), where a rise of 2°C-4°C was observed in urban environments when compared to the rural surroundings. There was a rise of air temperature in Bahrain varying from 2-3°C in artificial UHI (developed regions), to 3-5°C in natural UHI with sand based cover (Radhi, Fikry, & Sharples, 2013). While the sand based UHI that was measured in Bahrain is not applicable to the City of Melville, the urban UHI data should be similar in regard to Land Use/Land Cover types.

2. 2 LandSat

LandSat describes a project undertaken by the US Government using a fleet of different satellite to obtain imagery of the entire earth. The project has been ongoing for over 40 years, providing information on temperature, vegetation, water masses for a large range of projects and purposes. The majority of the data acquired from LandSat can be acquired using the EarthExplorer website, free of charge. The current LandSat satellite in use in the present day, is LandSat 8. The resolutions for LandSat 8 bands are as follows:

- Bands 1-7 = 30 meters
- Band 8 = 15 meters
- Band 9 = 30 meters
- Bands 10 & 11 = 100 meters

3 STUDY AREAS

3. 1 Areas of Interest

When analysing the whole of City of Melville at the start of the project, it became apparent that there was too much ground cover to analyse in one lump sum. There is too many individual ‘objects’ in the suburb that would increase the work load. The increased workload would increase the amount of time it would take to perform simple to complex tasks, for example, a simple clipping process could take up to a day, if not longer, for one high resolution image.

The solution to this issue was to choose three separate Areas of Interest. This number would provide enough land cover to produce significant results and trends in the data. The AOI were chosen to fit a desired spread of location in the City of Melville, and have distinguishable LC/LU types.

3.1.1 Size and Shape

The AOI had to cover enough area with enough variation in the Land Cover/Land Use (LCLU) types. It was also decided that the AOI would not have the same total coverage.

Areas would have to be simple in shape, being roughly rectangular in size. This would result in faster processing in ARCMAP as complex shapes result in slower processing speeds.

3.1.2 Variation in LCLU Types

The LCLU classes that were essential to be present in the AOI were Residential, Industrial, and Flora. The three AOI had to contain enough of each classification. It was also desirable for the ratios of each classification to vary from area to area, with the ideology behind this practice being that different ratios when combined would ensure that results followed the best trends.

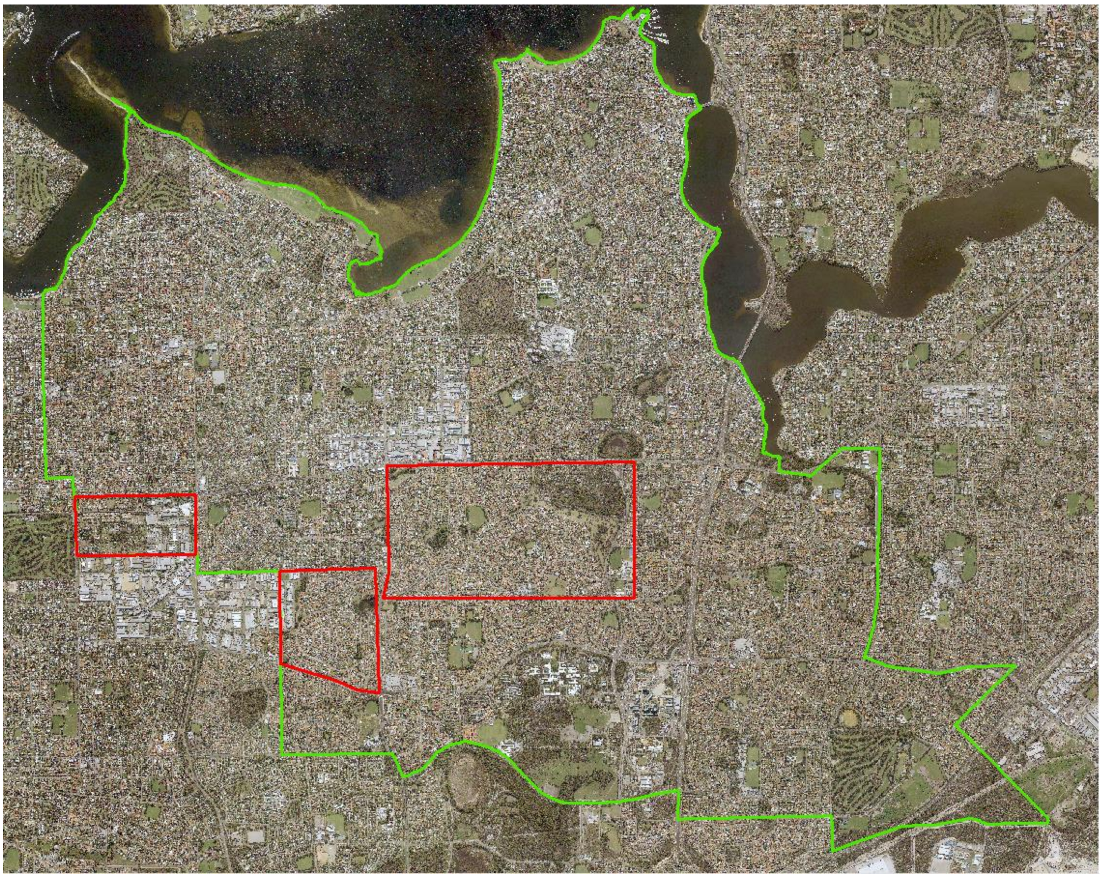


Figure 1 City of Melville Boundary in Green, Areas Of Interest in Red. From Left to Right, Area 1, Area 2, Area 3.

Table 1 Areas of Interest Coverage in m².

Areas_Of_Interest_Fixed

	FID	Shape *	Id	Area
	0	Polygon	1	846638.851979
	1	Polygon	2	1275149.4132
▶	2	Polygon	3	3963545.5675

3. 2 Time Periods

Using the year 2016 as the base time period, three other time periods were chosen. They provided the best progression of changes to the AIO regarding LCLU over time. A gradual change of the LCLU types would present a gradual change in Urban Heat Island temperatures.

As the earliest Aerial photo of the City of Melville was in 1953, this was the earliest year in the study. Two more years, being 1974 and 1985, were chosen due to containing the best gradient of change to the LCLU classes.

3. 3 Land Cover Land Use Shapefiles

The next step to be undertaken was to create shapefiles of the different LCLU classes. These would be custom made to fit the different classifications of Residential, Industrial, and Flora. There was interest in the beginning to include Road as an LC/LU class, however when processing low resolution images, the amount of area that roads occupied was not definable when compared to the other three classes. This process was undertaken for ALL time period images.

3.3.1 Residential LCLU Shapefile

Residential was a class that would cover all buildings and/or properties that are occupied for domestic purposes. At the start of the project, the idea was to clip out all rooftops from the areas of interest by using LIDAR (Light Detection and Ranging), however time constraints dictated that this was not an option. A blanket Cadastre shape-file was used instead.

3.3.2 Industrial LCLU Shapefile

Industrial structures were considered anything that was not considered to be a residential dwelling. All shopping centres, service stations etc. fell under the Industrial class, however sheds on residential properties did not. This is mainly due to the materials used in construction (residential sheds were made of every day construction materials, while industrial structures were made of different high construction grade materials).

3.3.3 Flora LCLU Shapefile

The Flora shapefile covered any large body of vegetation that had been set aside for the purposes of being parks and nature reserves. Although there is vegetation inside the Residential and Industrial LCLU class shapefiles, the amount of vegetation when in urban environments was not significant enough to make an impact on the land surface temperature.

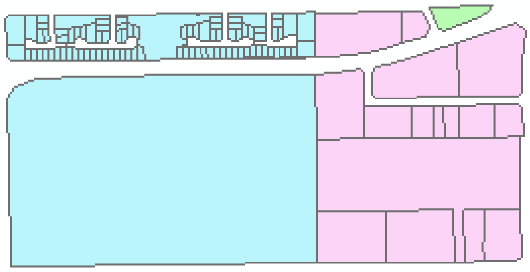


Figure 2 Area 1

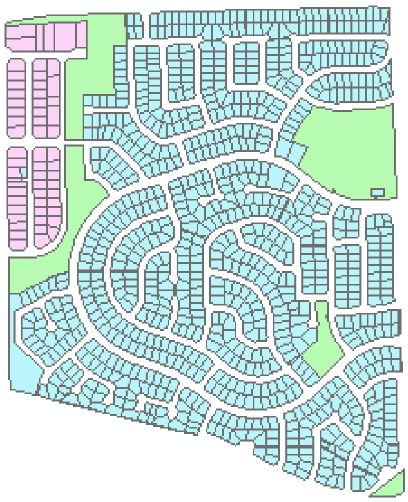


Figure 3 Area 2

Blue – Residential

Pink – Industrial

Green - Flora

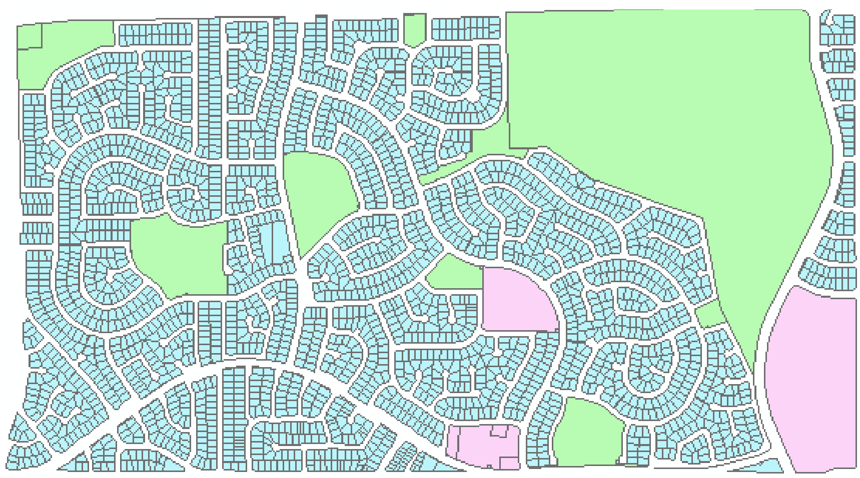


Figure 4 Area 3

4 IMAGERY

The images used in this project came from several sources, in several different resolutions. The High-Resolution images were aerial images, captured from an airborne platform (Aeroplane), while the Low-Resolution images were captured from LandSat platforms.

4.1.1 High-Resolution Images

All the High-Res aerial images were provided, for the purposes of the project, by the City of Melville. Every High-Res image had a GSD (Ground Sample Distance) of less than 1 meter.

4.1.2 Low-Resolution Images

The Low-Res images downloaded from the USGS EarthExplorer website. Three Low-Res images were downloaded for the year 2016, to account for seasonal change in temperature, as well as a single 1987 image. The 1987 image was eventually not used for the purposes of the project due to difficulties processing the data.
The Low-Res images that were downloaded were also used for providing thermal data, from Bands 10 and 11.

4.1.3 Clipping of Images

Once all the required images were obtained, a raster slipping operation was undertaken to clip the Areas of Interest, as seen in Figure 1, from the stock images.

Table 2 Image Resolution and Year of Capture

	High Res 2016	**High Res Thermal 2016**	**Landsat 2016**	**1985**	**1974**	**1953**
Resolution (GSD)	0.1m	0.6m	30m Thermal = 120(30)	0.4m	0.5m	0.3m
Date and time	Jun 2016	9/10 Feb 2016	25 Oct 2016	Apr/Jun 1985	Sep 1974	Nov1953

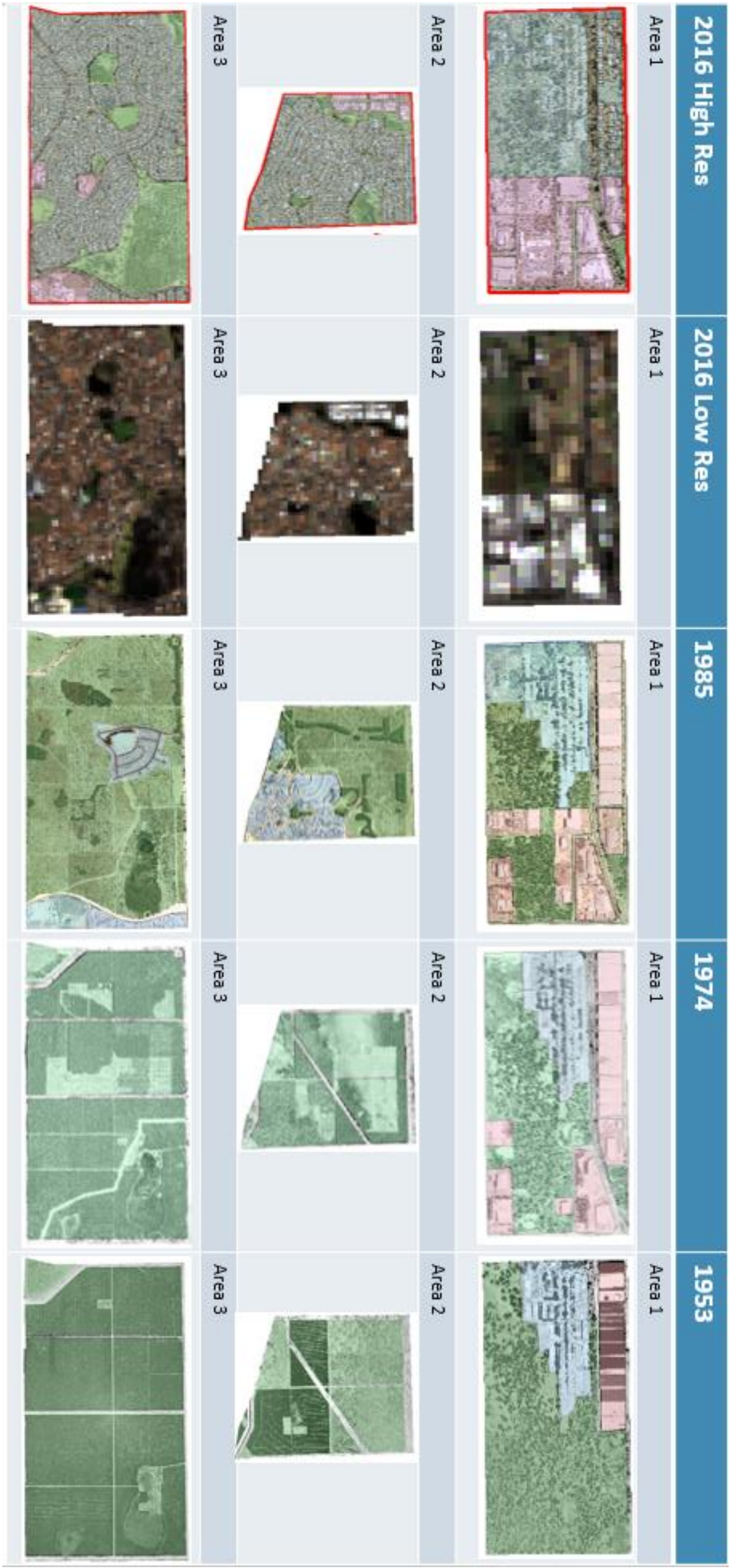


Figure 5 Clipped Areas of Interest. Low-Res Image Included for Resolution Comparison. LCLU Shapefiles Overlaid with 50% Transparency.

4. 2 Thermal Imagery

Two types of Thermal Imagery were used for the purposes of gathering UHI temperatures. They fell the categories of High-Res Thermal and Low-Res thermal. Both sets had to be adjusted in order to display land surface temperatures in degrees Celsius. After all the required value changing was completed, the thermal images were clipped to the AOI.

4.2.1 High-Resolution Thermal

This class consisted of only one image, captured in 2016 for gathering Land Surface Temperatures. The pixel values that were meant to contain temperatures in degrees Celsius, however, were in value range of -5000 to 10000. Therefore, a process was undertaken to join the table of value for the raster to a value lookup table. This process was undertaken in MatLab. The attribute lookup table was provided by the City of Melville from past projects.

The resulting thermal raster image displayed values ranging from 0°C to 37°C.

4.2.2 Low-Resolution Thermal

The Low resolution thermal images were comprised of all the 2016 LANDSAT images. An NDVI image had to be created in ARCMAP, followed by another ARCMAP process to combine the NDVI images with Bands 10 & 11 and create thermal images in degrees Celsius.

5 METHODS

Insert introduction text here.

5. 1 Calculation of LCLU Areas for All Time Periods

A decimal percentage had to be calculated relating to the total amount of area that each LCLU class for all years. This was accomplished by dividing the total area for one LCLU class, by the total area of all AOI. As a check at the end of each set of calculations, the sum of all three decimal percentages had to have a sum 1.
The decimal percentages obtained would fall under the value $\boldsymbol{A}$.

5. 2 Analysis of Temperature per LCLU Class in 2016

An average temperature was gathered for each LCLU class in each 2016 image. The reason for this is for comparison of the trends of different temperature after back projection and forward projection. The Spatial Analyst Zonal Statistics tool in ARCMAP was used to calculate the mean temperatures. It accomplished this by counting the pixel values that fell under each LCLU shapefile classification.
The mean temperatures for each 2016 image would fall under the value $\overline{\boldsymbol{T}}$.

5. 3 Calculation of Urban Heat Island Index (UHIi) for Each 2016 Image

Using the following formula, it was possible to calculate each UHIi for each 2016 image.

$$UHIi = \sum_{i}^{LULC} (A_i \cdot \overline{T_i})$$

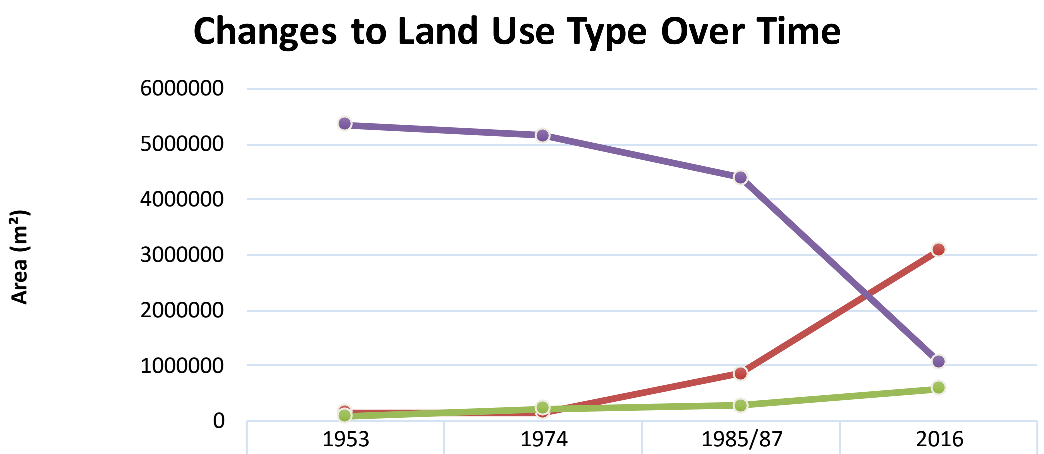
It describes UHIi to be equal to the sum of each LCLU's $\boldsymbol{A}$ multiplied with $\overline{\boldsymbol{T}}$.
This value would be used for all the following forward and back projections.

5. 4 Back Projection of previous years.

Using the above process and calculation, it was possible to undertake a back projection to calculate the UHIi for previous years. This was undertaken using the previous periods decimal percentages of LCLU classes, and the mean temperatures per LCLU class in each 2016 thermal image.

6 RESULTS

6. 1 Changes to Land Use Over Time



	1953	1974	1985/87	2016
Residential Area	148050.473	148050.473	857887.2571	3075325.99
Industrial Area	86147.1257	217157.4754	274052.9675	577681.1246
Flora Area	5344008.858	5158674.951	4402114.902	1078139.195

Figure 6 Changes in Area to LCLU Classes over time

As can be seen in the above graph, there has been significant change in LCLU class coverage between 1953 and 2016. Up until 1985, minimal clearing of Flora/vegetated area had taken place. The rate of change seemed to follow a linear trend. Between 1985 and 2016 however, there was a sharp decrease in Flora coverage, and a sharp increase in the Residential class growth.

After inspecting the High-Res images for each time period, the trends depicted in the above graph can be visually confirmed as being correct.

6. 2 Comparison of Urban Heat Island Index.

To determine which thermal images were the most suitable for forward and back projection, a comparison of the High and Low Resolution thermal images had to be undertaken. The different resolutions were determined to be not comparable with one another due to a number of factors.

The thermal images were taken at different times of the year; therefore, temperatures were different and would not follow the same trends due to having different thermal reactions with the different land surfaces.

The mean thermal temperatures would also be different. The High-Res thermal image contained thermal values from 0°C to 37°C. After visiting the Bureau of

Meteorology website, the minimum temperature of the day was determined to be 19°C. That mean that any value up to this threshold could not be included in the results. The absence of those values would skew the results and not be accurate for further interpretation.

6.2.1 High Resolution

Table 3 Decimal Percentage for High Resolution imags, as well as the average thermal temperatures.

Decimal Percentage per LCLU	
-	Index
Res	0.650017
Ind	0.122102
Flora	0.227881
Sum	1

Average Temp LCLU	
-	Av. Temp.
Res	26.1278162
Ind	26.8593675
Flora	25.8109862

6.2.2 Low Resolution

Table 4 Decimal Percentage for High Resolution imags, as well as the average thermal temperatures.

Decimal Percentage per LCLU	
-	Index
Res	0.650017
Ind	0.122102
Flora	0.227881
Sum	1

Average Temp LCLU	
-	Av. Temp.
Res	23.80006
Ind	22.69097
Flora	22.32074

6. 3 Urban Heat Island Back Projection

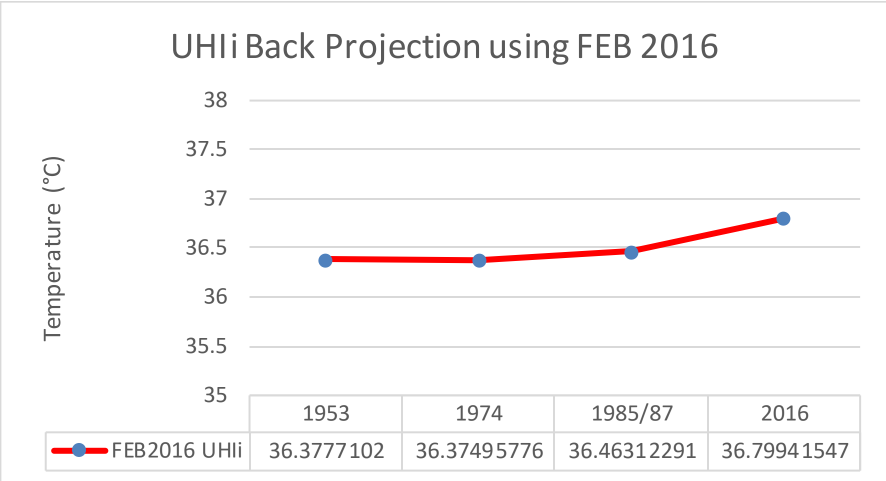


Figure 7 Back Projection Using FEB 2016

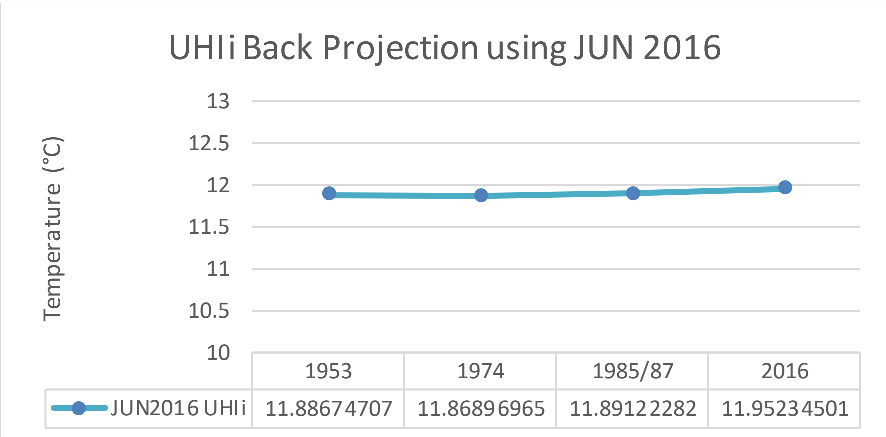


Figure 8 Back Projection Using JUN 2016

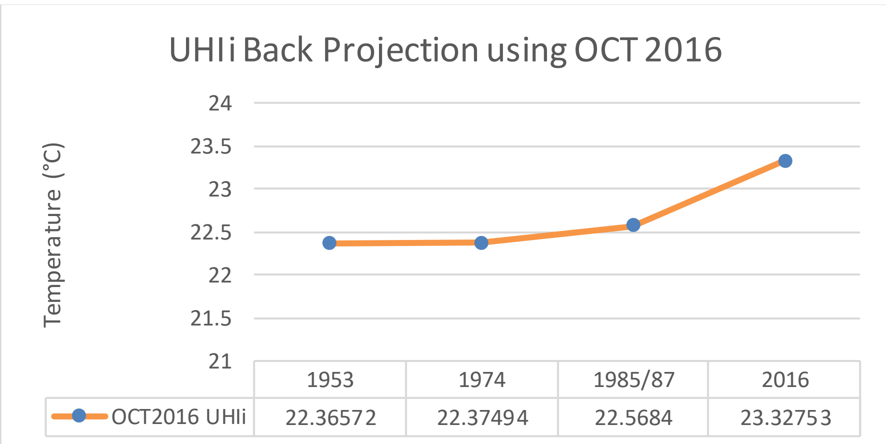
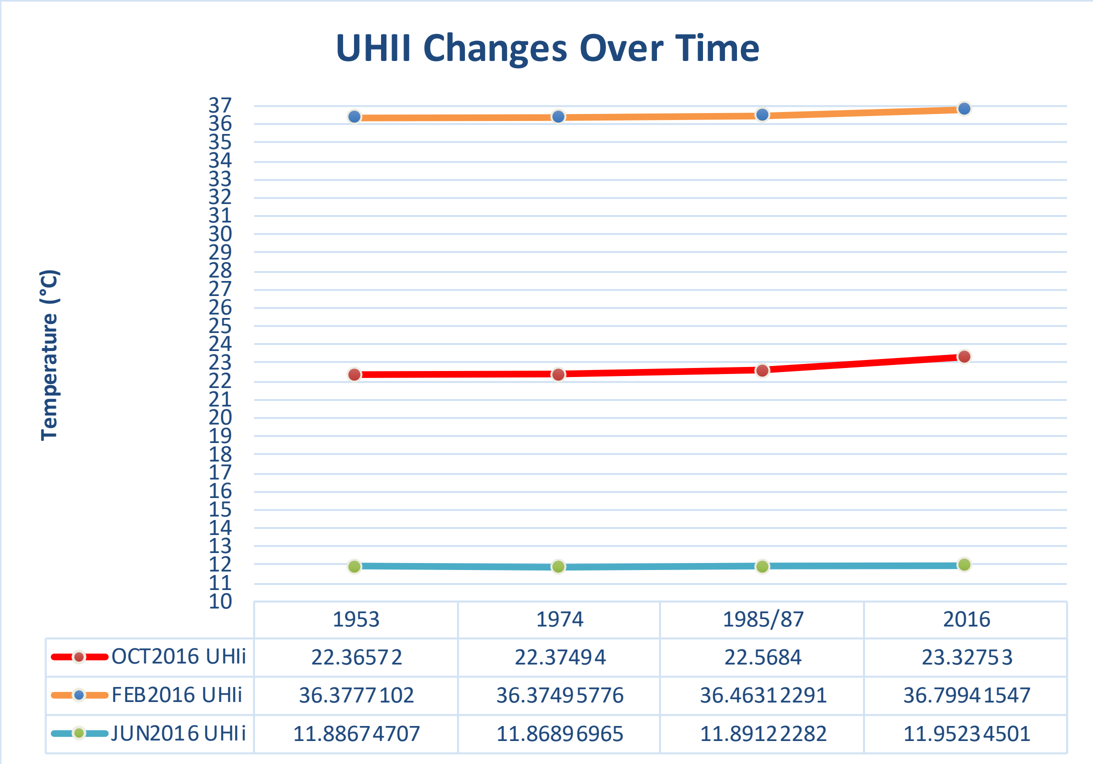


Figure 9 Back Projection Using OCT 2016



	1953	1974	1985/87	2016
OCT2016 UHIi	22.36572	22.37494	22.5684	23.32753
FEB2016 UHIi	36.3777102	36.37495776	36.46312291	36.79941547
JUN2016 UHIi	11.88674707	11.86896965	11.89122282	11.95234501

Figure 10 Comparison of all Back Projections

The above tables show a clear rise in UHIi temperatures over the years. The different months are used to show the changes to the UHI effects throughout different seasons. For the month of June, which would be in the middle of winter, the effects of Urban Heat Islands are minimal, showing just a 0.1°C increase between 1953 and 2016. However, when looking at February and October, the effects are far more dramatic, showing increases of 0.4°C and ~1°C respectively, between 1953 and 2016.

6. 4 Urban Heat Island Forward Projections

A Forward Projection was also possible using the same formula. LCLU area decimal percentages were estimated following the trends of change up until 2016. These decimal percentages were combined with the mean temperatures from OCT of 2016, as it saw the greatest difference in temperatures and was between winter and summer. The year 2025 was chosen due to it being sufficient enough time for LCLU changes to take place.

Table 5 Decimal Percentages for the Year 2025 and the Average temperatures for OCT 2016

Decimal Percentage per LCLU	
-	Index
Res	0.8
Ind	0.15
Flora	0.05
Sum	1

Average Temp LCLU	
-	Av. Temp.
Res	23.80006
Ind	22.69097
Flora	22.32074

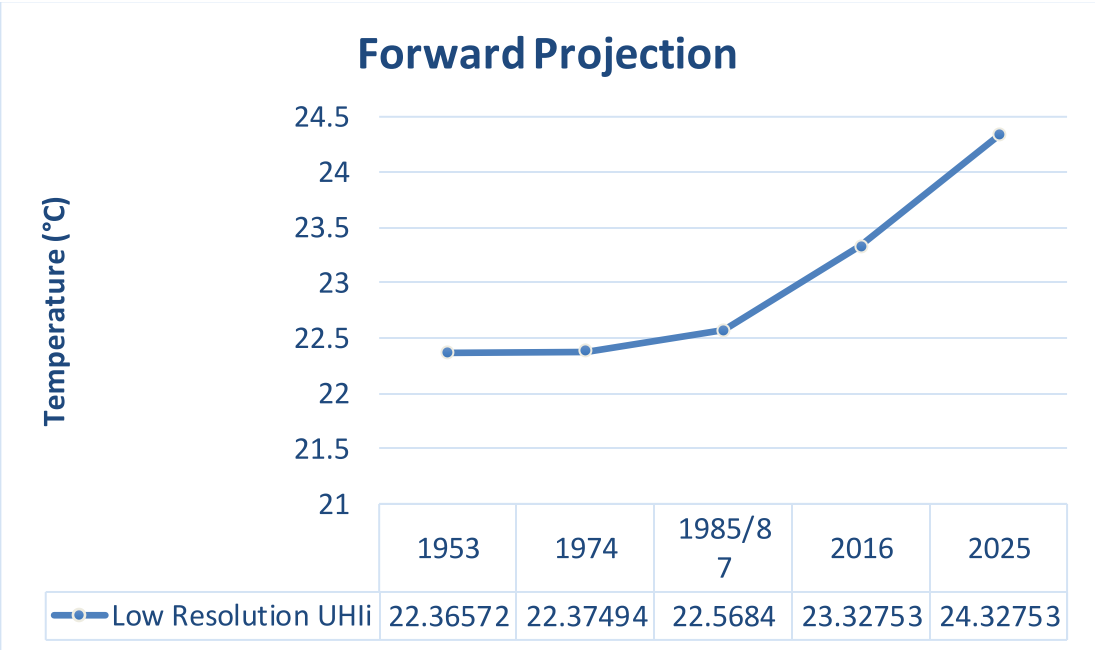


Figure 11 Forward Projection to 2025 Using OCT 0216 Thermal Data

As can be seen above, the projected UHIi temperature climbs another 1°C.

7 CONCLUSIONS AND RECOMMENDATIONS

7. 1 Summary

This Project has sufficiently identified the presence of Urban Heat Islands in the City of Melville. With an increase of nearly 1°C in the Spring/Autumn months, it is a worrying development in regard to the effects of rising temperatures, in not just the City of Melville, but cities and towns around Australia and the world. There is a clear correlation between the urbanisation of previously natural growth regions. If trends like this continue, the effects and temperatures will increase exponentially over time which in turn will increase negative effects on Climate Change.

Climate Change scientists have already predicted that an increase of 2°C between the present day and 2100 will eradicate all live coral reefs with no chance of regrowth. Therefore, the effects of Urban Heat Islands should not be taken lightly in their severity.

7. 2 Future Studies

Although there is already research into offsetting the effects of Urban Heat Islands, through the means of planting more trees and vegetation in urbanised regions, this is not offsetting the effects sufficiently enough. More research needs to be completed in regard to which species of flora are the most heat absorbent and resistant, so temperatures to not spiral out of control.

Research should also be completed, if it has not been already, regarding the effects of increasing UHI Land Surface Temperatures on ambient air temperature. This would hopefully quantify the rate of change that Urban Heat Islands have on Climate Change directly.

REFERENCES

Radhi, H., Fikry, F., Sharples, S. (2013). Impacts of urbanisation on the thermal behaviour of new built up environments: A scoping study of the urban heat island in Bahrain. *Landscape And Urban Planning, 113,* 47-61.
Abstract retrieved from https://catalogue.curtin.edu.au/primo-explore/fulldisplay?docid=TN_wos000317712500005&context=PC&vid=CUR_ALMA&lang=en_US&search_scope=CurtinBlended&adaptor=primo_central_multiple_fe&tab=default_tab&query=sub,exact,%20Heat%20Islands%20,AND&mode=advanced&offset=0

Gunawardena, K.R., Wells, M.J., Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of the Total Environment, 584-585,* 1040-1055.
Abstract retrieved from https://catalogue.curtin.edu.au/primo-explore/fulldisplay?docid=TN_sciversesciencedirect_elsevierS0048-9697(17)30175-4&context=PC&vid=CUR_ALMA&lang=en_US&search_scope=CurtinBlended&adaptor=primo_central_multiple_fe&tab=default_tab&query=any,contains,heat%20island,AND&sortby=rank&mode=advanced&offset=0

Mohajerani, A., Bakaric, J., & Jeffrey-Bailey, T. (2017). The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *Journal of Environmental Management, 197*, 522-538. doi:http://dx.doi.org.dbgw.lis.curtin.edu.au/10.1016/j.jenvman.2017.03.095

United States Environmental Protection Agency. 2008. "Urban Heat Island Basics." In: Reducing Urban Heat Islands: Compendium of Strategies. https://www.epa.gov/heat-islands/heat-island-compendium

Schupp, B. (2017). Urban Forest Canopy Coverage and its Effect on Heat Islands in the City of Melville (Spatial Sciences Project). Retrieved from Department of Spatial Sciences, Curtin University.