Identifying and quantifying turf grass ground cover in urban areas using online satellite imagery.

Shane Holborn
BioScience Australia Pty Ltd

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FINAL REPORT

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Shane Holborn and Will Pearce

BioScience Australia Pty Ltd

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Project Number TU12018

Project Leader: Shane Holborn
BioScience Australia Pty Ltd
PO Box 2590
Wellington Point
QLD 4160
ph: 0403 018 625
email: admin@bioscienceaustralia.com

Key Research Personnel: Will Pearce (Scientist, BioScience Australia, Wellington Point, QLD)

This report provides background information and summarises the methodology and outcomes of a project to examine the potential of software programs and satellite imagery to identify and quantify turfgrass cover in Sydney and Melbourne suburbs.

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Media summary

A clear idea of the size of the area covered in turf is currently unknown in Australia, but it is likely to be substantial. By developing a reliable and affordable method to measure turf coverage, this gap in knowledge can be addressed and the data can be used to quantify the benefits of turf in the community, such as measuring turf's oxygen production or carbon sequestration ability. This information will be useful not only for decision-making in relation to city planning and the effective application of turf in urban environments, but also for the promotion of turf to the homeowner and other end-users, leading to increased sales for the industry. It will also assist in providing a more holistic picture of the benefits provided by turfed areas in times such as drought where turfgrass is often maligned and viewed only in terms of its cost.

The study found that the average turf groundcover across all 16 sampled suburbs for Sydney was 17.23% (±0.55%). Percentage turfgrass cover varied widely between Sydney suburbs from high values of 34% in Concord, 33.3% in Colyton and 29% in Arncliffe to quite low coverage in Enmore (8%), Lindfield (9%) and Northwood (9.67%).

For Melbourne, average turf cover across all of the metropolitan areas measured was slightly higher at 18.94% (±0.57%). Again turf cover varied widely between sampled suburbs with outliers like the suburb of Ardeer, which contained a substantially higher percentage of turf groundcover with 42% of the suburb being covered with managed turfgrass. This example was due largely to nature of the suburb being small, entirely residential and containing large roadside, riparian areas and parklands of managed turf.

The lowest level of turf coverage was found in the Central Business District (CBD) and at 5 kilometers from the CBD for both Sydney and Melbourne, which was expected based on the population densities and infrastructure of these areas. Most of the turf in the CBDs was attributed to large parks and sports fields, such as the Albert Park golf course and the Royal Botanic Gardens in Melbourne. For both of the cities, when average turf cover is broken down into turf type, it is evident that the home lawn makes the biggest single contribution to the total being nearly a third of all types of turf. However, turfgrass in the other (nominally) publicly owned cover classes (i.e. roadsides, sports fields, parks, median strips) is cumulatively much larger than the private home lawn total.

Even at a macro level the figures derived from the study can be used to extrapolate further information. For example the total area under turf for the Greater Sydney and Greater Melbourne areas can be estimated at 2,131 km^2 (or 2,131,000,000 square meters) and 1,832.20 km^2 (or 1,832,200,700m^2) respectively. When calculated on a per capita basis, this provides an average of 431.20m^2 of turfgrass per person in Melbourne which is lower but surprisingly close to the Sydney average of 462.60 m^2 of turfgrass per person.

The project was conducted by BioScience Australia Ltd to identify and quantify urban turfgrass cover in a total of 32 Sydney and Melbourne suburbs running along three transects from each city's CBD. The i-Tree Canopy online program was used in combination with Google Earth and was found to be an effective system for mapping areas of each suburb, assigning cover classes to randomly-selected points and assessing turf type and coverage. The project has shown that the use of satellite imagery and appropriate software has considerable potential for the purposes of quantifying turf coverage, and the technique warrants further research and application by the Australian turf industry in other geographic regions and to build further on the results of this preliminary investigation.

Technical summary

Natural turfgrass offers a number of significant environmental benefits, including the ability to cool urban landscapes, sequester carbon and improve air quality. The extent to which these benefits is realised is debatable and varies according to a number of factors, including the amount of turfgrass within an area. The ubiquitous nature of turfgrass as a groundcover in urban and suburban environments has meant that it is often taken for granted and consequently afforded little value by government decision-makers or residents. A clear idea of the size of the area covered in turfgrass is currently unknown, but it is likely to be substantial in Australia.

A part of the reason for this is that the industry cannot reliably or affordably estimate the percentage of local council area that is covered with turfgrass. This refers to a regularly maintained area of grass that usually has a specific purpose, such as a sports field, roadside verge, park or public garden. The survey excluded areas such as grassed paddocks and unmaintained areas within and adjacent to forests and bushland. Council representatives and other landholders undoubtedly view the covering of an area with turfgrass through the lens of maintenance costs associated with managing that area. These costs can be associated with activities such as irrigation, mowing and chemical use, but ultimately involve the collective costs involved in the overall maintenance of the area and in managing the health of the turf. There is a need for the industry to be able to quantify the extent and impact of turfgrass, so that the costs are accurately balanced against the significant benefits that the turf provides to the community.

A project was conducted by BioScience Australia Ltd to identify and quantify urban turfgrass cover in 32 Sydney and Melbourne suburbs, using innovative new software and online satellite imagery. The aim of the project was to test the technology for its potential in estimating the amount of turfgrass in the wider metropolitan areas of Sydney and Melbourne. As turf plays such an important part in many environmental processes within urban areas (such as cooling, oxygen generation, erosion control, storm water management), the aim of the project was to provide a foundation upon which the true value of turfgrass to urban communities can begin to be measured.

The report includes a review of existing literature to outline the relevant issues, including a discussion of methodologies which have already been tested for the purposes of assessing groundcover. Two software systems were tested for their usability and accuracy for the purposes of the project. The first used SigmaScan Pro software to analyse sections of maps from Google Earth to determine the percentage of turfgrass in selected sample areas. Grid overlays and random number generation were first used to randomly select co-ordinates for each suburb's sample area. SigmaScan Pro was then used to search an image for a specific colour or range of colours which were used to categorise coverage types. It was found that the accuracy of this system was compromised by the quality of the images and the health of the turf at the time they were taken, which affects its colour and therefore interferes with the ability of the program to accurately distinguish and measure turf areas.

The second system tested used the i-Tree Canopy program in combination with Google Earth, and was found to be effective in mapping areas of each suburb and allowing the user to assign cover classes to randomly-selected points to determine coverage. The i-Tree Canopy program was effective in estimating the coverage of a number of cover classes, including hard surfaces, bare ground, bushland, farm land, turf in roadsides, and turf in median strips or easements.

The study found that the average turf groundcover across all 16 sampled suburbs for Sydney was 17.23% (±0.55%). Percentage turfgrass cover varied widely between Sydney suburbs from high values of 34% in Concord, 33.3% in Colyton and 29% in Arncliffe to quite low coverage in Enmore (8%), Lindfield (9%) and Northwood (9.67%). For Melbourne, average turf cover across all of the metropolitan areas measured was slightly higher at 18.94% (±0.57%). Again turf cover varied widely between sampled suburbs with outliers like the suburb of Ardeer, which contained a substantially higher percentage of turf groundcover with 42% of the suburb being covered with managed turfgrass. This example was due largely to nature of the suburb being small, entirely residential and containing large roadside, riparian areas and parklands of managed turf.

The lowest level of turf coverage was found in the Central Business District (CBD) and at 5 kilometers from the CBD for both Sydney and Melbourne, which was expected based on the population densities and infrastructure of these areas. Most of the turf in the CBDs was attributed to large parks and sports fields, such as the Albert Park golf course and the Royal Botanic Gardens in Melbourne. For both of the cities, when average turf cover is broken down into turf type, it is evident that the home lawn (privately owned turf) makes the biggest single contribution to the total being nearly a third of all types of turf. However, turfgrass in the other (nominally) publicly owned cover classes (i.e. roadsides, sports fields, parks, median strips) is cumulatively much larger than the private home lawn total.

Even at a macro level the figures derived from the study can be used to extrapolate further information. For example the total area under turf for the Greater Sydney and Greater Melbourne areas can be estimated at 2,131 km^2 (or 2,131,000,000 square meters) and 1,832.20 km^2 (or 1,832,200,700m^2) respectively. When calculated on a per capita basis, this provides an average of 431.20m^2 of turfgrass per person in Melbourne which is lower but surprisingly close to the Sydney average of 462.60 m^2 of turfgrass per person.

The project has shown that the use of satellite imagery and appropriate software has considerable potential for the purposes of quantifying turf coverage quickly, accurately and affordably. The only limitations were the availability of quality aerial photographic images for some areas (outside of this study) and the instances where this system could not easily determine the ground cover turf under trees or structures that cannot be confirmed from above (with the use of aerial photography) but rely on the operator making a judgment call based on experience and the surrounding land use.

The study concluded that further research should focus on expanding the research to address the following recommendations:

Recommendation	**Action**
Recommendation 1	Further fine tune the survey methodology and devise ways to account for limitations and assumptions or take advantage of improving access to quality photography.
Recommendation 2	Extend the survey area to include all capital cities and major population centers of interest based on industry priority (i.e. areas closest to production centers).
Recommendation 3	Combine the survey results with other research results that have identified the benefits of turfgrass in order to begin modeling the benefits to the community at a landscape scale and then value them (e.g. how many tons of oxygen does Melbourne's turf produce annually?).
Recommendation 4	Begin to identify and investigate the relationship between turfgrass coverage and other social and economic indicators of interest to the industry and community (e.g. turf cover and wealth; turf cover and house pricing; turf cover and water use; turf cover and resident's health).
Recommendation 5	The results should be communicated widely by the Turf industry to the media and also offered to other organisations (e.g. NGIA) for use in their promotional materials and also provide directly to the local governments included in this survey. Ideally this should include transforming the data and report results into more user-friendly info-graphics, animations, extension videos and fact sheets.

Introduction

The ubiquitous nature of turfgrass as a groundcover in urban and suburban environments has meant that it is often taken for granted, and consequently afforded little value by government decision-makers or residents. However, amenity turfgrass offers a number of environmental benefits, including the ability to cool urban landscapes, control erosion, manage storm water, sequester carbon and improve air quality (Holborn & Hewitt 2013). The extent to which these benefits are realised is debatable and differs according to a number of factors including the amount of turfgrass within an area.

Part of the issue with measuring the areas currently under turfgrass is that the industry cannot reliably or affordably estimate the percentage of land that is covered with turfgrass. The term turfgrass is here used to refer to a regularly maintained area of grass that (usually) has a specific purpose (e.g. sports field, roadside verge, parks, gardens and so on). Councils and other landholders undoubtedly view the covering of an area with turfgrass through the lens of maintenance and input costs associated with managing the area. These costs can be associated with activities such as irrigation, mowing and chemical use, but usually it comes down to the collective costs involved in maintaining the area.

A clear idea of the size of the area covered in turf in Australia is currently unknown, but is likely to be substantial. In the United States, turfgrass coverage for the entire country has been roughly estimated at between 40 and 50 million acres (Morris 2003; Hayden 2005). If either of these figures is correct, it may be true that turfgrass is indeed the largest cultivated area in that country. In urban areas in particular, turfgrass has been found to play a critical role and positively impacts on the social, environmental and economic values of the community (Beard, 1994; Beard and Green, 1994; Higginson and McMaugh, 2008; Holborn & Hewitt 2013). When quantified broadly across entire cities for homeowners as well as local and state governments, turf is likely to be found to be a high value asset and the extent of its coverage will provide a foundation from which to accurately calculate the benefits provided by this type of groundcover. For example, the areas of turf in a city could ultimately be extrapolated to provide figures on benefits such as oxygen generation, carbon sequestration and more. This process would be the first step in estimating the environmental and financial benefits afforded to the community from turfgrass.

This report outlines the results of a project that utilised desktop methodologies to determine types of groundcover and turfgrass coverage using satellite imagery within the Sydney and Melbourne regions. Given the important role that turf plays in many environmental processes within urban areas, this project attempted to provide a foundation upon which the true value of turfgrass to urban communities can begin to be measured. This project began the process of addressing these issues by identifying and using an affordable and accurate methodology for identifying and estimating groundcover percentage for large areas using satellite images.

Literature Review

Introduction & Background

Remote sensing techniques have been utilised in one form or another almost since the invention of photography. Remote sensing has come to be acknowledged as a reliable and accurate way to measure or estimate large areas without having to manually conduct on-site measurements. This is particularly useful in areas where physical measurement is not possible such as remote, inhospitable or very extensive areas. It is also a substantially more affordable methodology for measuring and monitoring areas and is used by governments and corporations to indentify and/or plan land use over large areas. Remote sensing of natural assets has been conducted extensively in Europe and the USA and now in Australia via the Nursery and Garden Industry Australia (NGIA) commissioned study on urban tree canopy cover (Jacobs 2014).

What has not yet been identified is an accurate methodology for estimating turfgrass areas quickly and reliably. In this literature review, previous reports that have quantified the amount of turfgrass areas have been identified and reviewed. This includes peer-reviewed published papers as well as non-reviewed industry magazine and newsletter articles. Also identified and reviewed are a number of non-turf-related reports looking more generally at identifying and measuring specific types of vegetation coverage in urban, rural and native wilderness areas from around the world. Although not all are turf-specific, these reports relate to the goal of developing a practical method for quantifying ground cover in urban areas and then how that data might be utilised by government, business, the public and the Turf industry.

In the United States, turfgrass coverage for the entire country has been roughly estimated to be between 40 and 50 million acres (or ~160,000 – 200,000 km^2) (Morris 2003; Hayden 2005). Melesi et al. (2005) similarly estimated via modeling that a total of 163,800 km^2 (±35,850 km^2) of the US mainland was covered in cultivated turfgrass. If either of these figures is correct, it may be true that turfgrass is indeed the largest cultivated area in that country. In urban areas in particular, turfgrass has been found to play a critical role within the community and positively impacts on the social, environmental and economic values of the area (Holborn & Hewitt 2013; Higginson & McMaugh 2008; Beard 1994, Beard & Green 1994). The value of turf when quantified broadly across entire cities for homeowners as well as local and state governments is likely to be a high value asset and will provide a foundation from which to accurately calculate the benefits provided by this type of groundcover. For example, the areas of turf in a city could be extrapolated to provide quantified benefits such as oxygen generation, carbon sequestration and more.

The history of remote sensing to determine on-ground characteristics using techniques such as aerial photography dates back to the 1850s, when a French photographer lifted early cameras using balloons to take a birds-eye views of Paris (Bied-Charreton 2005). These early efforts were rudimentary, but at the time would have provided a new and eye-opening viewpoint from which to view the city. This sort of approach continued until the early 1900s, when the more extensive use of planes and cameras were used in the First World War to assess battlefield conditions and enemy trenches (Bied-Charreton 2005). As a result of the success of this type of investigation, Remote Sensing emerged as a legitimate field of study being utilised by government, science and engineering including by organisations such as National Aeronautics and Space Administration (NASA) to determine a site for the moon landing of 1969 (Campbell 2007).

Remote sensing can be broadly defined as investigating an object or area without having to physically touch it or be present on the ground (Schowengerdt 2007). A number of methodologies and remote sensing systems have been used around the world for the purposes of identifying and measuring landscape features such as geology, seismology, geomorphology, contour mapping and for measuring areas of forest remotely. LiDAR is an example of one such methodology which utilises laser light that is beamed onto the earth surface (or water bodies and oceans) and the reflected light captured and analysed to form a 'picture' of the surface. This differs from the use of satellite or aerial photography by being able to provide, accurate three dimensional LiDAR images for analysis. Although this technique of landscape pattern analysis is well accepted it was not utlised due to the cost and complexity of use.

Aerial and satellite photography has been well utlised in measuring natural areas internationally and with the advent of public portals such as Google Maps, Google Earth and Near Maps access to these resources is now substantially easier and more affordable (Google Inc. 2014; Near Map Ltd 2014). This approach, rather than the more complex LiDAR or similar approaches allows more open access to the data as well as the ability to generate new data at any time by anyone. There has been literally dozens of studies utlising remote sensing examination of aerial and satellite photography to measure tree canopy cover in cities worldwide from China, India, the UK, Canada, Australia and the USA. What has been considerably less studied is turfgrass groundcover.

Measurement and analysis approaches – international examples

In the U.S. and Canada, there have been a number of attempts to identify and measure groundcover types using satellite imagery and aerial photography via remote sensing. Grasslands or prairies are an important habitat type and agricultural resource, with the governments and universities taking control of monitoring and managing the national grassland areas. Part of this process requires a clear and accurate identification of the groundcover of interest, its size, its species heterogeneity and its health. Guo et al. (2004) utlised remote sensing to identify the species make-up of grasslands in Canada and also to try and gauge the health of grassland areas based on colour differences (Guo & Wilmshurst 2004). In the second study a common turfgrass measure based on colour (greenness) using the Normalized Difference Vegetation Index (NDVI) measure was utilised. This measure is often used in small-scale studies of turfgrass as an indicator of quality or health. The issues in both studies were isolating grassland species from weedy and dead material as colour (and therefore the ability of analysis software to identify it) was compromised (Guo et al 2004; Guo & Wilmshurst 2004).

A proportion of remote sensing techniques that have been applied to the examination of turfgrass have been in relation to management issues. These include examinations of turfgrass pest and disease evaluation, a virtual irrigation audit and the examination of stress such as wear and defects with turfgrass surfaces for sports such as golf, horse racing and baseball. Similarly various turfgrass stressors can potentially be indentified remotely (Shaw and Guertal 2000; Frank 2008) and turfgrass colour has been used with varying rates of success to indicate quality in these instances (Taghvaeian et al 2013). Remote sensing has also been used to identify pest damage i.e. from Japanese beetle grubs *(Popillia japonica* Newman) prior to obvious visible signs being displayed by the turfgrass (Hamilton et al 2009). However these studies did not attempt to measure areas but instead differentiated healthy turf from unhealthy turf within one area.

Helmer et al. (2002) attempted to identify and measure differing vegetation covers in their study of Puerto Rico. This study successfully mapped the complex vegetation types throughout the island, which included forests, wetlands, agricultural land and barren or wasteland areas. The study found that an automated or semi-automated system could be used via a remote sensing approach that could delineate different land cover types and map them accordingly. The study provided the first accurate and detailed map of vegetation types, which led to a critical assessment of what was potentially under threat and what areas were well protected (Helmer et al. 2002). This area was reanalysed and the data updated by Ramos-Gonzalez in 2014 who examined aerial orthophotos of Puerto Rico. This study utlised the GUIDOS Toolbox (Graphical User Interface for the Description of image Objects and their Shapes) which uses online software to process geospatial data and to export it as overlay images in Google Earth. The GUIDOS Toolbox includes MSPA (Morphological Spatial Pattern Analysis), which essentially identifies connectivity of objects within the study area and in this example, was used to determine areas of connected green life across the city (GUIDOS 2014).

In Singapore, the government has a goal of turning the city into a ‘City within a Garden’, to which they have committed comprehensively. This includes some very ambitious goals for which they have legislated accordingly, to encourage the community, businesses and developers. The plan includes a requirement that any new development must replace its footprint with a similarly sized green area, in any way the developers see fit. This often includes green roofs or walls and has led to some imaginative solutions to the issue of ‘fitting’ a green area into developments. Liew Soo Chin (2010) utlised digital photography to estimate that above-ground plant biomass has increased over the study period (from 1986 – 2007) by quite a large factor from around 35.7% to 46.6% respectively (Chin 2010).

Glasgow City in Scotland has utilised remote sensing to identify areas that are derelict or empty and then overlaid those maps with basic demographics such as life expectancy, financial security and incidence of cancer, among many others (Maantay 2013). The results were interesting in that the technique seemed to be able to pinpoint areas of potential trouble, highlighting a small handful of areas that required priority attention based on the outcomes experienced by the community as a result of land use categories. The report also suggested that there were a number of small landscape changes that could be made within these areas to decrease the incidence of illness and isolation (Maantay 2013). Glasgow City Council (GCC), in conjunction with the Glasgow Housing Association (GHA), has launched the *Stalled Spaces* initiative which encourages community groups and schools to identify and renovate derelict or vacant land areas within the city. This award-winning initiative has already resulted in some very successful projects reclaiming (albeit temporarily) some important land within some of Glasgow’s lowest socio-economic areas. This includes land that was converted into community gardens (similar to allotments), as well as areas that were converted into parks and areas for children to play. This program is continuing, with the council putting in place a framework for the community to identify and then negotiate with the landowner so that everyone is clear that any measures are ultimately temporary and that the landholder loses nothing by participating. The entire program acknowledges that these spaces are wasted in their current condition and that the benefits of making them more useable for the community, outweighs the potential costs (GCC 2012). To date, between 40 and 50 areas have been renovated and brought back into use and the program has attracted more than £500,000 in external funding to the city from external organisations, for other related activities.

Australia

The assessment of land cover or land use in Australia utilising this sort of approach has been well tried in the private sector and universities offering remote sensing analysis for over a decade. Similarly some federal, state and local government units have utilised the analysis of aerial and satellite images to identify, measure, monitor and manage areas, usually native bushland areas, agricultural land or areas of national significance such as the Great Barrier Reef (Guerschman et al. 2013).

A number of large-scale, longer term initiatives are underway using different remote sensing techniques to measure and monitor land for management purposes. These include DustWatch (2014) monitoring wind erosion nationally; VegMachine (CSIRO 2014) which allows graziers to monitor their property’s groundcover vegetation; the Australian Collaborative Rangeland Information System (ACRIS 2014) a national mulit-partner initiative which collates and analyses data describing change in the rangelands (the more arid land areas covering around 75% of the Australian mainland). This information assists the Australian Government, state agencies and rangeland NRM groups in meeting reporting obligations, planning investments to facilitate change and evaluating the effectiveness of those investments.

An interesting example of remote sensing from the commercial sector is Remote Sensing Australia (2014), a business unit of Spatial Scientific Pty. Ltd. Remote Sensing Australia has been using aerial photography for over ten years to determine a number of vegetation coverage issues in urban, suburban and rural areas across Australia. This has been undertaken across entire local government area, or individually across a suburb to monitor individual tree cover, height and most interestingly vegetation *health*. This includes the basics (i.e. getting the lay of the land and identifying any areas of concern), as well as to monitor activity in areas such as:

- Calculating areas of urban green space
- Measurement of tree canopy area
- Monitoring changes in vegetation cover
- Health monitoring of significant trees
- Detection of illegal tree felling
- From individual fields to entire growing regions.

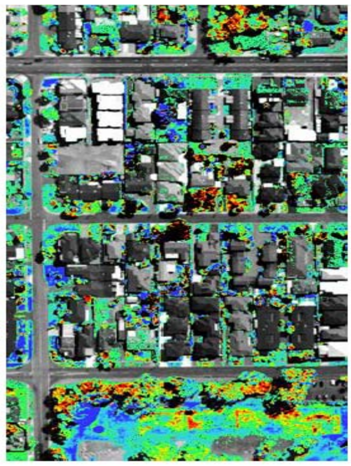


Image 1. Right: example of the kind of image information that can be provided - with different colours representing vegetation and the different health status of the vegetation in that area.

State governments as well as local government areas, such as Brisbane City Council (BCC) have also utlised remote sensing techniques to develop, augment and/or cross check their planning maps for issues such as identifying natural heritage or biodiversity areas for future protection (refer Image 2). The use of these techniques assists city planners, developers and rate payers at the broader landscape scale and allows the measurement of these areas across the region. These can the assist planning and budgeting as well as potentially valuing these areas by acknowledging and delineating them, but often they do not contain the necessary information or detail for purposes other than those originally envisaged. The undertaking of this sort of measuring and ‘mapping’ is also limited to individual councils, their budgets and their priorities. It is therefore critical that industries derive a set of statistics that capture and convey the data set of interest to them.

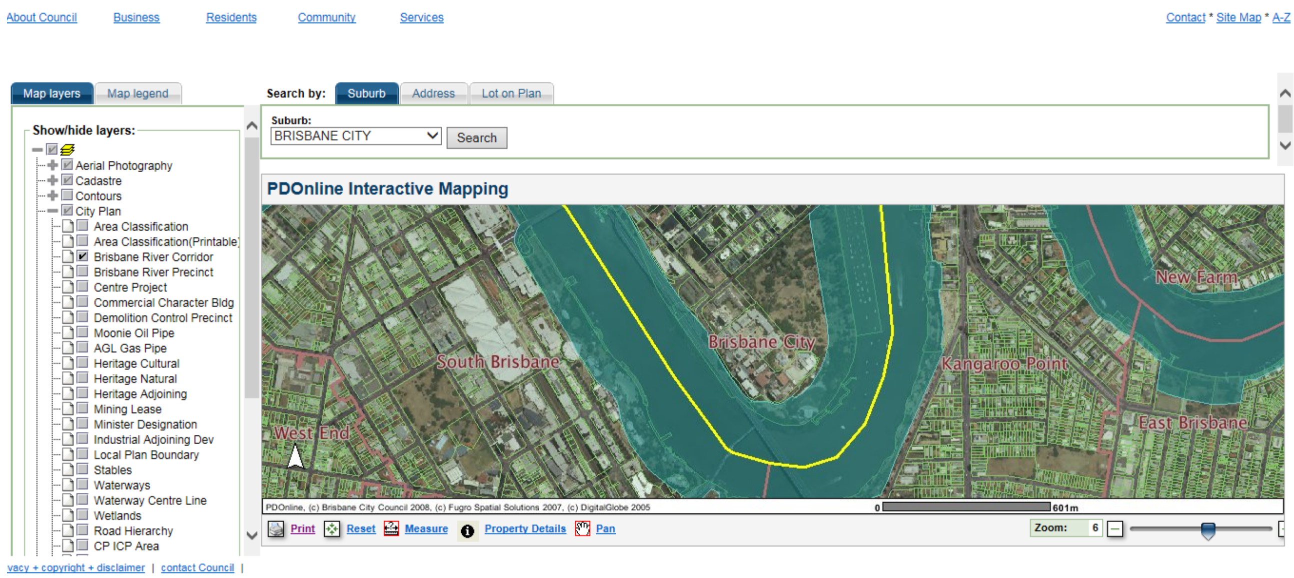


Image 2. Brisbane City Council – part of the interactive, online planning photography displaying the Brisbane River Corridor 2014 layer (blue shaded area).

A recent example is the study conducted by the University of Technology Sydney (UTS) on behalf of the Nursery & Garden Industry Australia (NGIA) investigated tree canopy cover in their report *Benchmarking Australia's Urban Tree Canopy: An i-Tree Assessment* (2014). The study resulted in some interesting findings and also highlighted the importance of selecting the correct cover class for the purpose intended. In this case, the study delineated cover classes into four categories based on what was currently in that spot and potentially what could be:

1. Hard Surface – currently non-plantable
2. Tree – Canopy cover
3. Shrub – Understory
4. Grass-Bare Ground – potentially plantable.

These categories suited the purpose of the study which was to begin the process of identifying green life cover in 139 Australian local government areas. The catalyst being that the nursery industry's consumer awareness campaign, the 202020 Vision, has the goal of increasing the amount of green life in Australia's urban areas by 20% by the year 2020. For these purposes the report identifies and measures those categories accurately and well. For the purposes of the turf industry as well as turf owners and managers the report masks the detail associated with turfgrassed areas by collectively counting them with areas of bare ground and also paddocks and fields (i.e. unmanaged turfgrass areas). This has resulted in minor difference (see Results & Discussion section) but is largely as a result of the UTS identifying areas in the grass/bare ground category as potentially plantable with trees and shrubs. This is admittedly with the acknowledgement that areas like established sports fields are not likely to be replanted with trees and shrubs but many of the other turf areas are potential planting sites.

These examples illustrate that the use of remote sensing is both a viable and accurate method for determining groundcover and land use over relatively large areas and also illustrates the benefits in conducting this type of examination for anyone wanting to underpin any proposed changes to an area with accurate data.

Conclusion

A commonality to all of the studies has been the measurement of areas to then use the results to educate and highlight the current situation and encourage the potential for change or improvement (in both management or conservation) to suit the purposes of the groups involved. It is envisaged the results from this study will be communicated widely to affect a similar response from turf owners and managers. Morris (2003) stated the figure of 50 million acres of land area in the USA as being covered with turfgrass. Although the methodology used to estimate these figures is not mentioned, the figures were used within a context of justifying funding and research support for the industry based on its size and importance in the US for the environment, the economy and the American people.

Although programs are emerging and being successfully employed to interpret and analyse images automatically, in the case of turfgrass estimation, this is not yet possible in urban areas. This is due to the complexity of the urban environment and the variable quality of the available images. This includes variation between areas (and within the same area) of turfgrass quality (i.e. greenness) as a result of varying management regimes, dry conditions and when the photographs were taken (summer vs. winter). Added to this is differing light quality; cloud cover, shading and the similarity in colour between turfgrass and some structures (such as green roof tiles and metal sheeting) within a photograph. Therefore, the other side of the analysis system is the interpretation or contextualisation of the factors influencing the image which is best done by someone, a person, with experience in the subject matter.

The main reason that the i-Tree program approach was selected in this study was based on the principle of remote sensing that stresses that the image being used (its quality and characteristics) is influenced by a number of other factors including; the light reflected by the subject (spectral resolution); differences between those objects within an image (radiometric resolution); the ability to distinguish small objects within an image (spatial resolution); and understanding that the image is a product of a number of physical factors such as the position of the sensor optics, the motion of the scanning vehicle, terrain relief, operating conditions and many others (geometric transformation). On top of these issues is the added influence of the Earth's atmosphere which is claimed to alter light and degrade image quality by as much as 90% in some cases. Therefore an image on its own represents just one part of the analysis equation or "remote sensing system" (Campbell 2007).

No matter what methodology of remote sensing is utilised, there is still a number of factors that remain unresolved (fully at least anyway) such as accurately comparing alternative methods of measurement for large areas; the validation of results across large areas; possessing adequate data in enough key areas to allow for longer term comparisons so that changes and any patterns of change in urban environments can be identified. Despite these limitations this project represents a first step for the Australian turf industry to measure turfgrass groundcover in two of Australia's major population centers, providing a baseline for future efforts in this area.

Materials and methods

Estimating turfgrass groundcover

SigmaScan Pro

SigmaScan Pro software was used to analyse sections of maps from Google Earth to determine the percentage of turfgrass in the selected sample area. In SigmaScan Pro, the user can search a picture for a specific colour or range of colours (for example green in Figure 1a) and the areas of that colour are idenfied (Figure 1b) and the resultant data is then transformed into a Microsoft Excel table and summarised (e.g. area in square meters). The program was specifically developed for scientists and technicians who wanted to save research time when measuring irregularly shaped items/areas without compromising accuracy. It has been extensively used on a small scale to objectively measure percentage groundcover in turf research, as well as experimentally within the nursery industry to objectively measure plant growth (Hunt and Pearce 2012, unpublished data). The method used to estimate the amount of turfgrass includes: (i) downloading appropriate images at a standardised resolution and aspect ratio; (ii) processing images in Adobe Photoshop if there is poor resolution or if structures appear to be the same colour as turfgrass (e.g. shrubs, trees, painted roofs); (iii) determining colour threshold settings, such as hue and saturation for turfgrass, and; (iv) analysis.

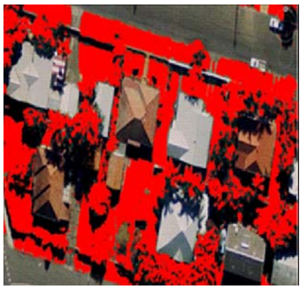


Figure 1. (a) Left - Original Image (Eye Alt 100m) and **(b)** Right - after analysing in Sigmascan Pro software for turf cover.

All pictures were taken from Google Earth software and saved in Joint Photographic Experts Group (JPEG) format with an image size of 400 x 400 pixels, with the elevation (Eye Alt) set at 100m. Some suburbs have very poor resolution and it was not always possible to analyse pictures from those areas in SigmaScan Pro, because the turfgrass and surrounding area were, in places, indistinguishable. It is possible in these cases to use other imagery instead of Google Earth where the resolution is better/higher. However, this was not required for this project as suburbs that were analysed were of suitable quality and resolution. Appropriate target suburbs were identified, and then randomly selected sampling points on the map were chosen using a grid pattern laid over each suburb and coordinates randomly selected for each sampling point. This was undertaken by using an online random number generator (randomn.org) and the information was then saved for further analysis in SigmaScan Pro.

The sampling point images which had poor resolution and/or some structures (roofs, swimming pools and so on) which appeared as a similar colour to turfgrass were processed in Adobe Photoshop, where brightness and colours were changed manually (Figure 2). Although this added to the time required it did improve the accuracy of the result and it was then possible to set appropriate hue and saturation levels.

Figure 2. (a) Left - Original Image (Eye Alt 100m) showing green roof (top left corner) which presented a potential form of error in estimating the percentage turf cover and; **(b)** Right - after processing in Adobe Photoshop.

Survey point selection for trial suburb

Drummoyne, a Sydney suburb, was chosen as an initial test suburb for scanning using SigmaScan Pro. The suburb was taken from Google Maps, with the scale set to 200m so the suburb boundary was viewable (Figure 3). A 100m X 100m grid overlay was placed over the suburb so sample areas could be determined by using randomly generated coordinates. The outermost western edge of each suburb was placed in vertical grid line 1 and the northernmost edge of the suburb was placed in horizontal grid line 1.

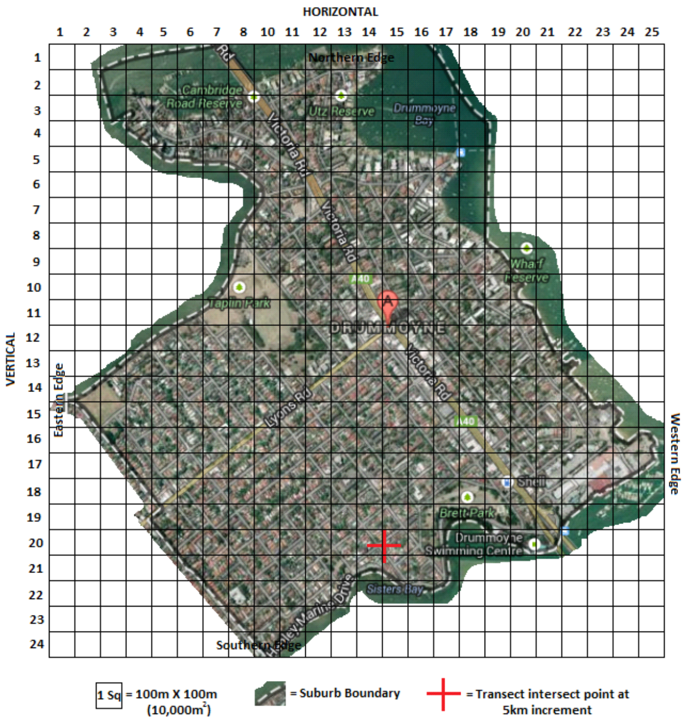


Figure 3. Sydney suburb of Drummoyne at 200m scale with 100m x 100m square overlay.

The grid overlay was designed to encompass the entire suburb so the grid extended until the easternmost and southernmost points of the suburb boundary were covered. In the case of the suburb Drummoyne, it was just under 2.5km from west to east boundary extents (so the grid went from 1–25) and 2.4km from north to south boundary extents (so the grid went from 1-24). An online random number generator was then used to select co-ordinates within the grid overlay (www.random.org). Any co-ordinates that fell outside of the suburb boundary or too far over the edge of the boundary were disregarded. In the case of Drummoyne, the co-ordinates were disregarded from the sampling if half of the test area was either outside the suburb boundary or if an area fell at a point where it was not relevant (e.g. in Sydney Harbour).

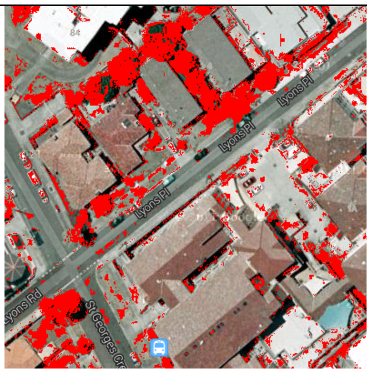
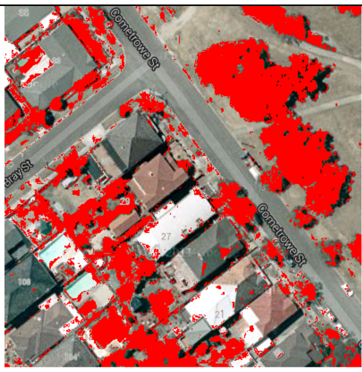
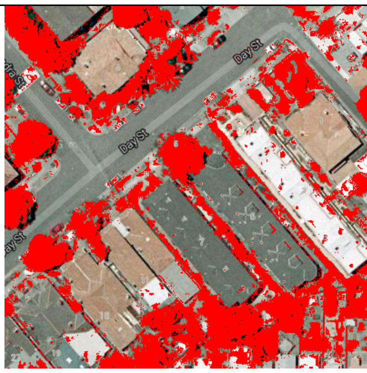
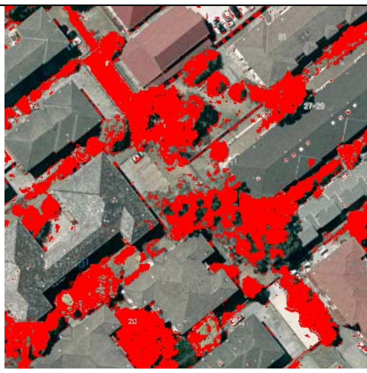
Before	After	Comments
 Before	 After: 15.99% cover	• Greenlife contributed to large inaccuracies being included on all occasions • The dull (grey, yellow and brown) colour of turf when the satellite imagery was taken was often missed by the scan due to the green colour threshold settings. • Certain sections of road, car park and median strip footpaths were aligned with the colour threshold provided inaccuracies in the result.
 Before	 After: 25.54% cover	• Large turfed area in the top right of the grid was missed due to off-colour turf. as the Image was obviously taken during a period of dry. • Greenlife contributed to large inaccuracies getting included in the result. • Parts of house roofs were also included.
 Before	 After: 30.31% cover	• Satellite imagery was obviously taken during a period of dry where the turfgrass was wilted/wilting and hence didn't match the predetermined green colour threshold that healthy turfgrass would display. • Greenlife contributed to large inaccuracies getting included in the result. • Sections of roof were also included in the result.
 Before	 After: 24.23% cover	• Satellite imagery was obviously taken during a period of dry where the turfgrass was wilted/wilting and hence didn't match the predetermined green colour threshold that healthy turfgrass would display. • Greenlife contributed to large inaccuracies getting included in the result. • Sections of roof were also included in the result.
Average = 24.02%		

Table 1. Testing for accuracy in Sigmascan comparing before and after colour threshold image and % cover estimates.

Colour threshold settings and using 'Turf Analysis' macro

For analysing the pictures in SigmaScan Pro it was decided to use the colour threshold option that is required to select parts within an image of suitable hue and saturation levels (in this case turfgrass areas). Hue levels ranging from 46 to 106 and saturation levels from 10 to 99 were selected. Once threshold settings were determined, all areas in the photograph that fall within those settings appear as bright red, which was then the area measured to estimate turf coverage (refer Table 1).

The initial test used the 'Turf Analysis' macro which automates the processing of pictures in SigmaScan Pro by analysing multiple pictures at one time. It was necessary to save pictures with the same format and a similar name with different numbers; for example, Grid1 and Grid2, for easier downloading into macro. The colour threshold settings were determined before downloading the images in macro. After the settings were chosen, the results from the macro were automatically transposed into a Microsoft Excel worksheet. The resultant data is represented as total pixels, selected pixels, percentage covered by overlay, the amount of red, green, blue colour produced for each pixel in the image, hue and saturation levels and brightness for each picture. The usage of the 'Turf Analysis' macro is described in detail by Karcher & Richardson (2005).

The percentage cover results were compared with their accompanying colour threshold image and the accuracy of the SigmaScan method was assessed (Table 1). In this example, the accuracy of using SigmaScan was directly affected by the quality and timing of when the photograph was taken. If aerial photographs were taken during a dry time, the hue and saturation needed to be decreased for the threshold to pick up turf colour (i.e. more grey and yellow included in the colour threshold). In doing so, certain sections of road and hard surfaces (e.g car parks and paths) tended to also be included in the scan.

Consequently, it was decided that a more accurate method of scanning for turfgrass cover was needed that would not require the reliance on the variable hue and saturation that turfgrass displays as a result of uncontrollable climate pressures, especially in Australia. Ideally, to achieve a high accuracy of this program it would require the turfgrass to be in sufficient health that would allow for the hue and saturation levels to be set to a more narrow and specific range. This unfortunately limits the use of the program to studies where turfgrass is the groundcover of primary concern (e.g. Karcher & Richardson 2005) and where other cover types or structures cannot introduce error into the scan results.

I-tree Canopy

I-tree Canopy was identified as an appropriate potential program that uses random point generation and eliminates the reliance on a colour threshold, instead using a user-identified cover class that is determined by the user. This online software system generates a sample point randomly within a defined boundary on Google maps (www.google.com.au/maps). The point is then assigned to a user-defined cover class. That is, if the co-ordinate sample point lands on a tree, the user assigns it to a cover class that a tree would belong to such as 'tree' or 'greenlife'. I-tree Canopy v6.0 is online software (available at http://itreetools.org/canopy). For this example, the suburb of Drummoyne was again used to allow for a comparison between the results and ease of use of SigmaScan and i-Tree Canopy in undertaking an analysis of turf cover.

In this example, the process is started by selecting an area using the 'Define Project Area' where the desired location is entered; in this case, the suburb of Drummoyne in Sydney, Australia. The suburb boundary is then outlined by highlighting the edges of the suburb boundary until the required suburb area has been selected for inclusion in the survey (Figure 4).

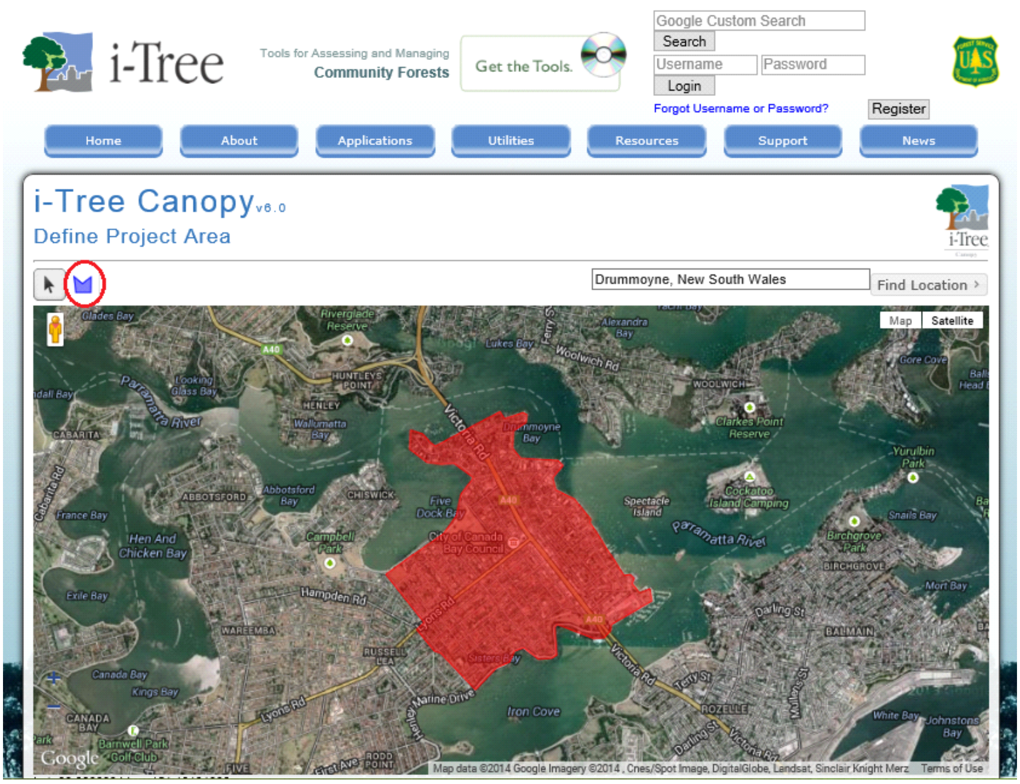


Figure 4. Outline the desired suburb and then highlight in the map by cross checking the suburb boundary.

The user must then configure the cover classes of interest that will be utilised in the survey. The default classes are Tree and Non-Tree, but any other type of cover class can be added or deleted, which is particularly important as this will determine the outcomes and the final results. It is expected that the more surfaces/cover types that are included, the more accurate and descriptive the result can be, allowing a more comprehensive analysis and discussion. For this reason, 13 cover types (including 5 different turf cover types) were included within the analysis for this particular project. This provides a breakdown of the types and uses of turf in a particular suburb as well as the ability to compare total turf cover with other cover types within the selected suburb. The cover types that were used in this project along with their description are outlined in Table 2.

Table 2. Cover classes used in i-Tree Canopy analysis

Cover class	**Description**	**Abbr.**
Greenlife	Managed tree, shrub, garden etc.	Tr
Construction	House/building	C
Hard Surface	Paving, driveway, footpath, concrete etc.	HS
Bare Ground	Bare earth surface (e.g. beach, empty plot that has no cover)	Bg
Water	Creek/water body (e.g. dam, swimming pool, river, harbour)	W
Bushland	Unmanaged natural or remnant vegetation	B
Farm Land	Farmland/open grassland	F
Road	Roads	Rd
Turf-Home Lawn	House surrounds	T-HL
Turf-Park	Park or public open space	T-P
Turf-Sportsfield	Sports field, school oval, golf course	T-S
Turf-Median Strip/Easement	Turf alongside pathway on the edge of a managed street	T-MS
Turf-Roadside	An area that is managed but does not fall into other categories	T-r

The program progressively selects sample points randomly on the map within the selected geographic boundary. Each sample point is assigned to its cover class by the user on a case-by-case basis (Figure5). For example if the point is situated over a tree, it was assigned to the 'Greenlife' class. It should be noted that the points are only a percentage of each other, not the percentage of the cover in the suburb. Therefore, the number of sample points utilised will determine how accurate the percentage cover estimate will be for the entire suburb. i-Tree Canopy updates the point data with each successive sample effort and determines a percentage cover estimate, as well as standard errors of the mean values which can be utlised to indicate when sufficient point data has been collected. It was decided that a sample size of 300 points per suburb would be generated to account for the random variation across the suburb. This number was decided upon for expediency but is sufficient to ensure that the variation across each area is accounted for and that a representative set of data is secured for the suburb.

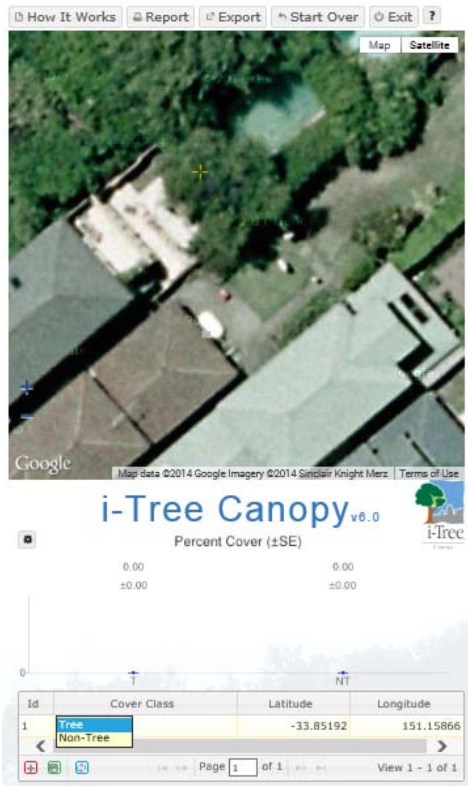


Figure 5. Example of program sample point generation and the process of analysing cover classes.

When undertaking an aerial analysis such as this, i-Tree canopy analysis is heavily reliant on the quality of the image. In some instances using i-Tree Canopy analysis, it can be difficult to tell the type or use of a turfgrass, particularly in rural areas due to the quality of the image. For example, if the randomly generated GPS coordinate landed on the turfgrass around a factory and there was a farm with a definite fence line next to the factory, the user would categorise it as 'Turf-Roadside'. However, if a fence line was indistinguishable (due to a poor quality image), the user would categorise it as 'Farmland'. This demonstrates that i-Tree Canopy analysis can be influenced by both human and program error; firstly, when undertaking the make-up of cover classes (user error), if there are not enough cover classes to categorise a point, allowing the data to be skewed by falling too much into its erroneous cover description; and secondly, the determination of a point (user and program error) is heavily reliant on the quality of aerial imaging and the user having enough focus to categorise a particular point into the correct cover class.

Similarly the use of i-Tree canopy to review aerial imaging, any turfgrass that may have been growing under a tree canopy or in heavy shadow may not have been identified as turf cover and consequently assigned to the green life or bushland category. This is one of the only limitations of using aerial imaging to determine percentage cover assessment of an area, however this is a relatively minor concern and must be weighed against the speed, convenience and very low costs of undertaking this sort of assessment using remote sensing.

Sydney suburb selection and sampling

Google Earth was used to explore greater Sydney and gain an overview of the urbanisation patterns leading away from the city. A 50km transect was selected to run from the Central Business District (CBD) of Sydney to Penrith, as this was deemed as a suitable way to account for variation spatially across the city, metropolitan areas and outer suburbs. Sample points starting with the central CBD were then selected at 5km intervals along the transect line for the first 20kms and then every 10 kms. Google Maps was used to cross-reference the transect line and determine which suburb fell at each sampling point (Figure 6). The list of sampling suburbs for Transect 1 can be seen in Table 3.

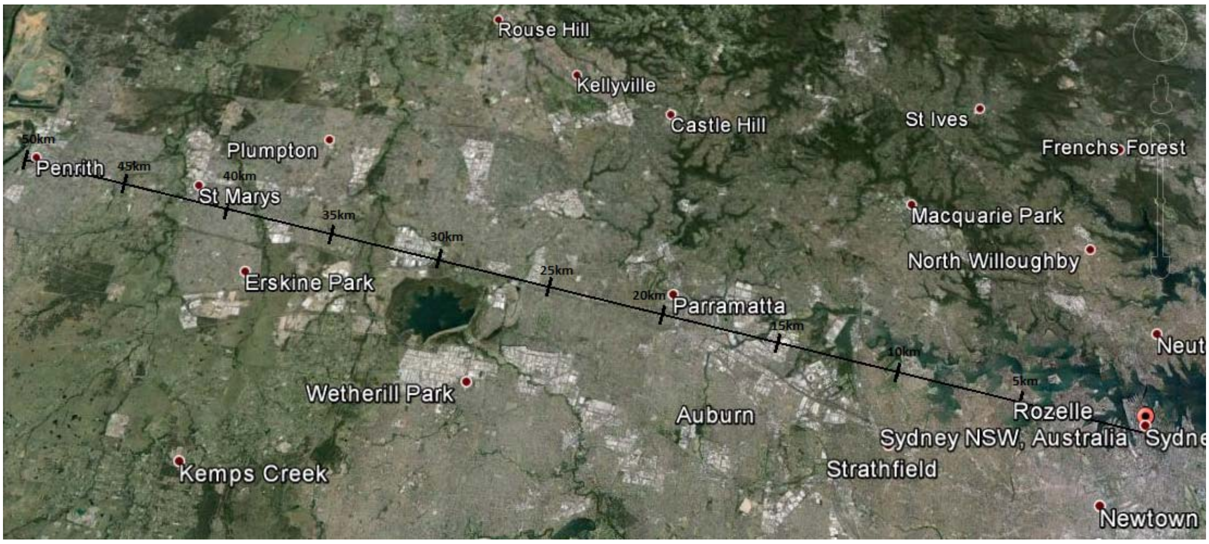


Figure 6. Sampling points indicated with 5km increments from Sydney CBD to Penrith (measured using Google Earth)

Table 3. Transect 1 - 50km from Sydney CBD to Penrith

Distance from CBD	Suburb
0km	Sydney CBD
5km	Drummoyne
10km	Concord
15km	Silverwater
20km	Parramatta
30km	Huntingwood
40km	Colyton
50km	Penrith

Two additional 20km transects were also included in the analysis with Transect 2 running north from the Sydney CBD to Hornsby (Table 4) and Transect 3 running south from the Sydney CBD to Sutherland (Table 5) with sample suburbs selected every 5km to allow comparison with the Sydney to Penrith transect .

Table 4. Transect 2 –20km from Sydney CBD to Hornsby

Distance from CBD	Suburb
0km	Sydney CBD
5km	Northwood
10km	Lindfield
15km	Pymble
20km	Hornsby

Table 5. Transect 3 – 20km from Sydney CBD to Sutherland

Distance from CBD	Suburb
0km	Sydney CBD
5km	Enmore
10km	Arncliffe
15km	South Hurstville
23km	Sutherland

These transects gave a total number of sample suburbs within the Sydney region of 16.

Melbourne suburb selection and sampling

Google Earth was used to explore greater Melbourne and gain a perspective of the urbanisation patterns leading away from the city. A transect was selected to run from the Melbourne Central Business District (CBD) to Bacchus Marsh as this was deemed a suitable way to account for landscape variation spatially across the city, metropolitan and suburban areas. A 50km transect running directly from the CBD to Bacchus Marsh was selected and sample points were selected at 5km intervals for the first 20kms and then every 10km thereafter (Figure 7). Google Maps was used to cross-reference the transect line and determine which suburb the intersection of the transect fell at each distance resulting in the selection of the suburbs displayed in Table 6.

Figure 7. Sampling points indicated with 5km increments from Melbourne CBD to Bacchus Marsh (measured using Google Earth)

Table 6. Suburbs on the transect line at 5km and then 10km increments.

Distance from CBD	Suburb
0km	Melbourne CBD
5km	Footscray
10km	Braybrook
15km	Ardeer
20km	Caroline Springs
30km	Rockbank
40km	Brookfield
50km	Bacchus Marsh

A further two 20km transects were also included in the analysis. Transect 2 went north from the CBD to Epping (Table 7) and Transect 3 went south-east from the CBD to Clayton (Table 8). As in the Sydney study these transects ran for 20km with sample points every 5kms to assist with comparisons between Melbourne transects as well as between the Sydney and Melbourne transects.

Table 7. Transect 2 - 20km from Melbourne CBD to Epping

Distance Away from CBD	Suburb
0km	Melbourne CBD
5km	Brunswick East
10km	Reservoir
15km	Thomastown
20km	Epping

Table 8. Transect 3 - 20km from Melbourne CBD to Clayton

Distance Away from CBD	Suburb
0km	Melbourne CBD
5km	Toorak
10km	Malvern East
15km	Oakleigh
20km	Clayton

These transects gave a total number of sample suburbs within the Melbourne region of 16.

Results and Discussion

Sydney

The average turf cover across all 16 sampled suburbs from the three transects for Sydney was 17.23% (±0.55%) as indicated by the red horizontal line on Figure 8. Percentage turfgrass cover varied widely between Sydney suburbs from high values of 34% in Concord, 33.3% in Colyton and 29% in Arncliffe to quite low coverage in Enmore (8%), Lindfield (9%) and Northwood (9.67%). A summary table of the percentage coverage for each class in each suburb is provided in Appendix 1. Additionally, a summary profile for each Sydney suburb is provided in Appendix 5. Each profile provides aerial photography and map of each suburb, basic demographic statistics from the Australian Bureau of Statistics (ABS), a breakdown of each cover class and its percentage for that suburb in a table and also as a graphical representation/pie chart format.

When the greater city area's average turf cover is broken down into turf type, it is evident that the home lawn makes the biggest single contribution to the total of nearly a third of all types of turf at 5.8%, followed by parks (4.2%), sports fields (3.39%), roadsides (2.14%) and median strips/easements (1.69%). However, the cumulative total of publicly owned and/or managed turfgrass is almost double that of privately owned turf at a cumulative total of 11.42%. This is of course based on an assumption that almost all of the areas within those categories are owned by governments at different levels from local, state and federal. This is not actually likely to be the case as some 'Roadside' and 'Sports fields' areas are privately owned but the delineation of all of these areas into ownership categories is beyond the scope of this preliminary investigation into the turfgrass land coverage.

When referring to the black trend line in Figure 8, it is noticeable that turf cover comes in at below average for the CBD and at the 5km mark. This is not unexpected, as housing density is high and block sizing is smaller as there is greater population density closer to the city centre. Furthermore, the style of building in these areas, predominantly flats, units or apartments (refer Appendix 5) usually does not accommodate enough space for turfgrass. The predominance of the turfgrass make-up in the CBD belongs to the large parks and other public owned assets; in this case it is predominantly the Royal Botanic Gardens (see Suburb profile in Appendix 5) whereas the majority of the turfgrass cover at the 5km mark is privately owned home lawns.

There is also a further drop below the average turfgrass ground cover levels at the 15km sample suburbs of South Hurtsville, Pymble and Silverwater. This drop in average is consistent across all three transects within suburbs at the 15 km mark. This is likely to be a result of diminishing levels of urban/suburban development at that distance from the CBD. For example, in the case of Pymble a large proportion (49%) of ground is covered under the category of 'Greenlife' which includes substantial tracts of forest (Sheldon Forest), parks (Rofe Park) and vegetation associated with a golf course (Avondale Golf Club). Conversely Silverwater is largely comprised of small and medium scale industrial-type developments including retail, storage and manufacturing developments with large car parks and paved areas. This accounts for Silverwater's results including 26.33% of the suburb being classified as 'Constructions' and 21% as 'Hard Surface'. Total turf area is just 13.33% which is largely made up of the 'Turf Roadside' category due to the high proportion of roads servicing the industrial activities in the suburb. The other main turf areas are represented in public parks with Wilson Park and Blaxland Riverside Park taking up large sections of the undeveloped areas in the north of the suburb adjacent to Parramatta River.

The increase in turfgrass cover at the 10km point across the three transects was largely influenced by the west and south transect lines, where a large portion of turfgrass cover was categorised into home lawns and sports fields (refer Appendix 7). This is also supported by the ABS (2011) 'Dwelling Structure' report of these suburbs, where 'separate houses' formed the largest contribution to the dwelling make-up (>60% of houses in these suburbs (Appendix 5). This is probably why there is more turfgrass in these areas, as there is more available space for turfed home lawns.

This is supported by ABS, where the average figures for land area of an Australian house is 735m^2 with a house footprint of 240m^2. Therefore, there is a potential 495m^2 of available land for turfgrass, greenlife and hard surfaces around the house. Notably, across all distances away from the CBD on the north transect line (20km sample points from Sydney CBD to Hornsby), all suburbs had below average turf cover, being on average 11.25% being less than one third of the broader average turf cover of 17.23%. When referring to Appendix 7, it is evident that greenlife and bushland have a large coverage within these suburbs which accounts for this difference.

Towards the more 'suburban' areas and entering the more rural fringe of the Sydney CBD (>20km), there is an increase in turfgrass cover (Figure 8). The main contribution towards the turfgrass total in these suburbs is home lawns, parks and roadsides (Appendix 7). This is to be expected, as large open spaces of land are available and block sizes are much larger in these areas including small acreage housing developments.

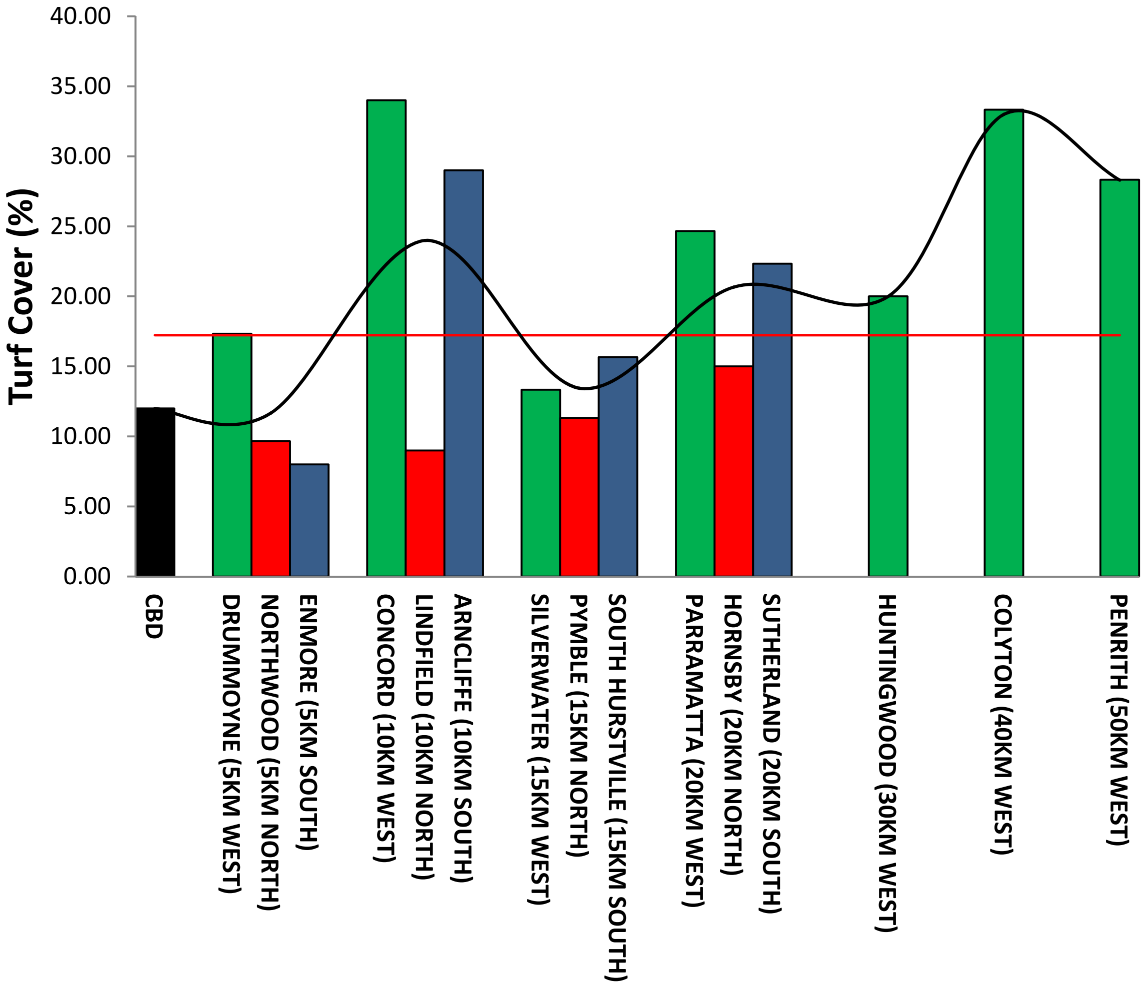


Figure 8. Total Turf Cover (%) in Sydney with average turf across all sample points indicated by the red horizontal line and the average for each distance indicted by the black line.

Even at a ‘macro’ level these figures can begin to be used to extrapolate further information. For example the City of Sydney (2014) state the size of metropolitan Sydney is 12,367.7km^2. Using the greater city average of 17.23% turfgrass groundcover, it can be estimated that total turfed areas in this region are approximately 2,131 km^2 (or 2,131,000,000 square meters). By then taking the City of Sydney’s greater metropolitan area population estimate of 4,605,992 it can be estimated that there is an average of 462.60m^2 of turfgrass per person.

Interestingly the results from the University of Technology Sydney (UTS) study conducted for the Nursery & Garden Industry Association (NGIA) differed in their measurement of turf areas as they also included areas with bare ground and other *unmanaged* grass areas. This category was used to assist in identifyinh potentially “plantable” areas for trees and shrubs. In Sydney for example this study’s suburb measures of turf ground cover when compared with the UTS measures of local government areas differs as the UTS study is routinely higher in its estimate due to the categorisation of cover classes. For example, the UTS measure for Hornsby at 20% compared to our 15% and UTS measured Parramatta at 27.7% compared to our turfgrass measure of 24.67%. The City of Sydney followed a similar pattern but was only slightly higher at 13.2% compared to our 12.10%, presumably because there is less bare ground and unmanaged turf areas in the city centre (UTS 2014). The comparison of these figures is worthwhile mainly to highlight the importance of selecting cover classes that are fit for the purpose of the study but also to illustrate that the potential planting areas identified by UTS are made up primarily of managed turfgrass in most areas.

Melbourne

A summary table of the overall turf cover heading away from the Melbourne CBD is shown in Figure 9. The average turf cover (indicated by the red line on Figure 9) across all 16 sampled suburbs from the three transects was slightly higher than Sydney at 18.94% (±0.57%). When this is broken down into turf type, it is again evident that the home lawn made the biggest single contribution to the total with just under a third (5.47%), followed by roadside (5.04%), sports fields (3.43%), parks (3.23%) and median strips/easements (1.77%). It is again the case however, that turfgrass in the other (nominally) publicly owned cover classes (i.e. roadsides, sports fields, parks, median strips) is cumulatively larger than the private home lawn total.

When referring to the black trend line in Figure 9, it is noticeable that turf cover comes in at below average within the CBD and also at the 5km mark. This is because inner city suburbs are high density living areas which do not accommodate enough space for turfgrass and also contain large commercial and infrastructure elements within those areas (Appendix 4). The predominance of the turfgrass make-up in the CBD belongs to the larger public open space areas of turfgrass such as the Royal Botanic Gardens Melbourne and Hyde Park, as well as sports fields like the Albert Park golf course which is in the southwest corner of the CBD area (refer Melbourne CBD suburb profile, Appendix 6). The predominance of the turfgrass make-up at the 5km mark is mainly home lawns, parks and sports fields as illustrated in Appendix 8 although these are relatively small areas compared to outer suburbs and satellite towns.

The increase in turfgrass cover at the 10km and 15km marks (Figure 9) in the three transects were largely influenced by the west and north transect lines, where a large portion of turfgrass cover was categorised as 'turf-roadside' (Appendix 8). This category was generated to define turfgrass that was maintained but did not fall into any of the other categories (e.g. spare allotments, turf around retail/commercial buildings). There was a notable increase in these turf-roadside areas when reviewing the aerial photography (Appendix 6). Home lawns also contributed substantially to the turfgrass cover total at the 10-15km mark. These observations are also supported by the ABS (2011) 'Dwelling Structure' of these suburbs, where 'separate houses' formed the largest contribution to the dwellings within these suburbs (Appendix 6).

There is a marked drop below the average turfgrass levels at the 30km sample point suburb of Rockbank. An examination of the aerial photography for this suburb (refer suburb profile Appendix 6) suggests that this suburb remains rural in nature with large areas of cultivated land and unmanaged paddocks (unmanaged in the turfgrass maintenance sense). This is a general trend in a more rural settings (>25km from the CBD in Melbourne), where there was a move towards below average turfgrass cover, and an increase in the percentage of farmland (Appendix 8). When reviewing the aerial imagery, it is noticeable that the distance between towns/suburbs also becomes greater and the population density is a lot lower. In satellite towns/suburbs such as Brookfield, the turfgrass cover is made up of home lawns, parks and roadside which is to be expected, as there are large open spaces of land available and block sizes are a lot larger in these newer development areas (Appendix 8).

The suburb of Ardeer was contained a substantially higher percentage of turfgrass groundcover with 42% of the suburb surveyed as being covered with managed turf areas. There are three main reasons for this. Firstly, the suburb is almost exclusively residential and there are no large commercial or industrial areas so each residential home has a lawn. Secondly, there are large parkland and managed environmental reserves within the suburb including More Park, Ardeer Community Park, Ardeer Park, Gateway Hill and the long Kororoit Creek riparian reserve and parkland as well as two schools, both with turfed sports fields. Finally there are also two major roads (Western Ring Road and Ballaratt Road) which form the boundary to two sides of the suburb, both of which have extensive managed turf along the roadside. These elements coupled with what was the smallest suburb in the Melbourne survey (2.21km^2) account for the very large percentage turfgrass.

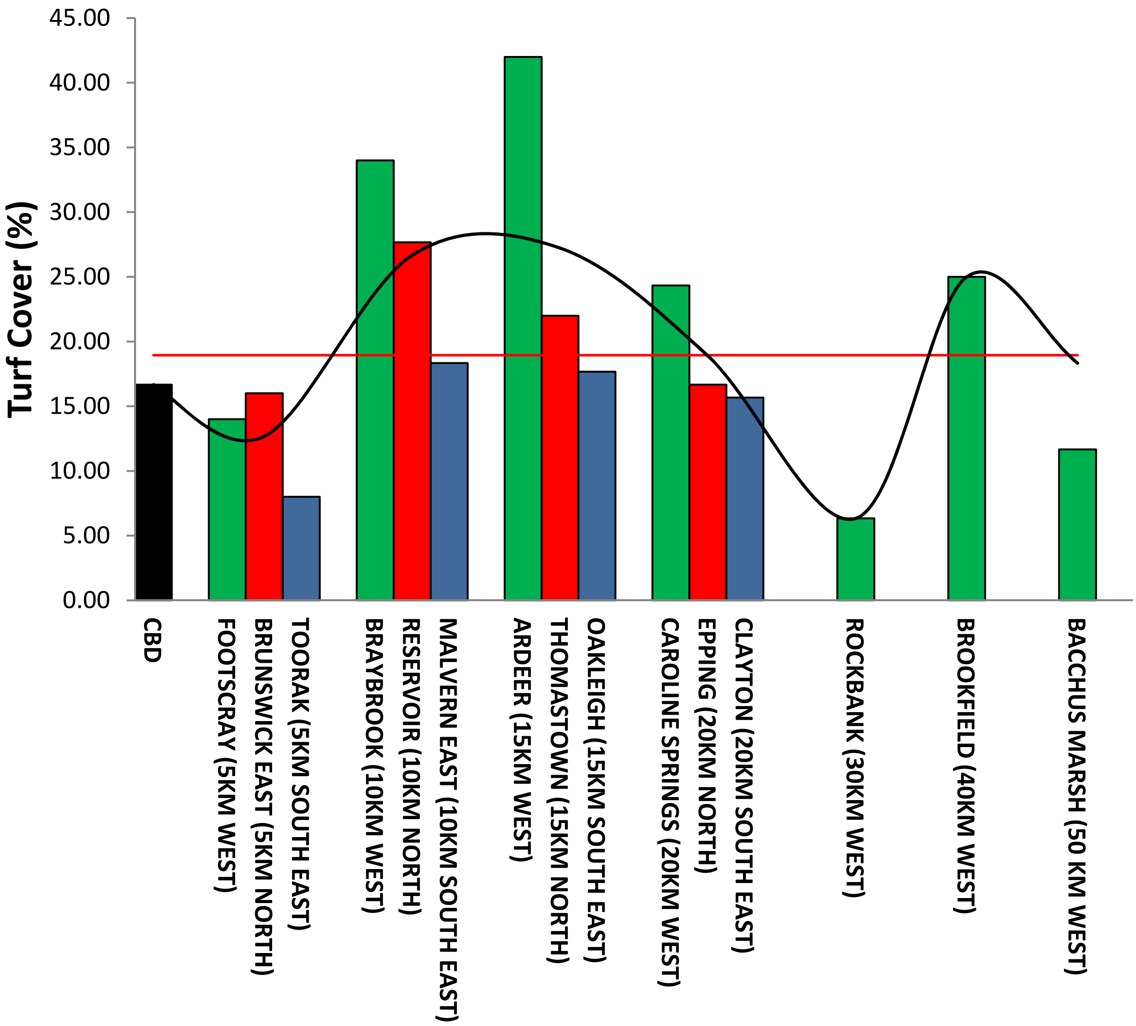


Figure 9. Total Turf Cover (%) in Melbourne with average turf across all sample points indicated by the red horizontal line and the average for each distance indicted by the black line.

The City of Melbourne (2014) state the size of the Greater Metropolitan Melbourne as being 9,990.5 km^2. Utilising the total turfgrass cover averaged across all sampled suburbs of 18.94% the total average areas under turfgrass in Melbourne is currently 1,832.20 km^2 (or 1,832,200,700m^2). Using the City of Melbourne's population estimate of 4,248,344 that then equates to an average of 431.20m^2 of turfgrass per person (which is lower but surprisingly close to the Sydney average per person of 462.60 m^2).

A similar trend was also evident in the comparison of this study's data with that of the University of Technology Sydney (UTS) study with Melbourne CBD for instance measuring 16.67% of turfgrass ground cover in this study but rating at a higher rate of 22.3% when included in the UTS study's grass/bare ground category which includes turf with bare ground and other *unmanaged* grass areas.

Conclusions

This report represents the initial effort to identify appropriate methods of measuring turfgrass coverage in Australian local government areas that is both accurate and affordable. The nature of the task necessitates a generalised approach which requires a level of acceptance of error inherent in the methodology as it is with all remote sensing methodologies to some extent. This however does not undermine the results to the extent that they are not valid and more importantly, that they cannot be subsequently used to inform both the industry as well as the wider public and governments responsible for the ownership and maintenance of turf areas.

Implications of governments and communities

The survey found that turfgrass coverage decreased substantially in both cities in built up areas with high density living. This is not surprising but does reinforce the importance of public access parks and gardens for the people living and working within the CBD and inner suburbs to provide an area to recreate, relax and enjoy but also to ensure that the benefits provided by turfgrass (environmental, economic and social) are not lost to the inner city. These include environmental benefits such as habitat provision, the production of oxygen, dust suppression, erosion control and more. But of higher importance to heavily built up areas, the recognised and substantial cooling effect that turfgrass provides (Holborn & Hewitt 2013). The social benefits to inner city communities include the provision of space to relax, eat lunch and meet with friends or family but also the substantial health benefits from providing areas to exercise and play organised sports on golf courses, bowling greens and sports fields. These benefits of course also relate directly to the economic benefits provided to inner city areas by turfgrass. This includes providing employment in areas such as turf maintenance and also within sporting clubs, social clubs and community groups as well as boosting the local economy by hosting major local, national and international events – both sporting and entertainment (Higginson & McMaugh 2008).

It is hoped that the results from this initial survey are used to underpin decision making within the community, particularly at the local government level. For example, turfgrass represents a substantial asset in most local government areas surveyed where it is regularly between 25-40% of the entire local government ground area. The costs of managing this asset should be contextualised within its area size and the subsequent benefits (environmental, social and economic) that turfgrass areas provide to the community. In some areas these figures could, and perhaps should, be used to address budget allocation issues that seem a common concern across local government areas when dealing with the management and maintenance of turf in public access areas.

Although beyond the scope of this project, there is also likely to be relationships between percentage turf cover and house price, possibly income and as discussed in the literature review, maybe even resident life span and crime levels. Establishing the truth and rigour behind these claims should be a priority for government as it could inform short term resource allocation and planning for established suburbs as well as inform longer term planning for new housing developments.

The information gained by measuring turfgrass groundcover can also be used to extrapolate the environmental benefits from turfgrass and begin the process of putting quantified measures against the identified benefits. For example, if one square meter of turf produces $X economic benefit through health improvements to residents, house price increases or community activities (such as fetes, festivals, concerts or sporting events) then the dollar values of those activities across a suburb or city can be modeled and used as justifications for retention, expansion or simply just acknowledgment of the value of the asset. Similalry this type of modeling can be undertaken to determine the tons of oxygen produced by turf each year, the levels of carbon sequestration, water capture and retention etc…

The use of these survey results in this manner has implications for not just governments in their urban planning, budget allocation and resource management processes, but also has implications for the industry. All of the indicators and modeled statistics can be equally employed by the industry to argue their value and importance and also underpin presentations to government on the amount of turfgrass in an area and its value.

Implications for the turf industry

The turf production industry is a significant economic contributor to the Australian economy and provides jobs across the country, often in outer suburban and rural areas. The industry contains over 240 (levy paying) producers with as much as 37,892,443 m^2 of turf under production at any time (HAL 2012). Survey results such as these should be used to inform at the industry-wide level as well as potentially for individual turf production businesses. They can, for example, be used to advocate for turfgrass maintenance and investment with local governments and also to assist growers in identifying priority current and potential future markets.

Paradoxically it is the suburbs with the lowest turfgrass groundcover that present both the best and poorest opportunities for future sales for the turf industry. When considering suburbs such as the Melbourne and Sydney CBDs as well as other inner-city areas (Northwood, Enmore, Footscray, Toorak) it is apparent that these suburbs are well established, built-up and have limited space for further development and therefore little opportunity for increasing turf sales beyond small area renovations and the (very) occasional larger jobs re-turfing sports fields and public open space areas. On the other hand, outer suburbs such as Rockbank outside of Melbourne are characterised by low levels of turfgrass coverage as they often have large undeveloped areas which, depending on the area, may represent an opportunity for the industry as some of these areas scheduled for residential development over the coming decades. From an industry and individual business perspective, these suburbs represent potential growth areas and may be worth bearing in mind for future marketing or promotional efforts.

A common finding for both cities was that suburbs with the higher percentage turf cover tended to have a water body within the suburb, usually a creek or river, and that riparian area had been made into a community parkland area. These areas represent an important asset and encourage locals to recreate in their local area while also attracting others from outside the community to visit. This may represent an opportunity for turf sales in areas where riparian areas exist but are perhaps not manicured or designed as public open spaces. All Australian capitals (excluding Canberra) and most major population centers are situated on rivers so the redevelopment of these areas as public parklands could be proposed to local and state governments. This is especially the case in areas where the riparian zone is weedy or scrubby and may not have been maintained for some period of time.

The Australian nursery industry has undertaken a similar exercise recently examining the green life of major cities across Australia. This study was part of their 202020 Vision promotion which is advocating an increase in green life of 20% in all Australia local government areas by the year 2020. This strategy is being employed for a number of reasons including a strategic industry push to highlight the importance that green life plays in the urban environment, measure the existing levels of greenery in areas and then encourage increased efforts to improve upon that. This includes encouraging governments to consider legislating for the inclusion or retention of green life in all areas. The Australian turf industry has committed to the 202020 Vision and figures such as those derived from this project can be fed directly into the promotion and educational materials developed as part of that initiative.

The nursery industry's report however has grouped grassed areas in with bare ground and unmanaged turf areas as they have been 'earmarked' as potential planting areas for shrubs and trees. This highlights the need for careful classification of cover types from the outset to ensure that the results suit the purposes of all stakeholders and that areas are clearly delineated (for example sports fields as opposed to what may be a plantable area like a vacant lot or unmanaged riparian zone). This would make the survey more complex and more time consuming but ultimately more accurate.

Recommendations

It has been successfully shown through this project that the use of satellite imagery in combination with suitable software has considerable potential for the purposes of quantifying turf coverage in the Australian landscape. The technique warrants further research and exploration by the Australian turf industry, to quantify the extent of turfgrass usage in Australia and to establish its role as a central part of urban planning in Australian suburbs. There are however still some limitations to the system explored during this project which could be explored in further research.

For example, aerial photography can prevent the accurate assessment of ground coverage if it is obscured by other elements, such as vegetation or buildings. Similarly, image quality can affect the results by reducing the ability of the investigator to differentiate one cover type from another, so there may be a requirement to reassess the results over time as image quality improves with improving advances in technology. Revisiting the project over time could also assist in identifying landscape changes over time for instance, as a result of higher density development.

The obvious potential for further research in this area is to expand the survey into all capital cities as well as major population centers across Australia. This would provide a more comprehensive picture but also allow all governments to recognise the extent of their turfgrass assets and begin to value them more accurately. Any further surveys should be prioritised around growing areas and the proximity to turf production levy payers (the research funders) so that these industry members have local market information and can formulate or adjust their business plans accordingly. The potential for this methodology to successfully identify potential urban growth areas and expanding markets for turfgrass is also worthy of further exploration.

A substantial amount of research been conducted (and is continuing) investigating the specific, measurable benefits of turfgrass, particularly in urban environments. The identified benefits are substantial and include, as stated earlier, economic, social and environmental benefits. Future research should begin the process of merging ground cover survey results with some of the quantified benefits of turfgrass to estimate at a larger, landscape scale these benefits and their value to the community. For example, an accurate figure quantifying the amount of oxygen produced or carbon sequestered by turf within a capital city would be of immense benefit as interest in these types of issues intensifies over time.

These types of valuations are particularly important as during difficult times, such as the water crisis of the 2000s where many cities initiated water restrictions and not only severely limited the application of water onto turfgrass but in many cases advocated the removal of existing turf in favour other, usually hardscape, substitutes. An accurate assessment or even estimate of the values provided by turfgrass with rigorous quantified measures attached to them will assist the industry to advocate the use and maintenance of turf based on its true value. Similarly reliable figures will allow decision makers to formulate policy during tough times based on a more complete picture of turfgrass's role within the community rather than responding to one element of the broader picture.

This study was a preliminary investigation into the use of remote sensing methodology in assessing turfgrass areas. Throughout the process of conducting the investigation and discussions with people within and outside of the industry it is apparent that this methodology can be used to measure and compare a large number of factors with turfgrass coverage. For example, this could include investigations into the relationship between turf coverage and soci-economic status of different suburbs to see if any relationship exists or are there links between average water use for a suburb and its turf coverage. The coverage numbers could be utilised by other research projects and assist in contextualising the results to make them more relevant and applicable.

It is hoped that this project forms the basis and beginning of a series of efforts to more definitively measure and value turfgrass nationally. Any future work should be clearly defined so that it can accurately provide data and information to governments on which to base their decision making and the industry to inform its strategic direction and its members can develop their business planning and investment accordingly.

Table 9. Recommendations for further research summary table

Recommendation	**Action**
Recommendation 1	Further fine tune the survey methodology and devise ways to account for limitations and assumptions or take advantage of improving access to quality photography.
Recommendation 2	Extend the survey area to include all capital cities and major population centers of interest based on industry priority (i.e. areas closest to production centers).
Recommendation 3	Combine the survey results with other research results that have identified the benefits of turfgrass in order to begin modeling the benefits to the community at a landscape scale and then value them (e.g. how much oxygen does Melbourne's turf produce annually?).
Recommendation 4	Begin to identify and investigate the relationship between turfgrass coverage and other social and economic indicators of interest to the industry and community (e.g. turf cover and wealth; turf cover and house pricing; turf cover and water use; turf cover and health).
Recommendation 5	The results should be communicated widely by the Turf industry to the media and also offered to other organisations (e.g. NGIA) for use in their promotional materials and also provide directly to the local governments included in this survey. Ideally this should include transforming the data and report results into more user-friendly info-graphics, animations, information videos and fact sheets.

Technology transfer

Notification of the project was provided to levy payers through the Horticulture Australia Limited 2013/2014 annual report. The project results will be communicated to industry via a number of means, including a presentation by the project leader to the Turf Industry Advisory Committee (IAC). An offer to present the results to industry at the next national turf industry event will also be made by the project leader.

The final report will be made available via Horticulture Australia Limited and Turf Australia's website with a summary document or fact sheet also provided to Turf Australia. A magazine article will also be made available to Turf Australia for publication in the next issue of the national magazine (at the discretion of the Editor). A media release will also be provided to Turf Australia to release at its discretion, promoting the findings of the report and highlighting the importance of turfgrass within the communities in question.

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Appendix 1 – Summary of all Sydney suburbs assessed.

	Greenlife	Construction	Hard Surface	Bare Ground	Water	Bushland	Farm Land	Road	Turf-Home Lawn	Turf-Park	Turf-Sportsfield	Turf - Median Strip/Easement	Turf-Roadside	Turf TOTAL	Population	Population Density (People/Ha)	Median Age (yrs)	Area of Suburb (km^2)	Household Income ($)
CBD	19.33	36.67	13.00	1.00	1.33	0.00	0.00	16.67	0.00	11.00	1.00	0.00	0.00	12.00	14308	49.34	32	2.90	1488
DRUMMOYNE (5KM)	22.00	34.33	11.67	0.33	0.33	0.00	0.00	14.00	10.67	3.00	2.00	1.33	0.33	17.33	11378	50.79	39	2.24	2148
CONCORD (10KM)	23.00	20.00	12.67	0.00	0.67	0.00	0.00	9.67	9.00	7.00	13.67	3.33	1.00	34.00	14150	27.97	39	5.06	1734
SILVERWATER (15KM)	14.67	26.33	21.00	1.67	1.67	7.00	0.00	14.33	1.00	5.33	1.67	0.67	4.67	13.33	3162	9.91	32	3.19	1289
PARRAMATTA (20KM)	20.00	24.67	12.00	0.33	3.00	0.00	0.00	15.33	5.33	8.00	8.00	2.33	1.00	24.67	19745	36.56	30	5.40	1314
HUNTINGWOOD (30KM)	18.33	24.00	19.67	1.00	0.00	0.00	8.33	9.33	0.00	0.00	1.00	1.67	17.33	20.00	Industrial (No data available)				
COLYTON (40KM)	15.33	23.67	11.67	0.00	0.33	0.00	5.33	10.33	16.33	2.67	5.00	6.33	3.00	33.33	7993	23.44	34	3.41	1180
PENRITH (50KM)	21.33	18.00	12.33	5.00	5.00	0.33	2.33	7.33	3.67	6.67	5.33	1.33	11.33	28.33	11813	9.62	37	12.28	949
NORTHWOOD(5KM)	44.33	21.00	9.33	0.00	1.00	7.00	0.00	7.67	6.67	0.33	1.00	1.33	0.33	9.67	907	25.19	42	0.35	2918
LINDFIELD (10KM)	32.00	19.00	9.00	0.33	0.33	23.00	0.00	7.67	5.00	1.00	1.33	1.67	0.00	9.00	8657	16.58	40	5.22	2414
PYMBLE (15KM)	49.00	17.67	8.00	1.00	0.33	5.33	0.00	7.33	4.00	0.67	5.00	0.00	1.67	11.33	10582	16.51	40	6.41	2671
HORNSBY (20KM)	19.67	12.33	6.00	0.00	0.67	39.33	0.00	7.00	9.00	1.00	1.67	2.33	1.00	15.00	19863	22.70	35	8.75	1436
ENMORE (5KM)	27.33	39.67	13.33	0.00	0.33	0.00	0.00	11.33	6.67	0.67	0.00	0.33	0.33	8.00	3572	79.38	34	0.45	1714
ARNCLIFFE (10KM	18.67	21.00	11.67	2.00	3.00	0.67	0.00	14.00	9.00	1.67	13.67	1.00	3.67	29.00	8420	27.34	37	3.08	1251
SOUTH HURSTVILLE (15KM)	25.00	27.33	16.67	1.33	1.00	0.00	0.00	13.00	10.67	0.33	0.33	3.33	1.00	15.67	4928	45.63	37	1.08	1305
SUTHERLAND (20KM)	21.67	17.00	12.00	1.00	0.00	15.33	0.00	10.67	7.33	8.00	2.33	4.67	0.00	22.33	9923	26.60	36	3.73	1375

Appendix 2 – Summary of all Melbourne suburbs assessed.

	Greenlife	Construction	Hard Surface	Bare Ground	Water	Bushland	Farm Land	Road	Turf-Home Lawn	Turf-Park	Turf-Sportsfield	Turf - Median Strip/Easement	Turf-Roadside	Turf TOTAL	Population	Population Density (People/Ha)	Median Age (yrs)	Area of Suburb (km^2)	Household Income ($)
CBD	21.00	34.67	10.67	1.33	4.33	0.00	0.00	11.33	0.00	7.33	8.33	0.67	0.33	16.67	28371	43.78	28	6.48	1230
FOOTSCRAY (5KM)	16.00	23.33	25.67	5.33	3.67	0.00	0.00	11.67	2.67	4.33	3.33	2.00	1.67	14.00	13203	26.30	32	5.02	1059
BRAYBROOK (10KM)	13.33	30.67	13.00	1.33	0.67	0.00	0.00	7.00	10.67	1.67	4.33	1.67	15.67	34.00	8180	18.94	32	4.32	792
ARDEER (15KM)	15.67	20.33	11.67	2.00	0.67	0.00	0.00	7.67	6.33	2.00	4.00	5.67	24.00	42.00	2823	12.77	37	2.21	891
CAROLINE SPRINGS (20KM)	13.67	19.33	15.33	14.33	2.67	0.00	0.00	10.33	7.00	2.67	0.67	2.00	12.00	24.33	20366	24.19	31	8.42	1653
ROCKBANK (30KM)	4.67	1.67	0.00	0.00	0.00	0.00	85.67	1.67	2.00	0.00	0.33	1.67	2.33	6.33	1349	0.35	39	38.30	964
BROOKFIELD (40KM)	8.33	11.67	4.33	4.33	0.67	0.00	41.33	4.33	8.00	5.67	0.33	2.33	8.67	25.00	6104	5.97	31	10.22	1377
BACCHUS MARSH (50KM)	13.33	9.67	4.33	1.67	0.67	6.67	48.67	3.33	5.00	1.00	0.67	2.00	3.00	11.67	5760	5.07	41	11.36	972
BRUNSWICK EAST (5KM)	17.00	32.33	17.33	0.33	0.00	2.00	0.00	15.00	5.00	5.67	3.00	1.00	1.33	16.00	8476	38.18	33	2.22	1468
RESERVOIR (10KM)	20.00	29.67	11.00	0.00	0.00	0.67	0.00	11.00	13.67	3.33	3.67	5.67	1.33	27.67	47637	25.23	38	18.88	972
THOMASTOWN (15KM)	12.00	22.33	20.00	2.67	0.33	0.33	8.33	12.00	4.00	1.33	0.33	2.33	14.00	22.00	20331	13.69	38	14.85	900
EPPING (20KM)	8.67	6.00	7.00	5.67	0.33	0.00	48.33	7.33	4.33	2.67	0.67	2.33	6.67	16.67	26346	7.82	32	33.71	1283
TOORAK (5KM)	37.33	30.67	11.67	0.33	1.67	0.00	0.00	10.33	5.00	0.00	2.67	0.00	0.33	8.00	12871	30.00	43	4.29	1977
MALVERN EAST (10KM)	29.67	25.00	11.33	1.00	1.00	0.00	0.00	13.67	8.67	2.67	5.67	0.33	1.00	18.33	20066	25.79	43	7.78	1715
OAKLEIGH (15KM)	20.00	35.00	18.67	0.00	0.00	0.00	0.00	8.67	8.00	2.67	2.67	2.00	2.33	17.67	7535	21.47	43	3.51	1393
CLAYTON (20KM)	17.33	31.00	21.33	1.67	0.67	0.00	0.00	12.33	7.33	0.00	2.33	0.33	5.67	15.67	15543	19.95	43	7.79	953

Appendix 3 – Summary of Sydney suburbs dwelling structure.

	Separate House (# and %)	Semi-detached row or Terrace House, Townhouse etc. (# and %)	Flat, Unit or apartment (# and %)	Other Dwelling (# and %)
CBD	129 (2.4%)	3 (0.1%)	5209 (97.3%)	0
DRUMMOYNE (5KM)	1556 (34.7%)	754 (16.8%)	2161 (48.2%)	8 (0.2%)
CONCORD (10KM)	3422 (72.4%)	382 (8.1%)	878 (18.6%)	41 (0.9%)
SILVERWATER (15KM)	263 (43.5%)	32 (5.3%)	307 (50.7%)	3 (0.5%)
PARRAMATTA (20KM)	995 (14.0%)	460 (6.5%)	5646 (79.3%)	0
HUNTINGWOOD (30KM)	Industrial (No data available			
COLYTON (40KM)	2563 (96.8%)	73 (2.8%)	9 (0.3%)	3 (0.1%)
PENRITH (50KM)	2334 (47.3%)	1250 (25.3%)	1283 (26.0%)	7 (0.1%)

NORTHWOOD(5KM)	266 (97.1%)	0	8 (2.9%)	0
LINDFIELD (10KM)	1956 (67.6%)	127 (4.4%)	806 (27.8%)	0
PYMBLE (15KM)	2807 (83.3%)	113 (3.4%)	446 (13.2%)	3 (0.1%)
HORNSBY (20KM)	2877 (37.8%)	586 (7.7%)	4116 (54.1%)	12 (0.2%)

ENMORE (5KM)	262 (18.1%)	739 (51.1%)	438 (29.6%)	13 (0.9%)
ARNCLIFFE (10KM	1695 (63.7%)	244 (9.2%)	705 (26.5%)	15 (0.6%)
SOUTH HURSTVILLE (15KM)	918 (54.8%)	353 (23.5%)	357 (21.3%)	6 (0.4%)
SUTHERLAND (20KM)	1145 (26.6)	506 (11.7)	2657 (61.6)	3 (0.1)

Appendix 4 – Summary of Melbourne suburbs dwelling structure.

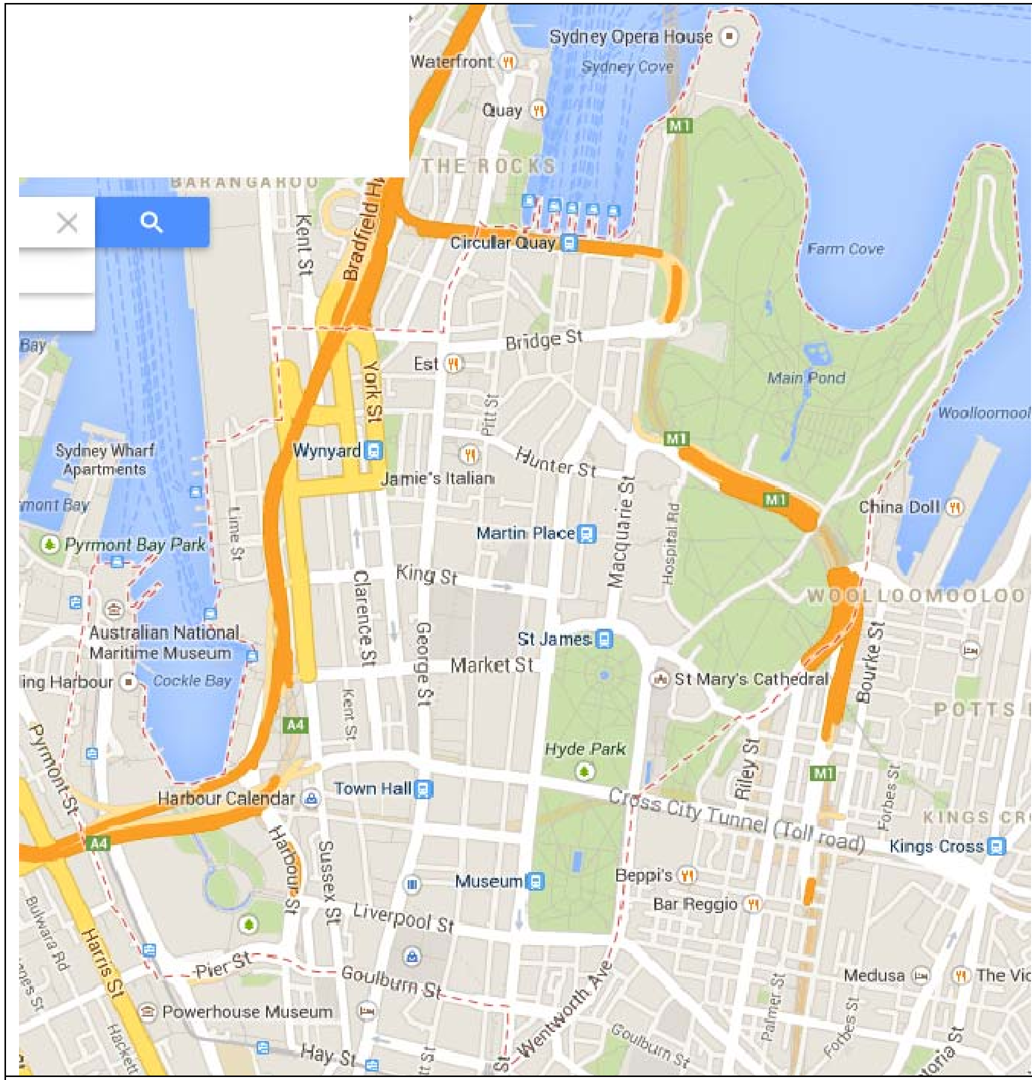
	Separate House (No. and %)	Semi-detached row or Terrace House, Townhouse etc. (No. and %)	Flat, Unit or apartment (No. and %)	Other Dwelling (No. and %)
CBD	14 (0.1%)	52 (0.4%)	13147 (99.4%)	9 (0.1%)
FOOTSCRAY (5KM)	2323 (47.4%)	729 (14.9%)	1819 (37.1%)	21 (0.4%)
BRAYBROOK (10KM)	1646 (62.4%)	431 (16.3%)	544 (20.6%)	18 (0.7%)
ARDEER (15KM)	903 (89.9%)	21 (2.1%)	46 (4.6%)	35 (3.5%)
CAROLINE SPRINGS (20KM)	5730 (90.1%)	613 (9.6%)	19 (0.3%)	0
ROCKBANK (30KM)	359 (73.3%)	11 (2.2%)	3 (0.6%)	114 (23.3%)
BROOKFIELD (40KM)	1771(89.4%)	194 (9.8%)	15 (0.8%)	0
BACCHUS MARSH (50KM)	1697 (84.0%)	59 (2.5%)	279 (11.9%)	38 (1.6%)

BRUNSWICK EAST (5KM)	1513 (42.2%)	987 (27.5%)	1058 (29.5%)	27 (0.8%)
RESERVOIR (10KM)	12970 (71.5%)	2385 (13.2%)	2719 (15%)	51 (0.3%)
THOMASTOWN (15KM)	6163 (90.3%)	214 (3.1%)	438 (6.4%)	7 (0.1%)
EPPING (20KM)	6851 (81.2%)	972 (11.5%)	606 (7.2%)	3 (0.0%)

TOORAK (5KM)	1905 (34.7%)	872 (15.9%)	2707 (49.3%)	3 (0.1%)
MALVERN EAST (10KM)	4560 (62.8%)	1160 (16%)	1494 (20.6%)	39 (0.5%)
OAKLEIGH (15KM)	1898 (71.6%)	162 (6.1%)	571 (21.5%)	19 (0.7%)
CLAYTON (20KM)	2596 (52.4%)	1113 (22.5%)	1224 (24.7%)	3 (0.1%)

Appendix 5 – Sydney suburbs included in the i-Tree Canopy assessment.

Suburb Case File: Sydney CBD



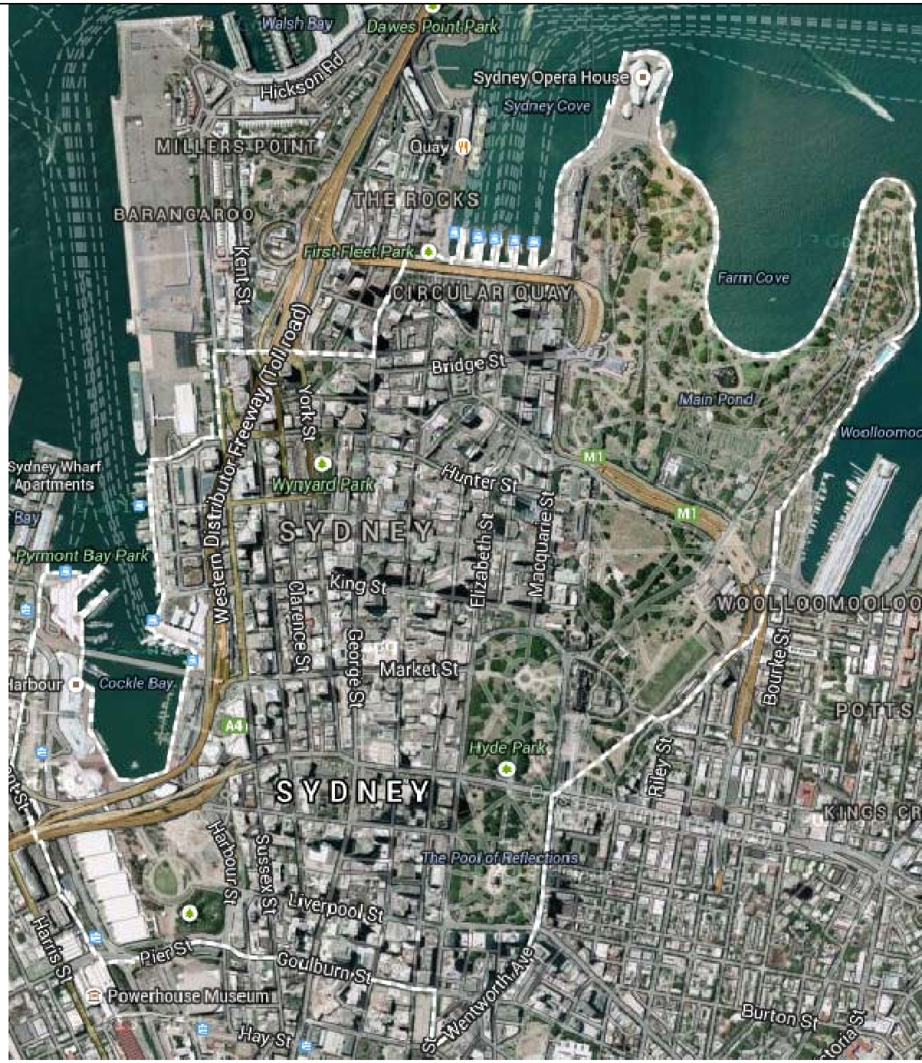
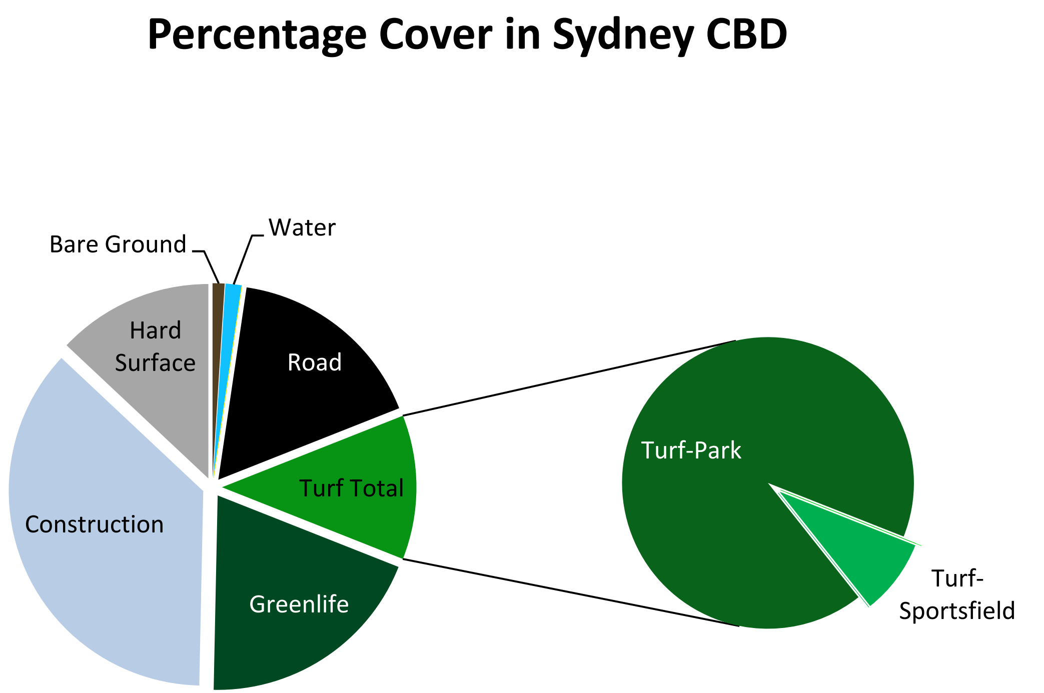


Figure 1. Sydney CBD Aerial Map

Figure 2. Sydney CBD Aerial Photograph

Cover Class	Cover (%)
Greenlife	19.33
Construction	36.67
Hard Surface	13.00
Bare Ground	1.00
Water	1.33
Bushland	0.00
Farm Land	0.00
Road	16.67
Turf-Home Lawn	0.00
Turf-Park	11.00
Turf-Sportsfield	1.00
Turf - Median Strip/Easement	0.00
Turf-Roadside	0.00
Turf TOTAL	12.00

In the 2011 Census of Population and Housing, the population of the Sydney CBD stood at 14,308 people, with a median age of 32 years. Sydney CBD's household income is slightly higher than the Australian average, with a median weekly household income of $1,488, compared with $1,234 in Australia. Total area of the suburb is 2.9km^2 which means that the population density is 49.34 people per hectare.



Suburb Case File: Drummoyne

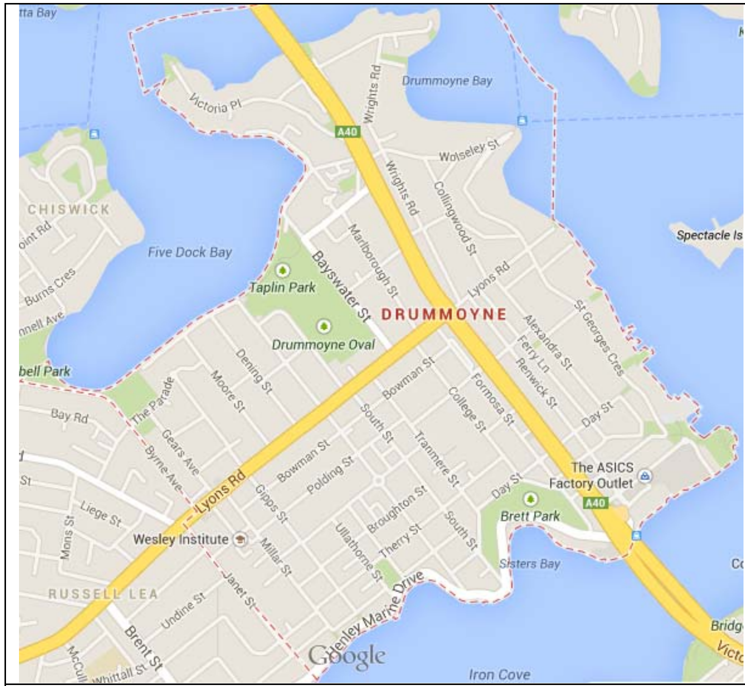


Figure 1. Drummoyne Aerial Map

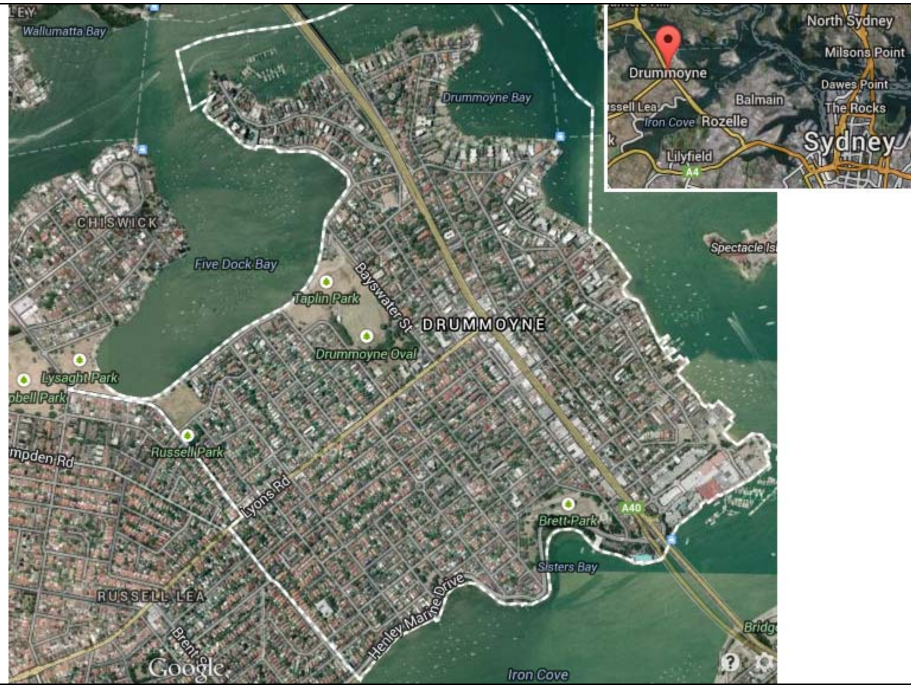
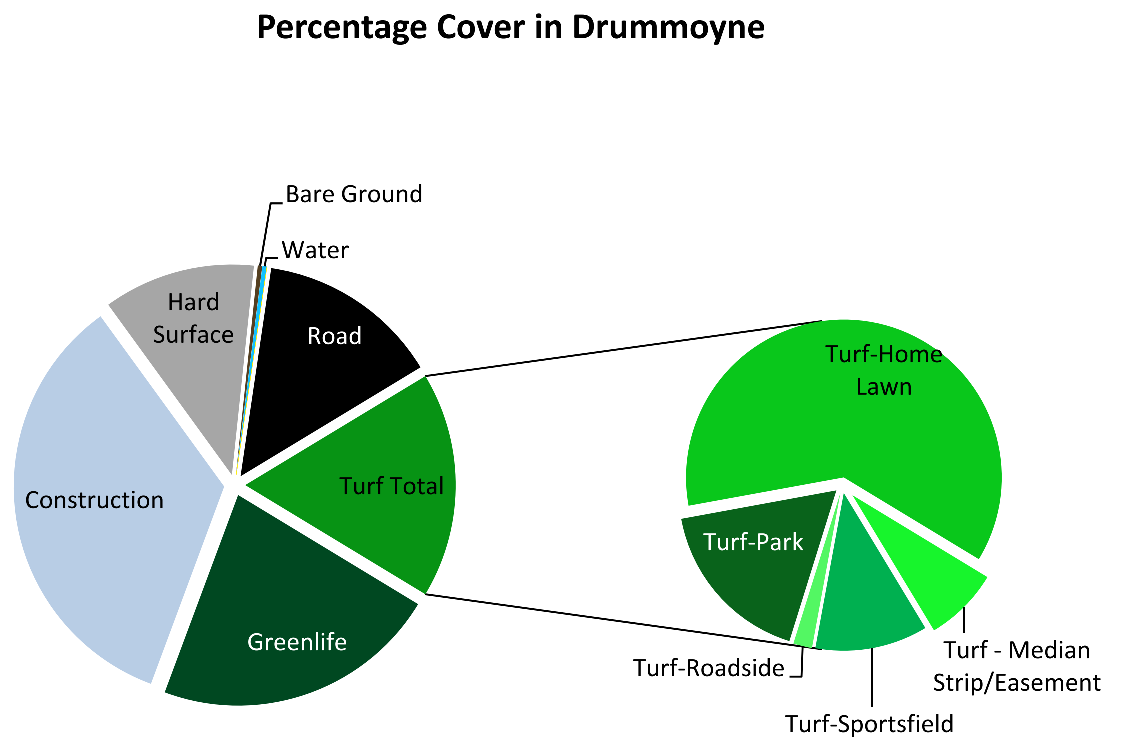


Figure 2. Drummoyne Aerial Photograph

Cover Class	Cover (%)
Greenlife	22.00
Construction	34.33
Hard Surface	11.67
Bare Ground	0.33
Water	0.33
Bushland	0.00
Farm Land	0.00
Road	14.00
Turf-Home Lawn	10.67
Turf-Park	3.00
Turf-Sportsfield	2.00
Turf - Median Strip/Easement	1.33
Turf-Roadside	0.33
Turf TOTAL	17.33

Drummoyne is in the Inner West of Sydney situated 5km from the Sydney CBD. It is the administrative centre for the local government area of the City of Canada Bay. In the 2011 Census of Population and Housing, the population of Drummoyne stood at 11,378 people, with a median age of 39 years. Drummoyne's population is wealthier than the Australian average, with a median weekly household income of $2,148, compared with $1,234 in Australia. Total area of the suburb is 2.24km^2 which means that the population density is 50.79 people per hectare.



Suburb Case File: Concord

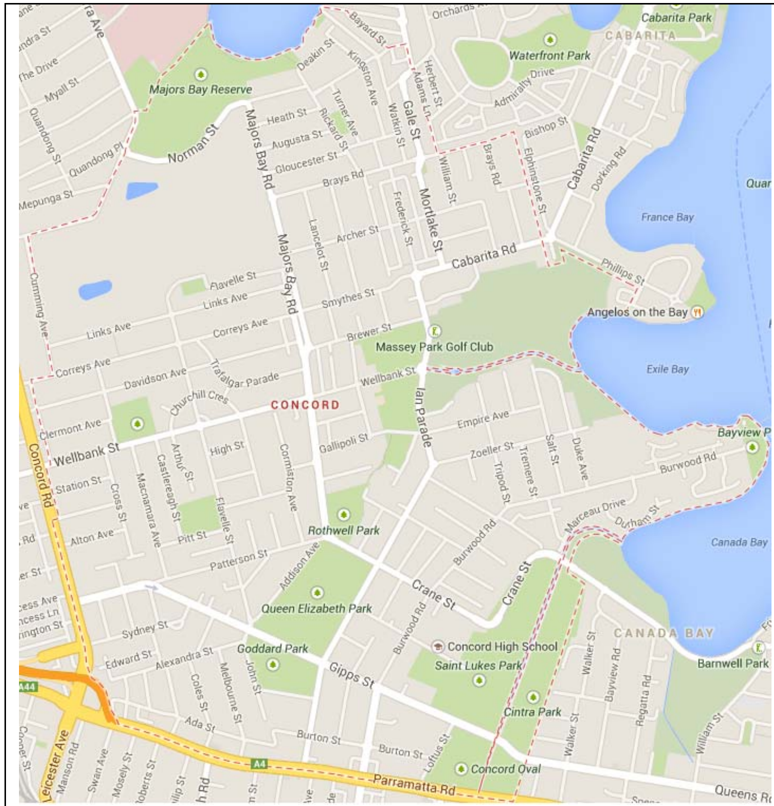


Figure 1. Concord Aerial Map

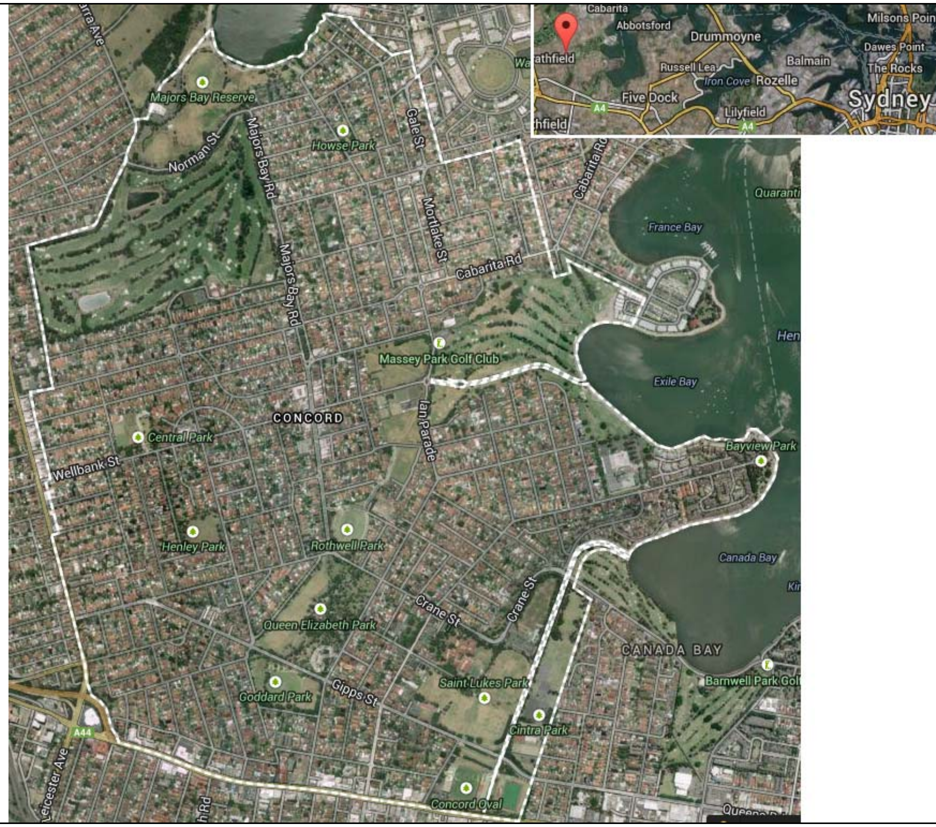
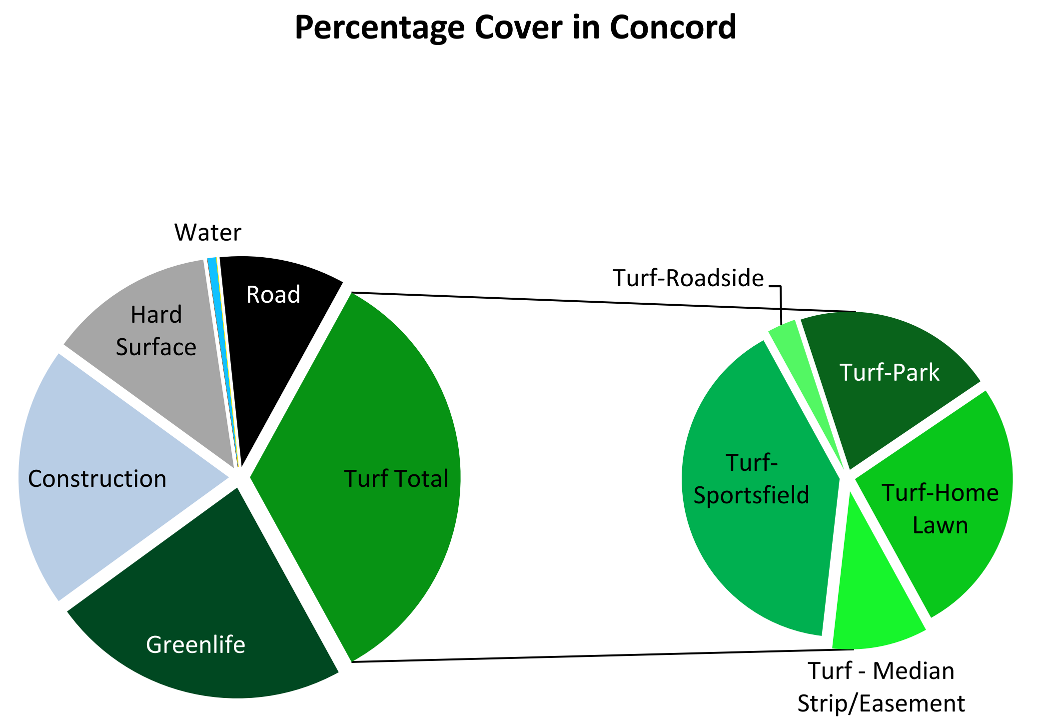


Figure 2. Concord Aerial Photograph

Cover Class	Cover (%)
Greenlife	23.00
Construction	20.00
Hard Surface	12.67
Bare Ground	0.00
Water	0.67
Bushland	0.00
Farm Land	0.00
Road	9.67
Turf-Home Lawn	9.00
Turf-Park	7.00
Turf-Sportsfield	13.67
Turf - Median Strip/Easement	3.33
Turf-Roadside	1.00
Turf TOTAL	34.00

Concord is the administrative centre for the local government area of the City of Canada Bay. In the 2011 Census of Population and Housing, the population of Concord stood at 14,150 people, with a median age of 39 years. Concord's population is wealthier than the Australian average, with a median weekly household income of $1,734, compared with $1,234 in Australia. Total area of the suburb is 5.06km^2 which means that the population density is 27.97 people per hectare.



Suburb Case File: Silverwater

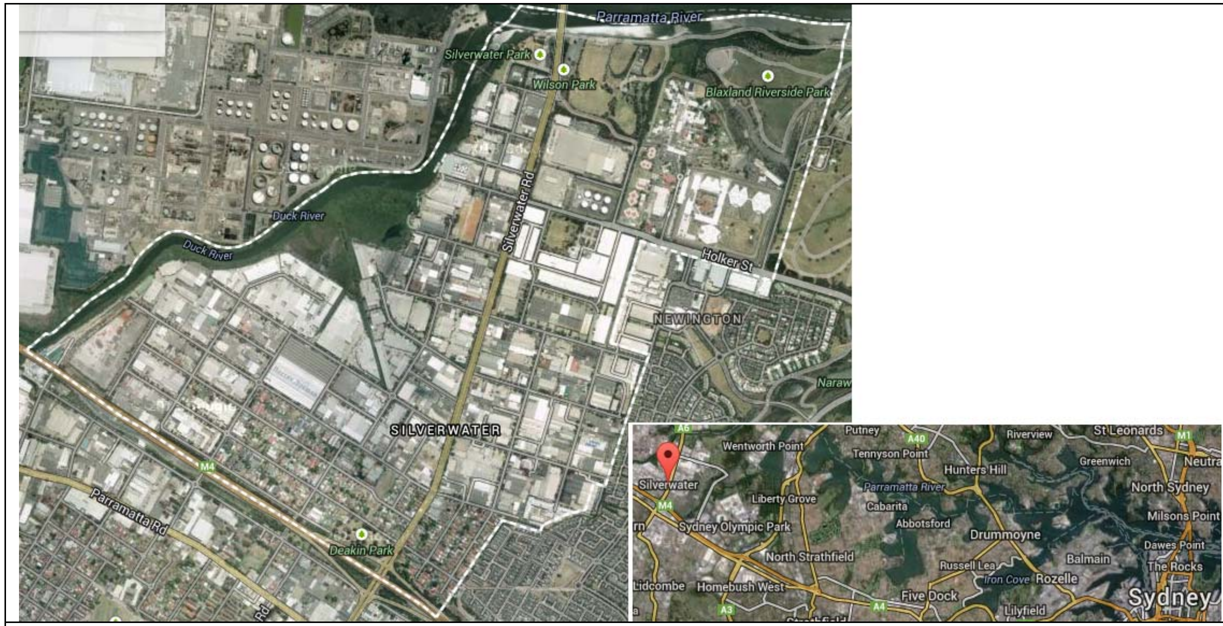


Figure 1. Silverwater Aerial Map

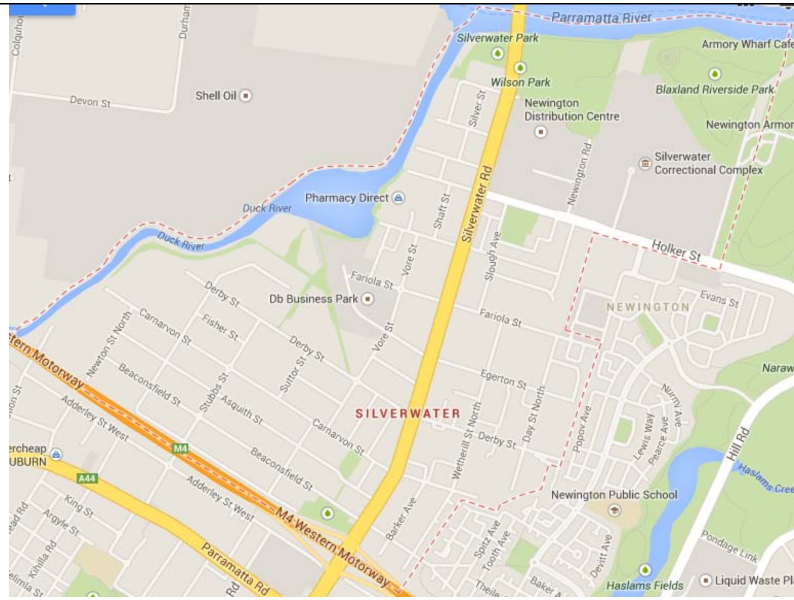
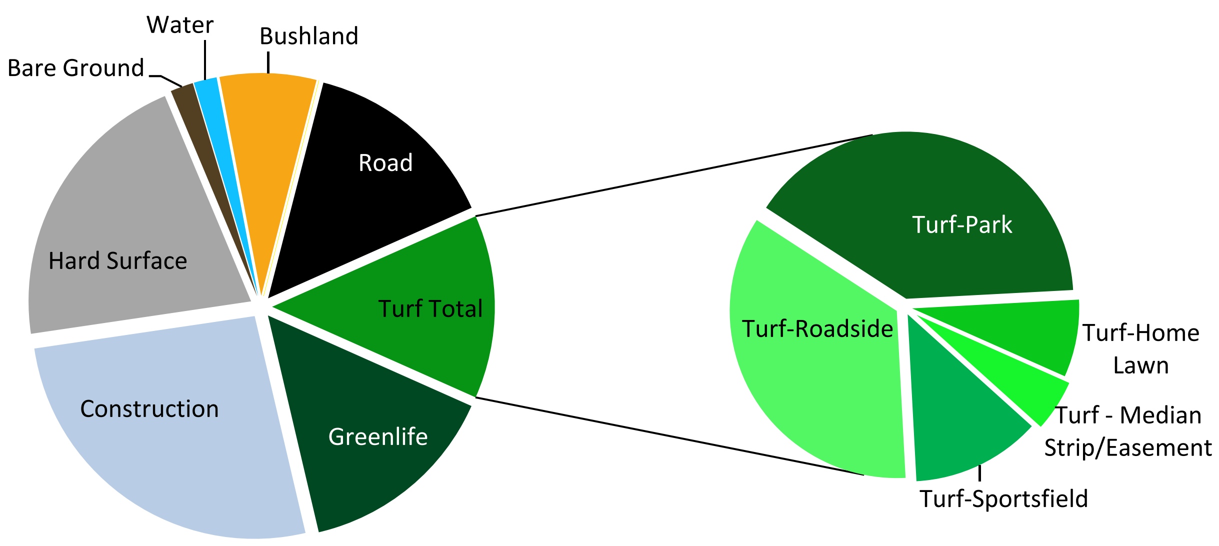


Figure 2. Silverwater Aerial Photograph

Cover Class	Cover (%)
Greenlife	14.67
Construction	26.33
Hard Surface	21.00
Bare Ground	1.67
Water	1.67
Bushland	7.00
Farm Land	0.00
Road	14.33
Turf-Home Lawn	1.00
Turf-Park	5.33
Turf-Sportsfield	1.67
Turf - Median Strip/Easement	0.67
Turf-Roadside	4.67
Turf TOTAL	13.33

Silverwater is situated 15km west from the Sydney CBD. It is in the local government area of Auburn City. In the 2011 Census of Population and Housing, the population of Silverwater stood at 3,162 people, with a median age of 32 years. Silverwater's household income is similar to the Australian average, with a median weekly household income of $1,289, compared with $1,234 in Australia. Total area of the suburb is 3.19km^2 which means that the population density is 9.91 people per hectare.

Percentage Cover in Silverwater



Suburb Case File: Parramatta

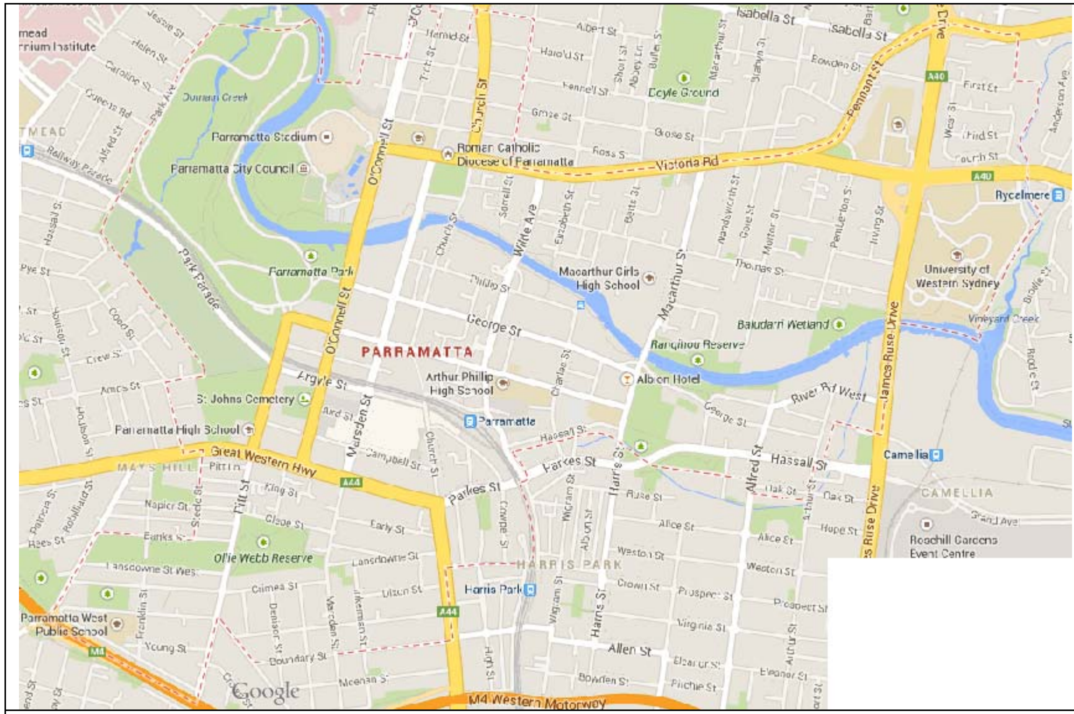
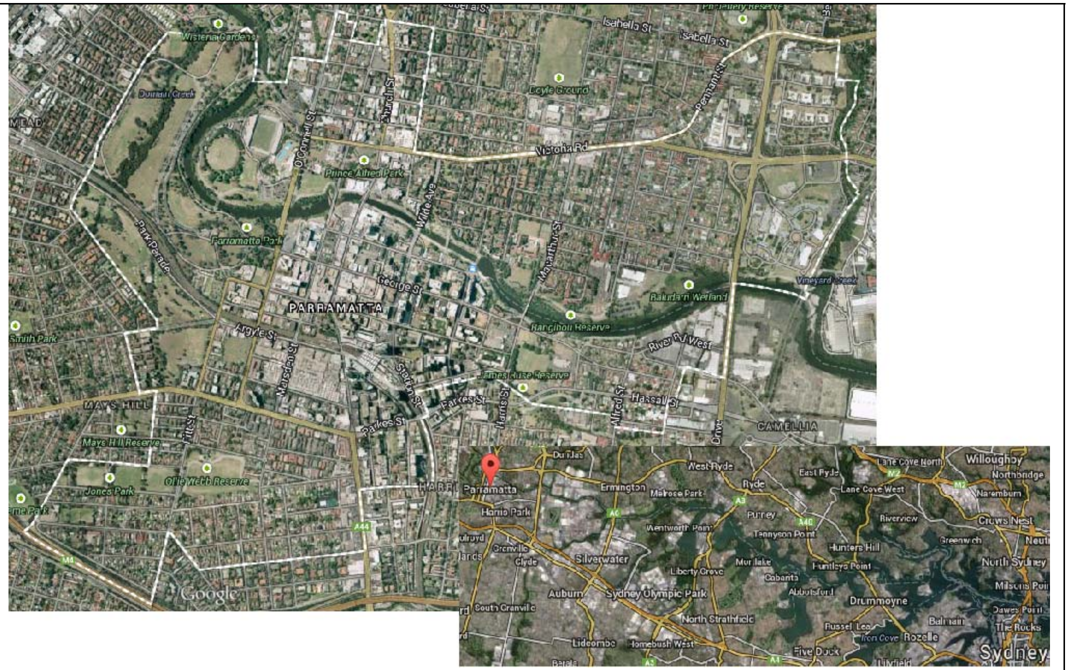
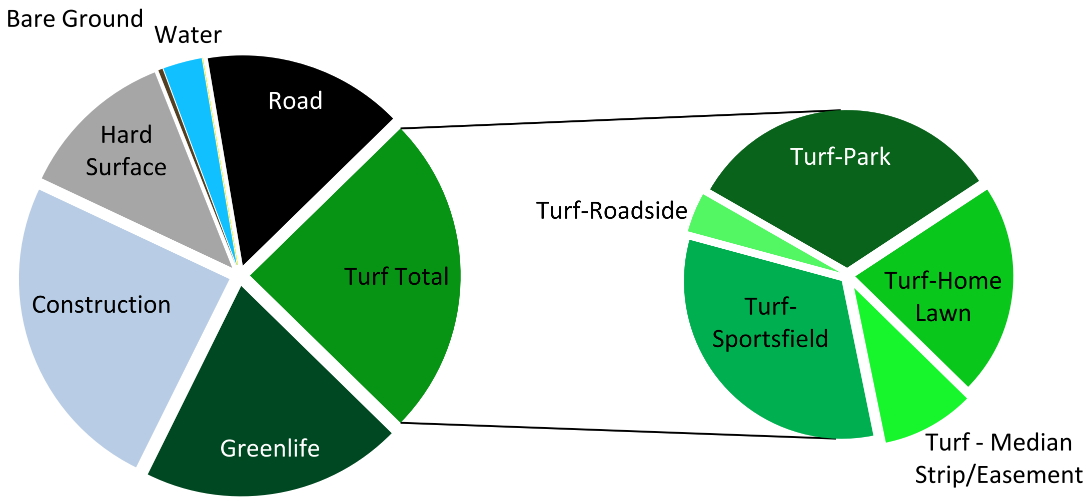
	

Figure 1. Parramatta Aerial Map	**Figure 2.** Parramatta Aerial Photograph

Cover Class	Cover (%)
Greenlife	20.00
Construction	24.67
Hard Surface	12.00
Bare Ground	0.33
Water	3.00
Bushland	0.00
Farm Land	0.00
Road	15.33
Turf-Home Lawn	5.33
Turf-Park	8.00
Turf-Sportsfield	8.00
Turf - Median Strip/Easement	2.33
Turf-Roadside	1.00
Turf TOTAL	24.67

Parramatta is in the local government area of the City of Parramatta. It is situated 20km west of the Sydney CBD. In the 2011 census of Population and Housing, the population of Parramatta stood at 19,745 people, with a median age of 30 years. Parramatta's weekly household income is similar to the Australian average, with a median weekly household income of $1,314, compared with $1,234 in Australia. Total area of the suburb is 5.4km^2 which means that the population density is 36.56 people per hectare.

Percentage Cover in Parramatta



Suburb Case File: Huntingwood

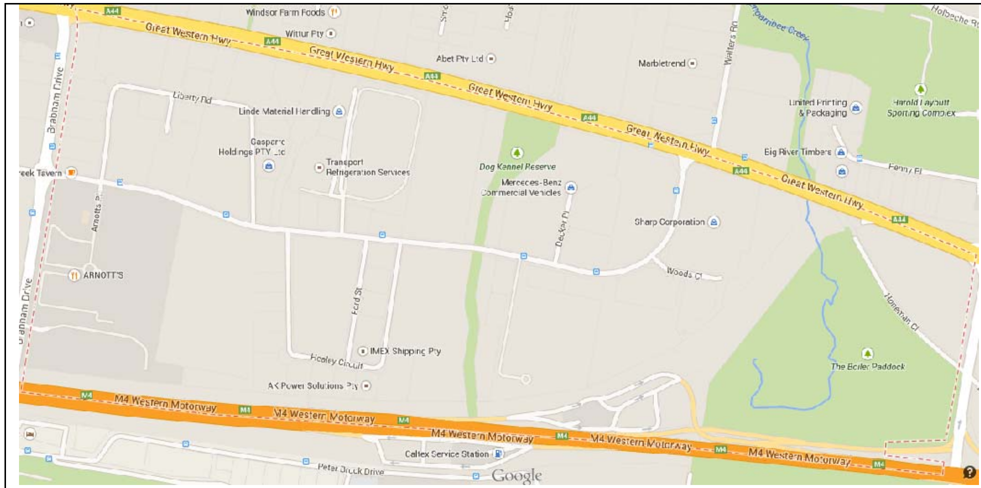
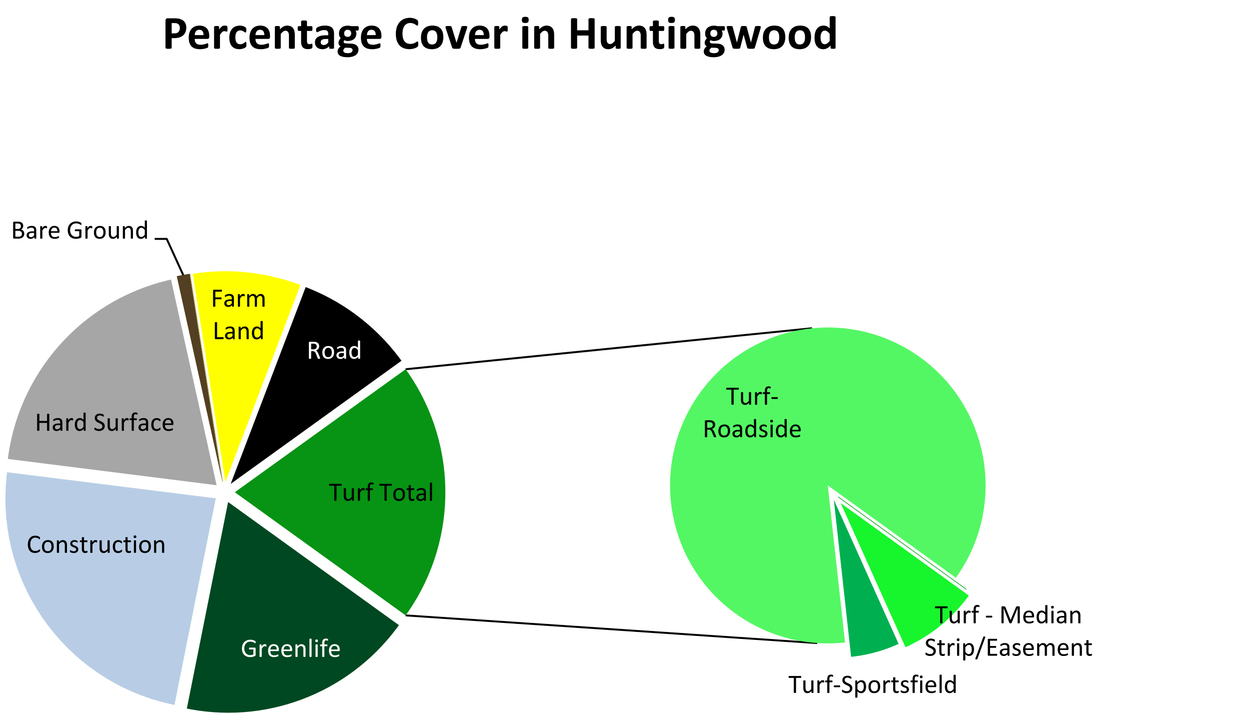


Figure 1. Huntingwood Aerial Map

Figure 2. Huntingwood Aerial Photograph

Cover Class	Cover (%)
Greenlife	18.33
Construction	24.00
Hard Surface	19.67
Bare Ground	1.00
Water	0.00
Bushland	0.00
Farm Land	8.33
Road	9.33
Turf-Home Lawn	0.00
Turf-Park	0.00
Turf-Sportsfield	1.00
Turf - Median Strip/Easement	1.67
Turf-Roadside	17.33
Turf TOTAL	20.00

Huntingwood is a predominantly industrial suburb in the Local Government area of the City of Blacktown. This suburb is managed as a part of the Eastern Creek Area, along with Arndell Park. With this in mind most statistics and demographic information is not available for this suburb.



Suburb Case File: Colyton

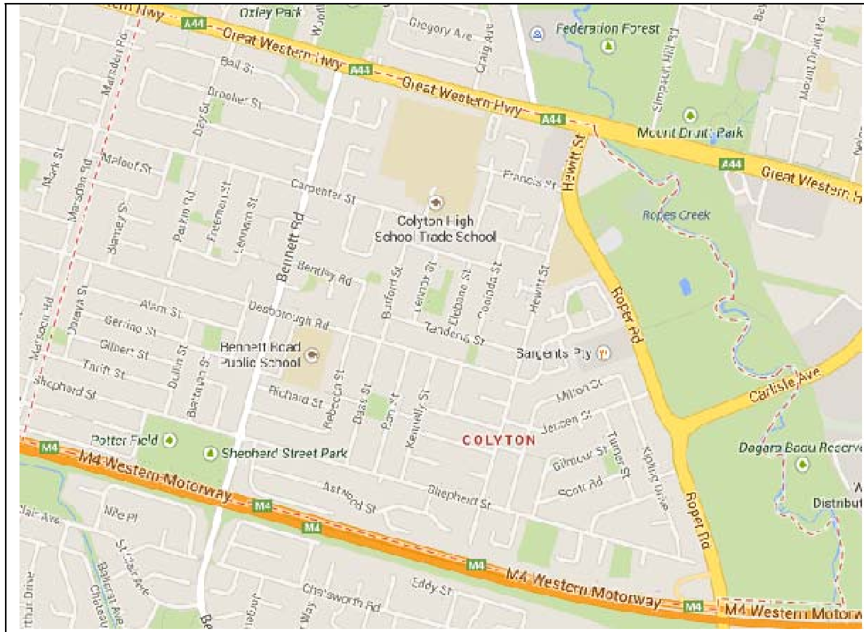


Figure 1. Colyton Aerial Map

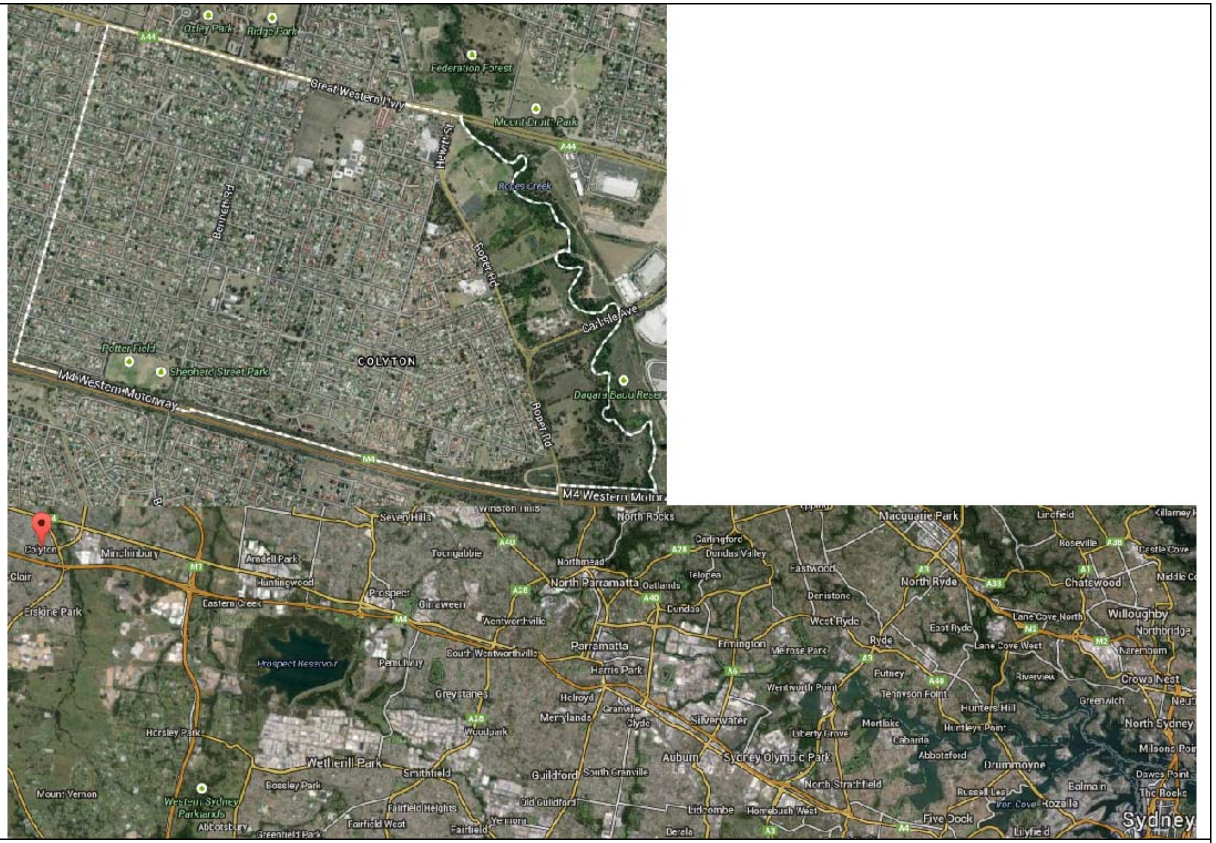
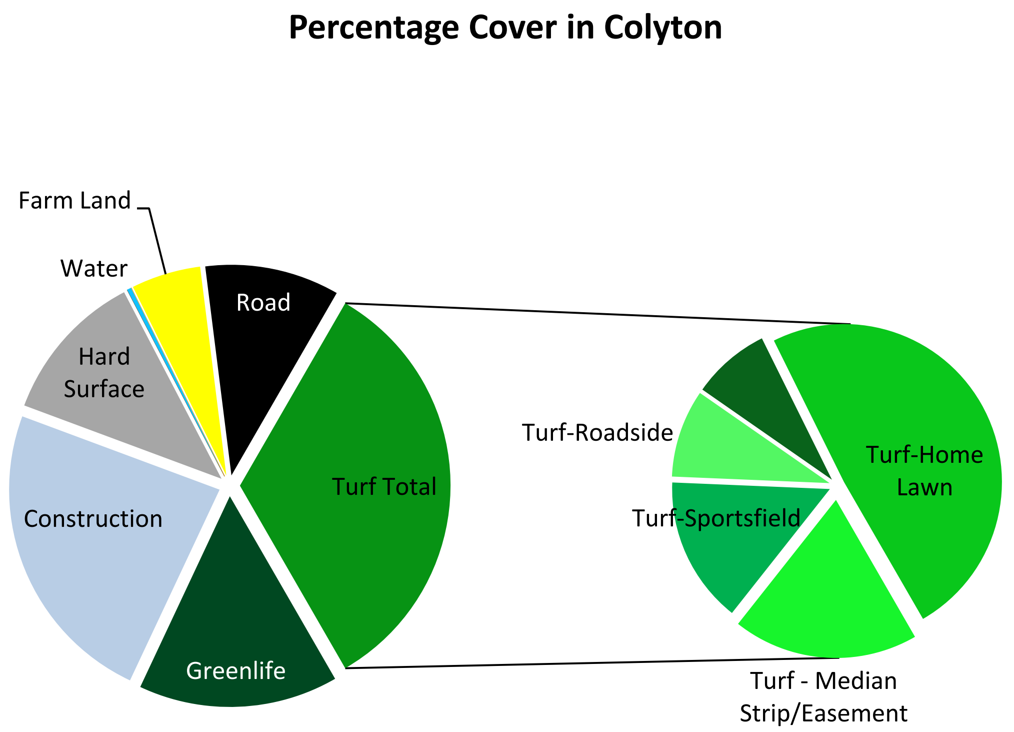


Figure 2. Colyton Aerial Photograph

Cover Class	Cover (%)
Greenlife	15.33
Construction	23.67
Hard Surface	11.67
Bare Ground	0.00
Water	0.33
Bushland	0.00
Farm Land	5.33
Road	10.33
Turf-Home Lawn	16.33
Turf-Park	2.67
Turf-Sportsfield	5.00
Turf - Median Strip/Easement	6.33
Turf-Roadside	3.00
Turf TOTAL	33.33

Colyton is in the in the local government area of the City of Penrith. In the 2011 Census of Population and Housing, the population of Colyton stood at 7,993 people, with a median age of 34 years. Colyton's median household income is slightly less than the Australian average, with a median weekly household income of $1,180, compared with $1,234 in Australia. Total area of the suburb is 3.41km^2 which means that the population density is 23.44 people per hectare.



Suburb Case File: Penrith

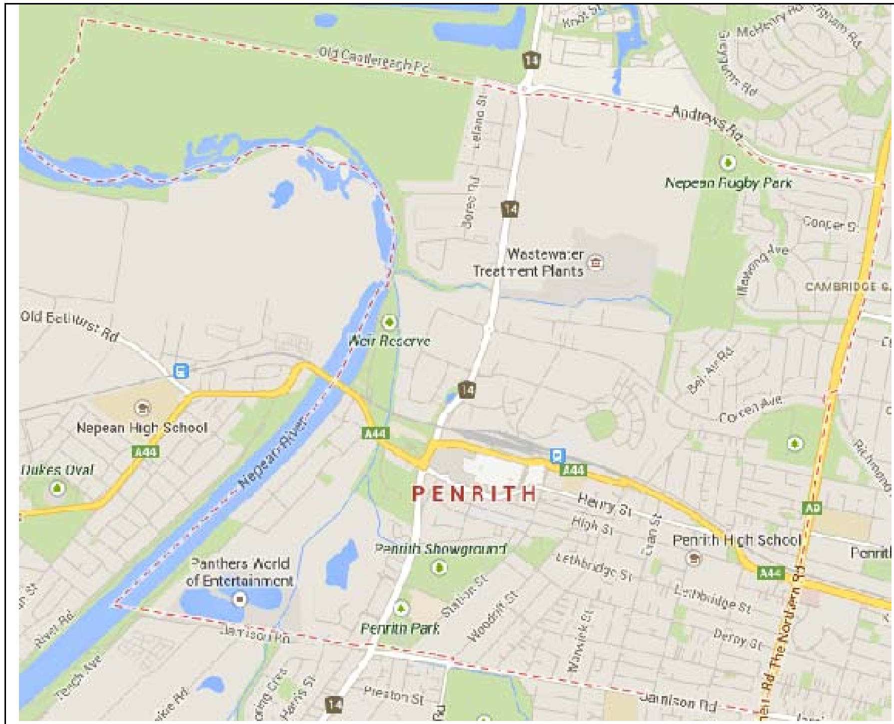


Figure 1. Penrith Aerial Map

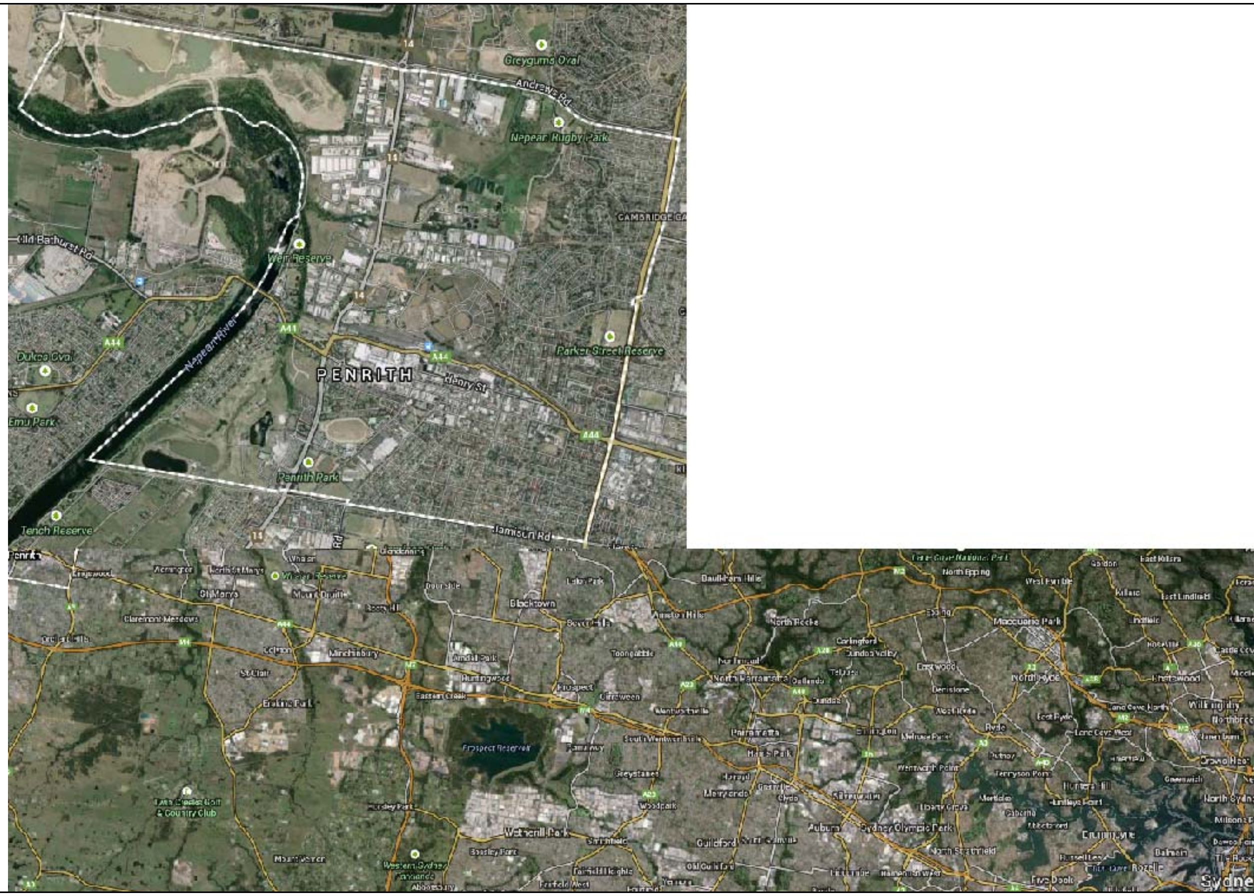
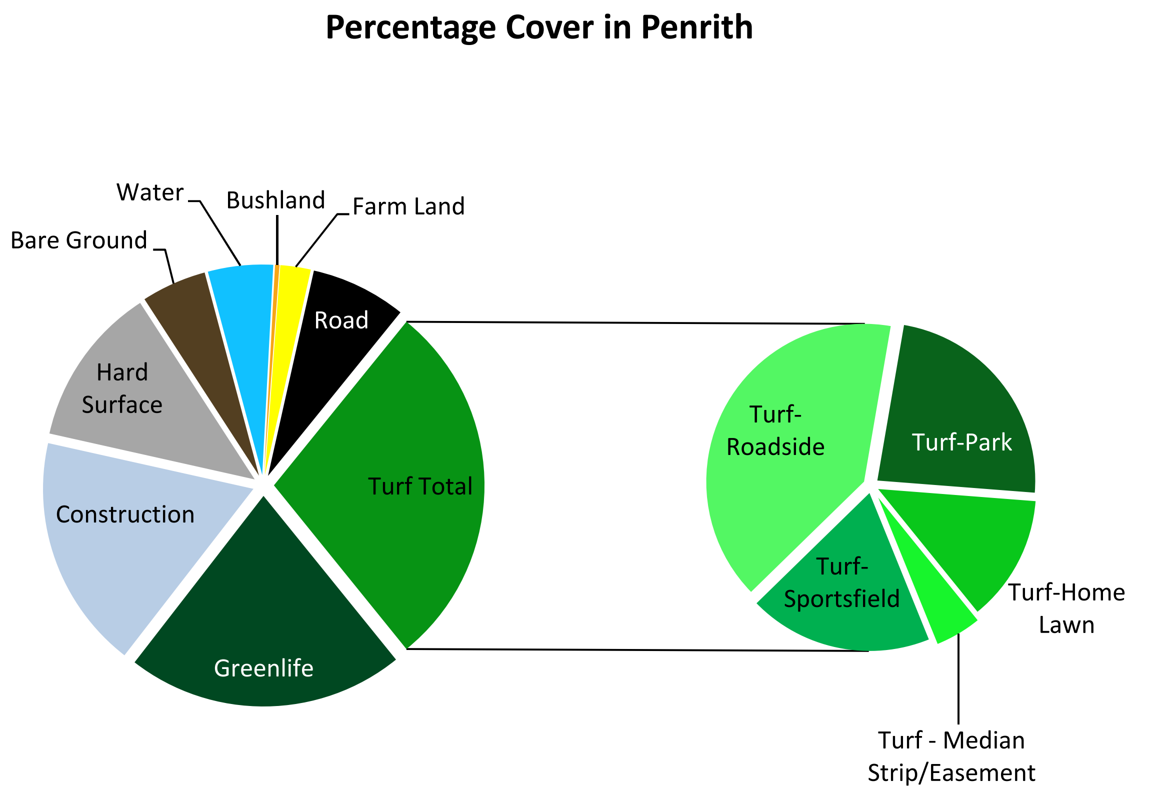


Figure 2. Penrith Aerial Photograph

Cover Class	Cover (%)
Greenlife	21.33
Construction	18.00
Hard Surface	12.33
Bare Ground	5.00
Water	5.00
Bushland	0.33
Farm Land	2.33
Road	7.33
Turf-Home Lawn	3.67
Turf-Park	6.67
Turf-Sportsfield	5.33
Turf - Median Strip/Easement	1.33
Turf-Roadside	11.33
Turf TOTAL	28.33

Penrith is located 50km north-west from the Sydney CBD. It is the administrative centre for the local government area of City of Penrith. In the 2011 Census of Population and Housing, the population of Penrith stood at 11,813 people, with a median age of 37 years. Penrith's population is less wealthy than the Australian average, with a median weekly household income of $949, compared with $1,234 in Australia. Total area of the suburb is 12.28km^2 which means that the population density is 9.62 people per hectare.



Suburb Case File: Northwood

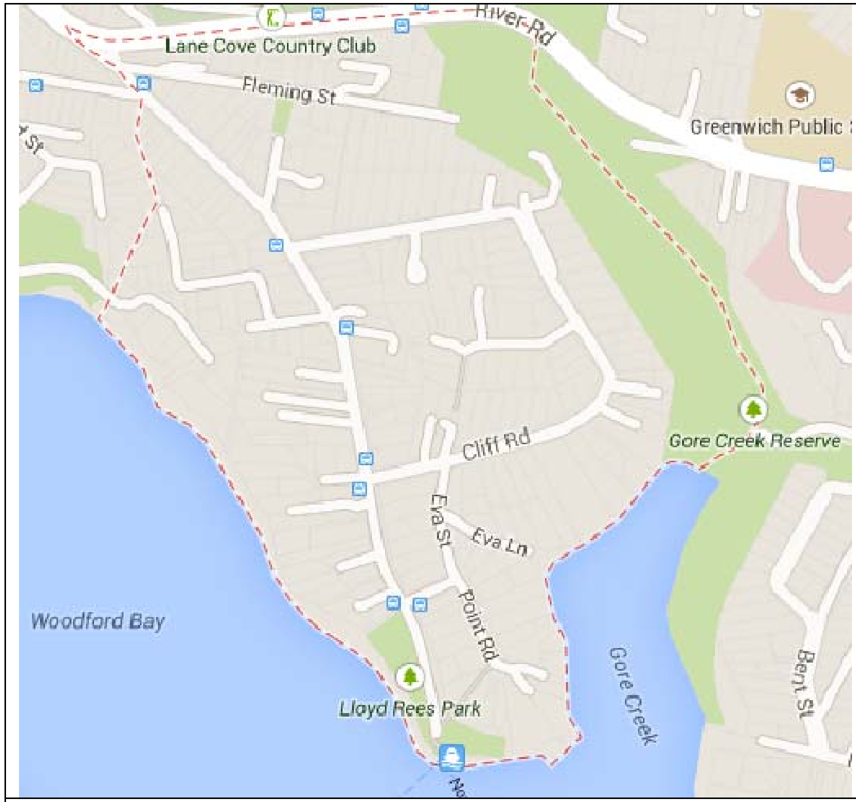


Figure 1. Northwood Aerial Map

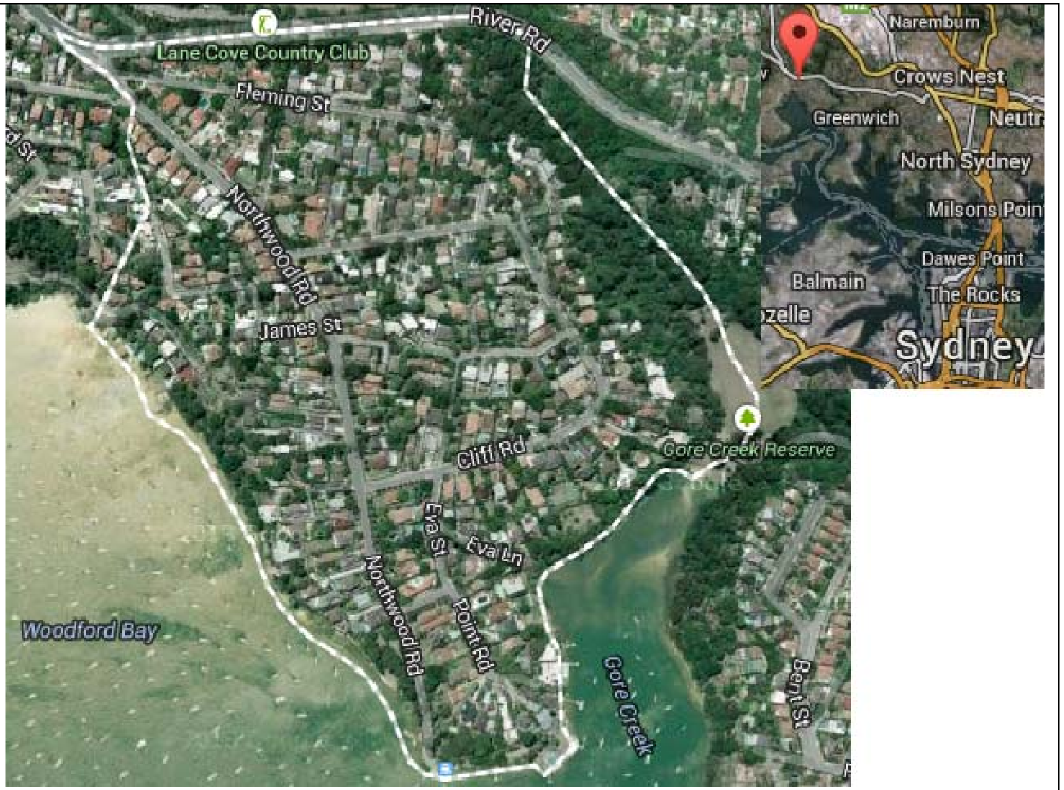
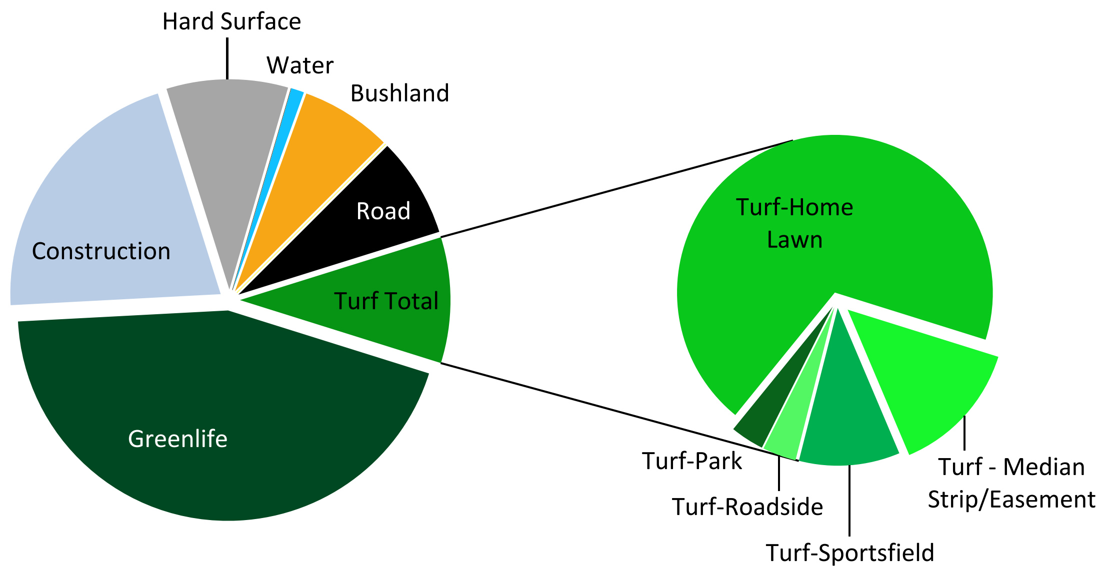


Figure 2. Northwood Aerial Photograph

Cover Class	Cover (%)
Greenlife	44.33
Construction	21.00
Hard Surface	9.33
Bare Ground	0.00
Water	1.00
Bushland	7.00
Farm Land	0.00
Road	7.67
Turf-Home Lawn	6.67
Turf-Park	0.33
Turf-Sportsfield	1.00
Turf - Median Strip/Easement	1.33
Turf-Roadside	0.33
Turf TOTAL	9.67

Northwood is located in the Inner North of Sydney situated 5km from the Sydney CBD. It is the administrative centre for the local government area of Municipality of Lane Cove. In the 2011 Census of Population and Housing, the population of Northwood stood at 907 people, with a median age of 42 years. Northwood's population is higher earner than the Australian average, with a median weekly household income of $2,918, compared with $1,234 in Australia. Total area of the suburb is .35km^2 which means that the population density is 25.91 people per hectare.

Percentage Cover in Northwood



Suburb Case File: Lindfield

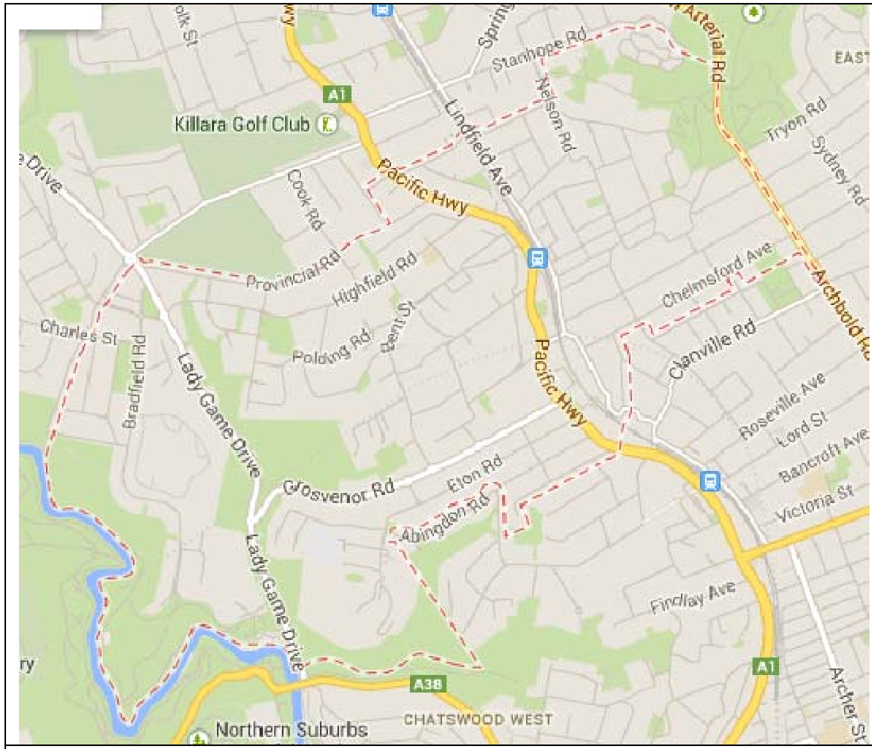


Figure 1. Lindfield Aerial Map

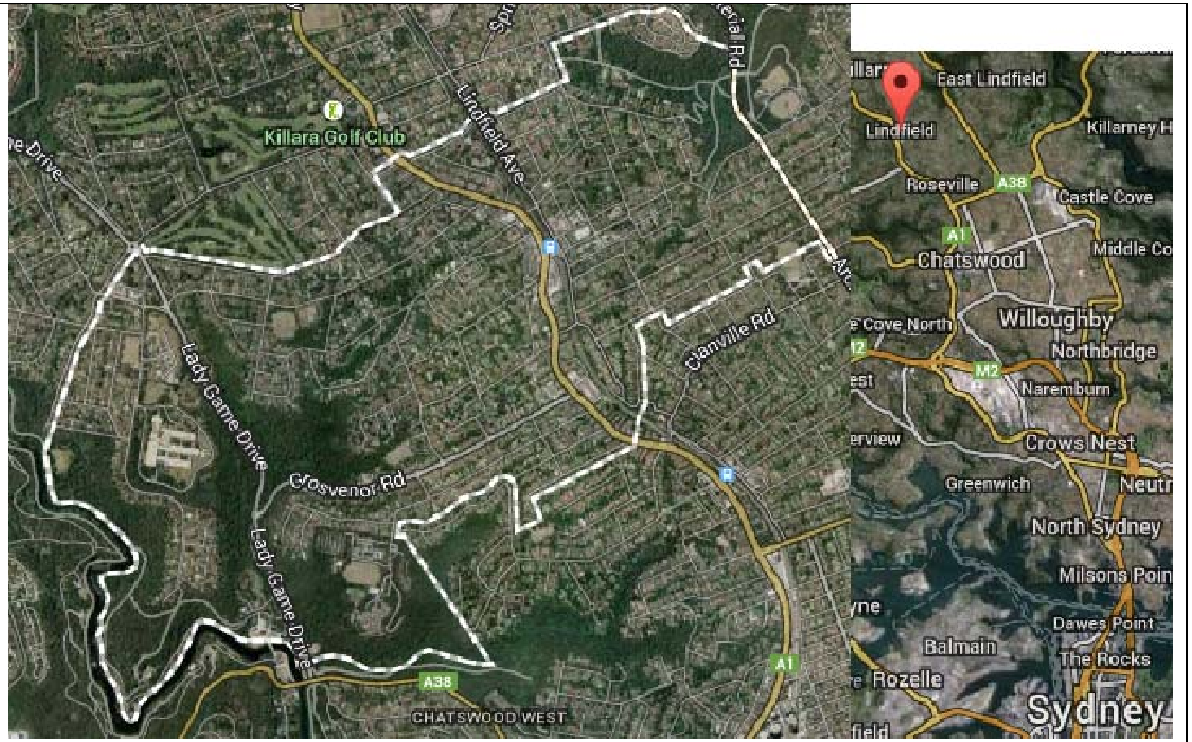
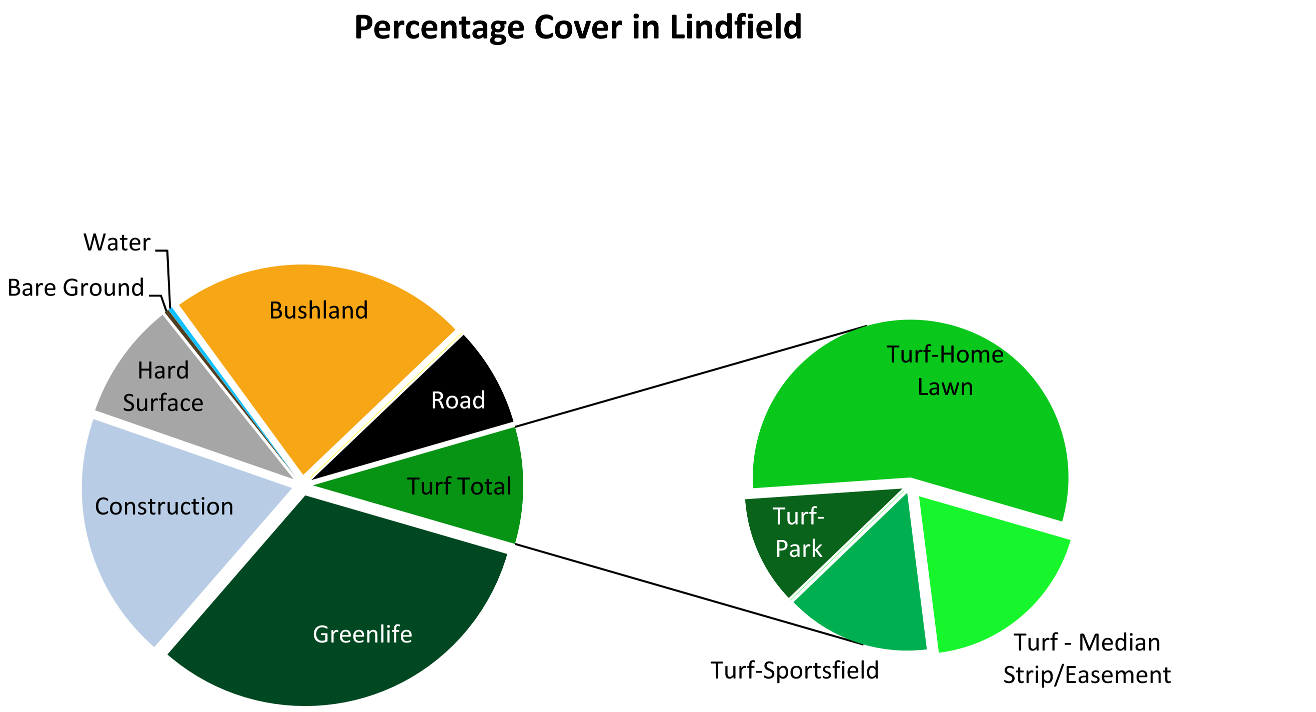


Figure 2. Lindfield Aerial Photograph

Cover Class	Cover (%)
Greenlife	32.00
Construction	19.00
Hard Surface	9.00
Bare Ground	0.33
Water	0.33
Bushland	23.00
Farm Land	0.00
Road	7.67
Turf-Home Lawn	5.00
Turf-Park	1.00
Turf-Sportsfield	1.33
Turf - Median Strip/Easement	1.67
Turf-Roadside	0.00
Turf TOTAL	9.00

Lindfield is located 10km north of the Sydney CBD. It is the administrative centre for the local government area of Ku-ring-gai Council. In the 2011 Census of Population and Housing, the population of Lindfield stood at 8,657 people, with a median age of 40 years. Lindfield's population is wealthier than the Australian average, with a median weekly household income of $2,414, compared with $1,234 in Australia. Total area of the suburb is 5.22km^2 which means that the population density is 16.58 people per hectare.



Suburb Case File: Pymble

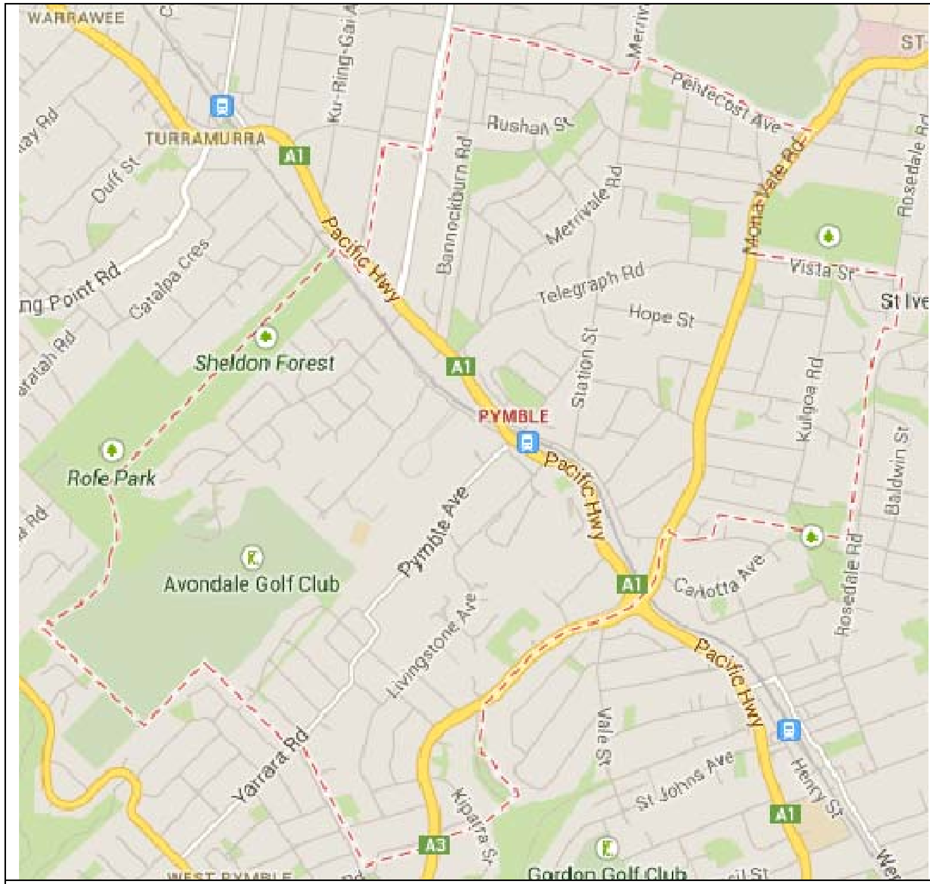


Figure 1. Pymble Aerial Map

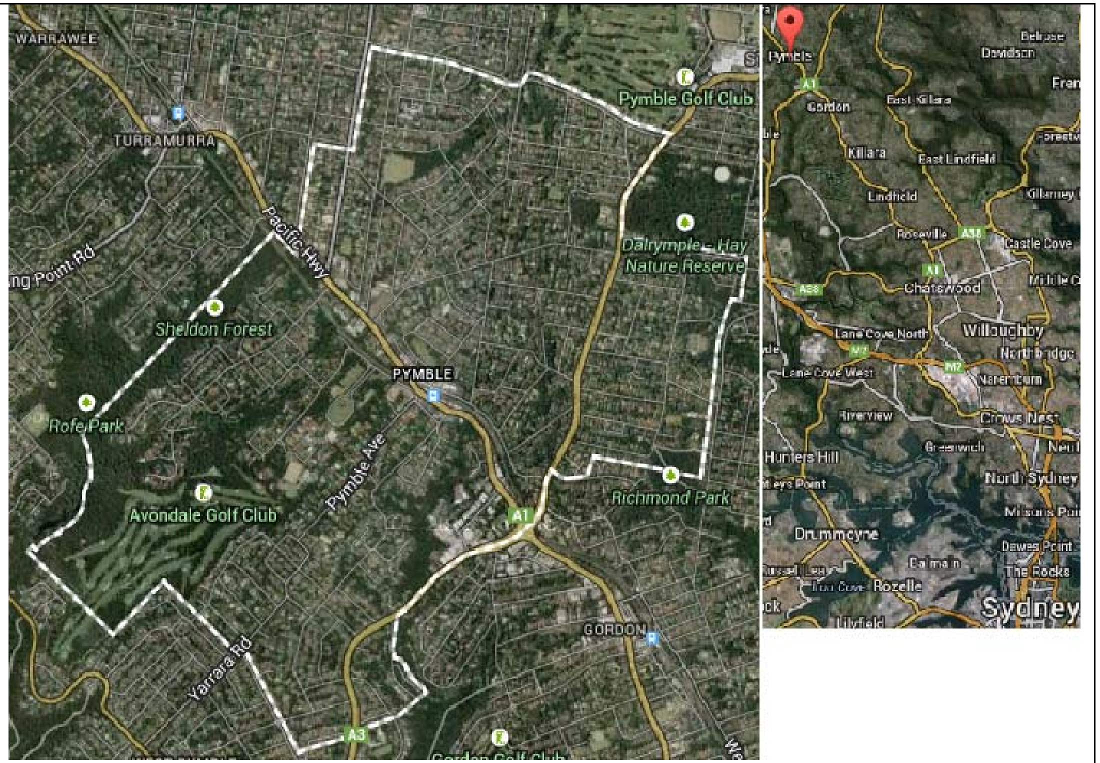
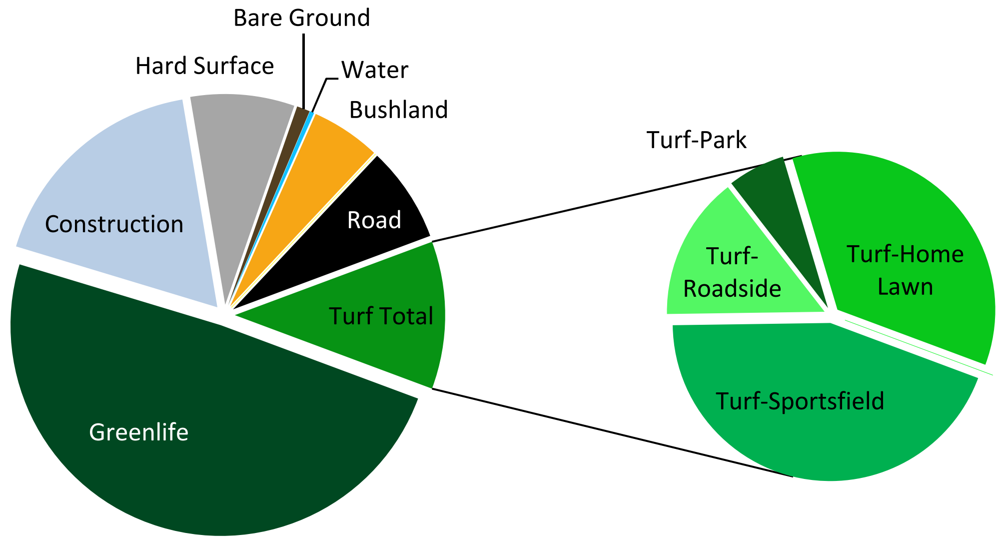


Figure 2. Pymble Aerial Photograph

Cover Class	Cover (%)
Greenlife	49.00
Construction	17.67
Hard Surface	8.00
Bare Ground	1.00
Water	0.33
Bushland	5.33
Farm Land	0.00
Road	7.33
Turf-Home Lawn	4.00
Turf-Park	0.67
Turf-Sportsfield	5.00
Turf - Median Strip/Easement	0.00
Turf-Roadside	1.67
Turf TOTAL	11.33

Pymble is located 15km north of the Sydney CBD. It is the administrative centre for the local government area of Ku-ring-gai Council. In the 2011 Census of Population and Housing, the population of Hornsby stood at 10,582 people, with a median age of 40 years. Pymble's population is wealthier than the Australian average, with a median weekly household income of $2,671, compared with $1,234 in Australia. Total area of the suburb is 6.41km^2 which means that the population density is 16.51 people per hectare.

Percentage Cover in Pymble



Suburb Case File: Hornsby

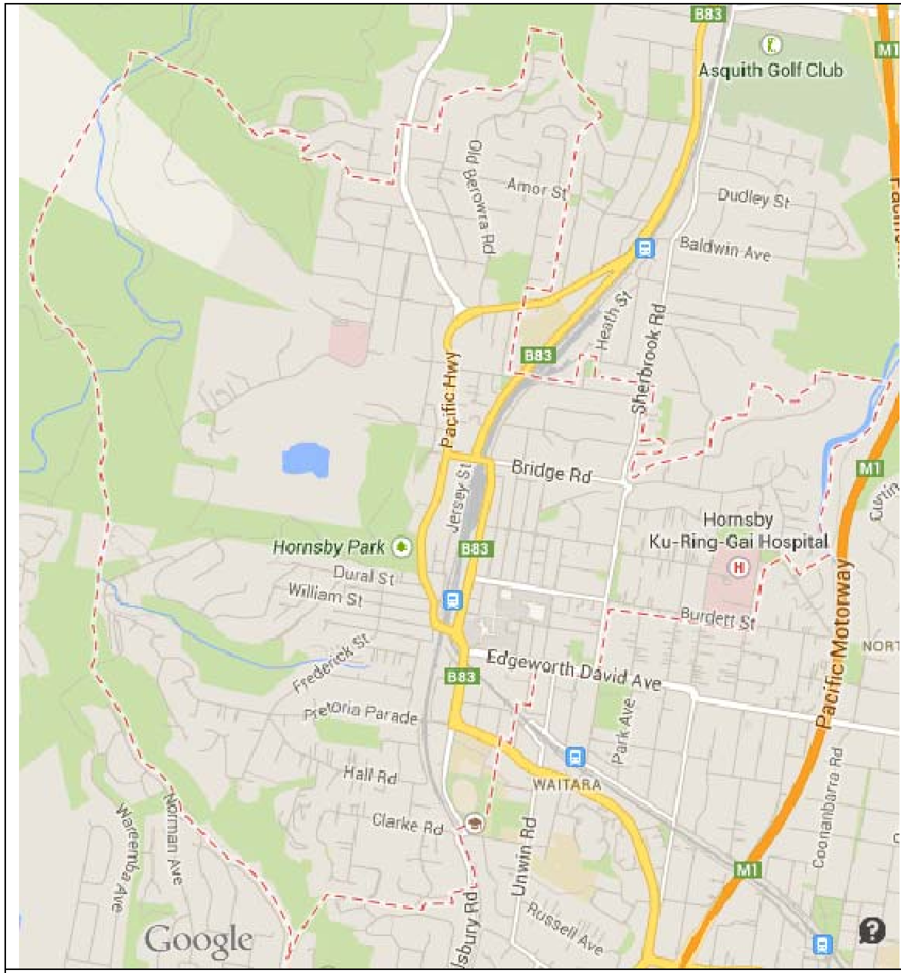


Figure 1. Hornsby Aerial Map

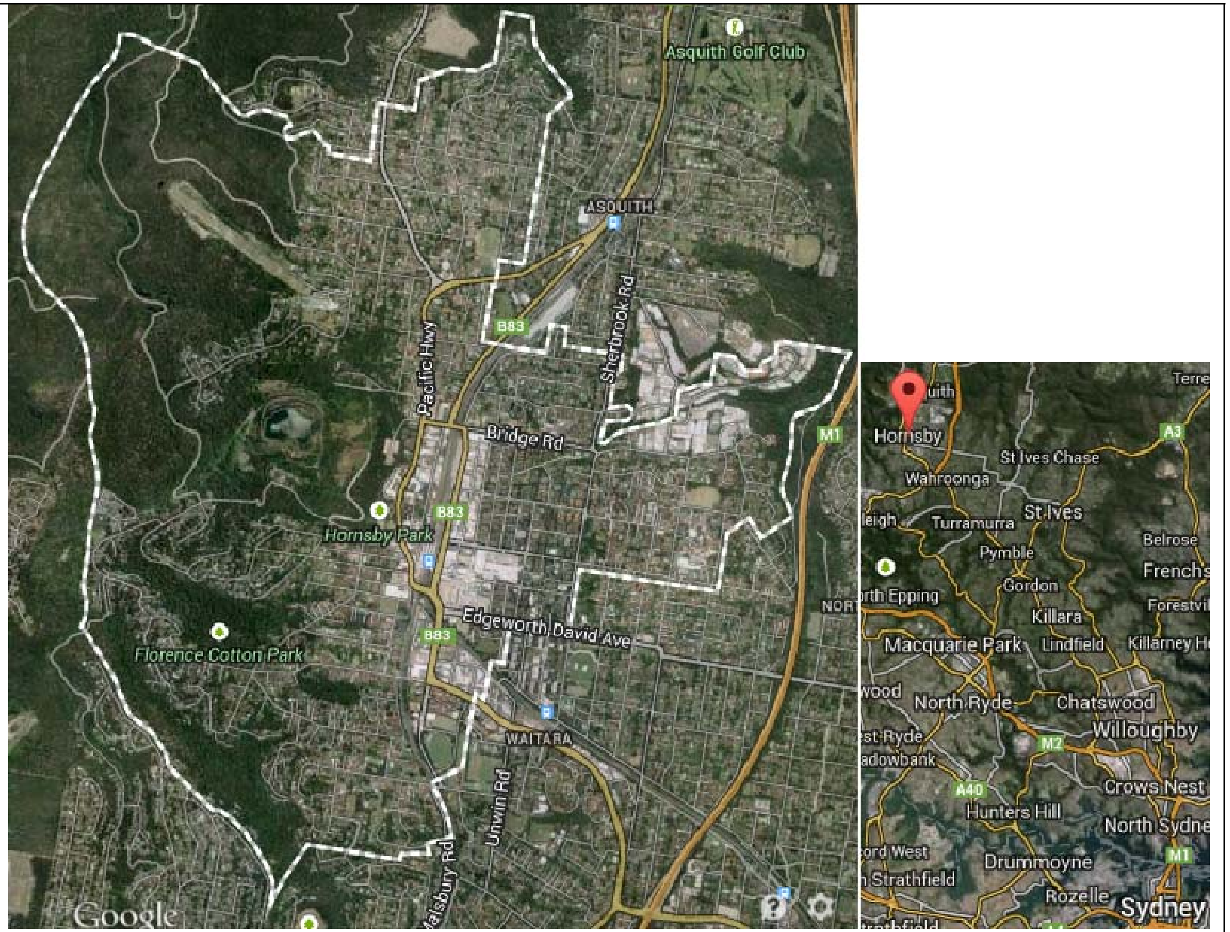
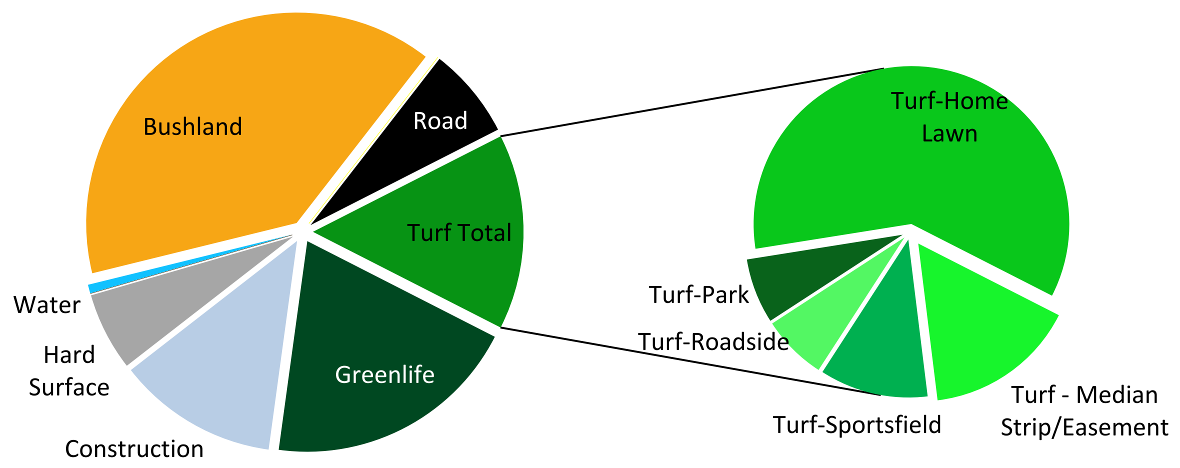


Figure 2. Hornsby Aerial Photograph

Cover Class	Cover (%)
Greenlife	19.67
Construction	12.33
Hard Surface	6.00
Bare Ground	0.00
Water	0.67
Bushland	39.33
Farm Land	0.00
Road	7.00
Turf-Home Lawn	9.00
Turf-Park	1.00
Turf-Sportsfield	1.67
Turf - Median Strip/Easement	2.33
Turf-Roadside	1.00
Turf TOTAL	15.00

Hornsby is in the north of Sydney situated 20km from the Sydney CBD. It is the administrative centre for the local government area of Hornsby Shire. In the 2011 Census of Population and Housing, the population of Hornsby stood at 19,863 people, with a median age of 35 years. Hornsby's population is slightly wealthier than the Australian average, with a median weekly household income of $1,436, compared with $1,234 in Australia. Total area of the suburb is 8.75km^2 which means that the population density is 22.7 people per hectare.

Percentage Cover in Hornsby



Suburb Case File: Enmore

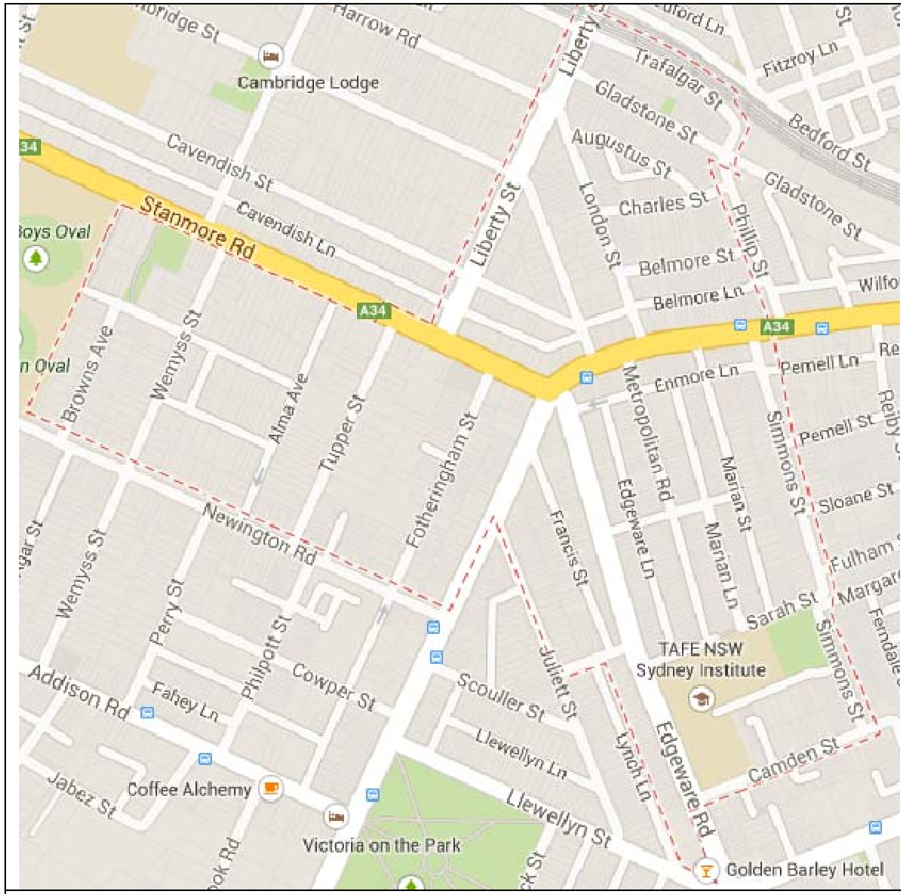


Figure 1. Enmore Aerial Map

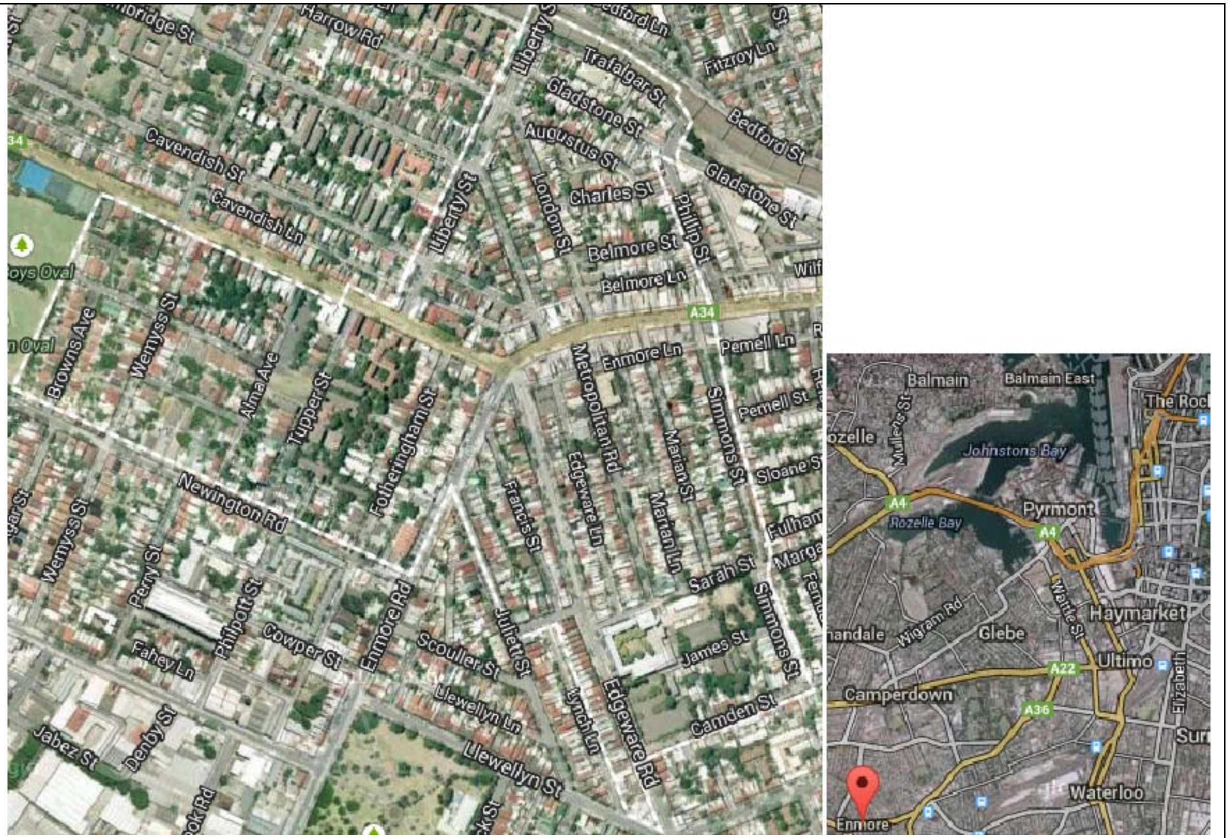
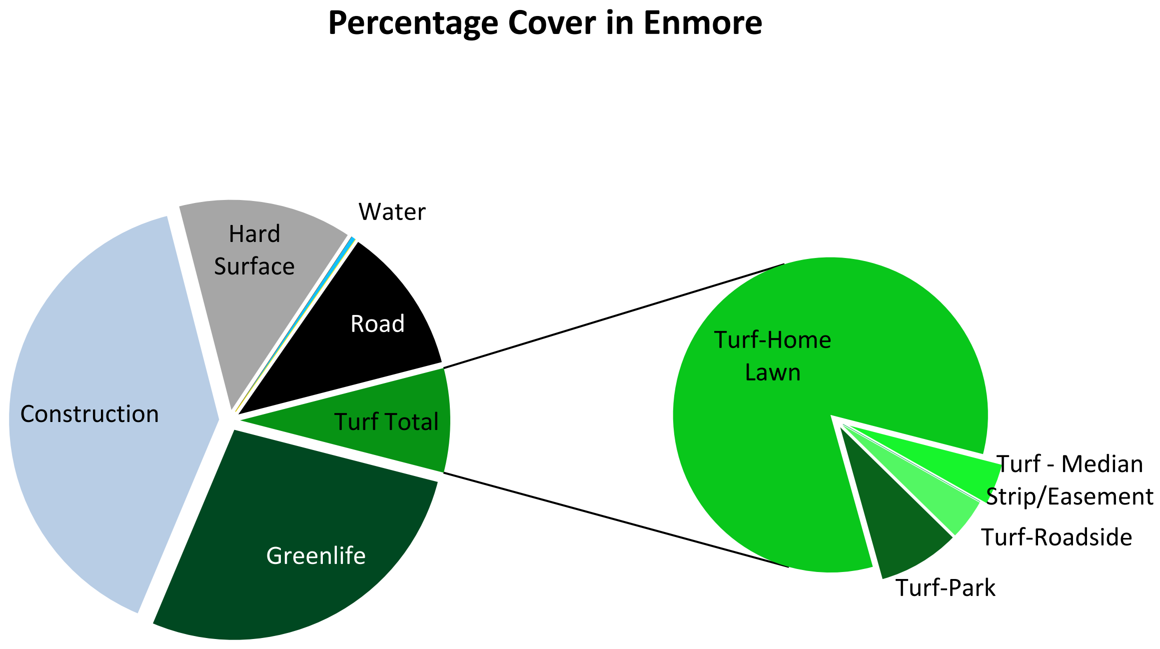


Figure 2. Enmore Aerial Photograph

Cover Class	Cover (%)
Greenlife	27.33
Construction	39.67
Hard Surface	13.33
Bare Ground	0.00
Water	0.33
Bushland	0.00
Farm Land	0.00
Road	11.33
Turf-Home Lawn	6.67
Turf-Park	0.67
Turf-Sportsfield	0.00
Turf - Median Strip/Easement	0.33
Turf-Roadside	0.33
Turf TOTAL	8.00

Enmore is in the south of Sydney situated 5km from the Sydney CBD. It is the administrative centre for the local government area of Marrickville Council. In the 2011 Census of Population and Housing, the population of Enmore stood at 3,572 people, with a median age of 34 years. Enmore's population is wealthier than the Australian average, with a median weekly household income of $1,714, compared with $1,234 in Australia. Total area of the suburb is .45km^2 which means that the population density is 79.38 people per hectare.



Suburb Case File: Arncliffe

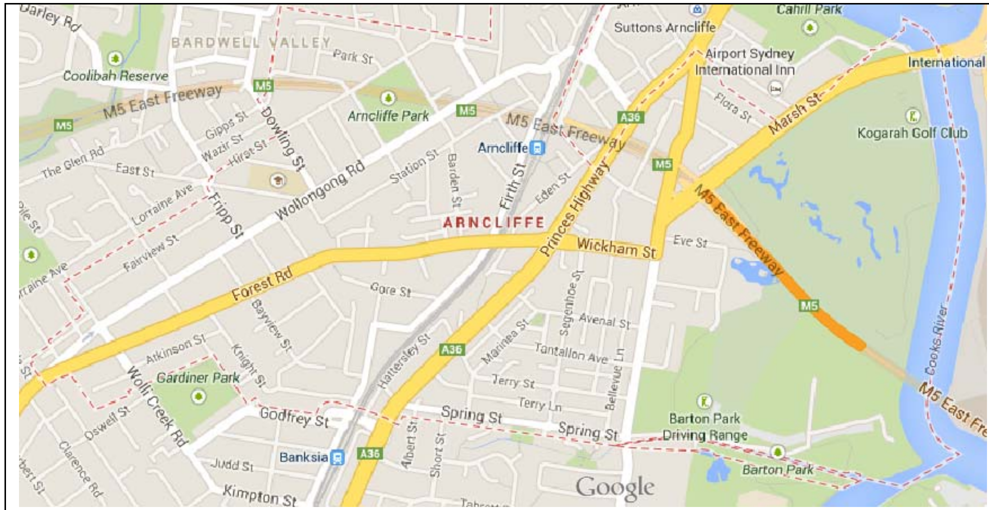


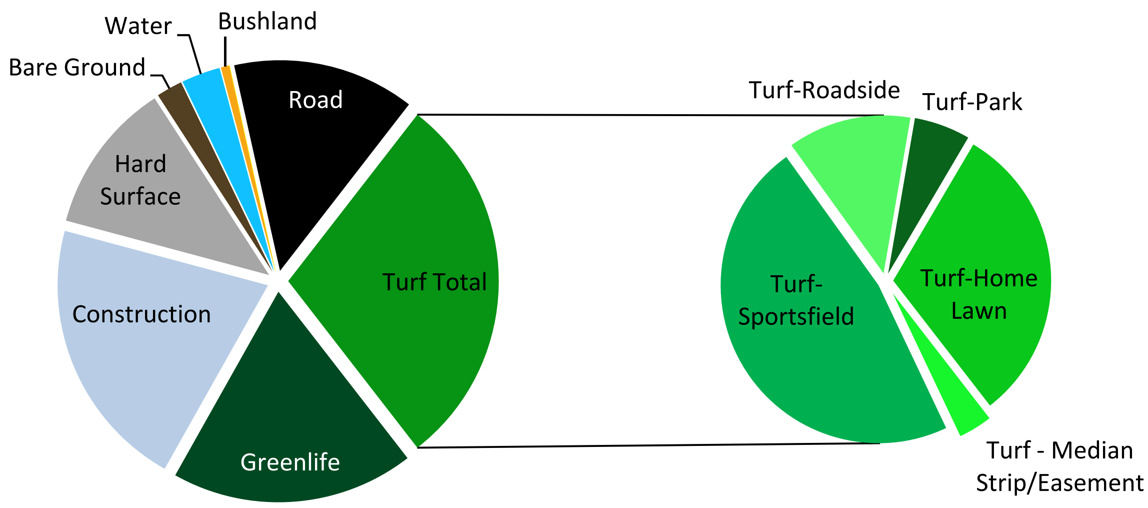
Figure 1. Arncliffe Aerial Map

Figure 2. Arncliffe Aerial Photograph

Cover Class	Cover (%)
Greenlife	18.67
Construction	21.00
Hard Surface	11.67
Bare Ground	2.00
Water	3.00
Bushland	0.67
Farm Land	0.00
Road	14.00
Turf-Home Lawn	9.00
Turf-Park	1.67
Turf-Sportsfield	13.67
Turf - Median Strip/Easement	1.00
Turf-Roadside	3.67
Turf TOTAL	29.00

Arncliffe is in the south of Sydney situated 10km from the Sydney CBD. It is the administrative centre for the local government area of City of Rockdale. In the 2011 Census of Population and Housing, the population of Arncliffe stood at 8,420 people, with a median age of 37 years. Arncliffe's population is on par with the Australian average, with a median weekly household income of $1,251, compared with $1,234 in Australia. Total area of the suburb is 3.08km^2 which means that the population density is 27.34 people per hectare.

Percentage Cover in Arncliffe



Suburb Case File: South Hurstville

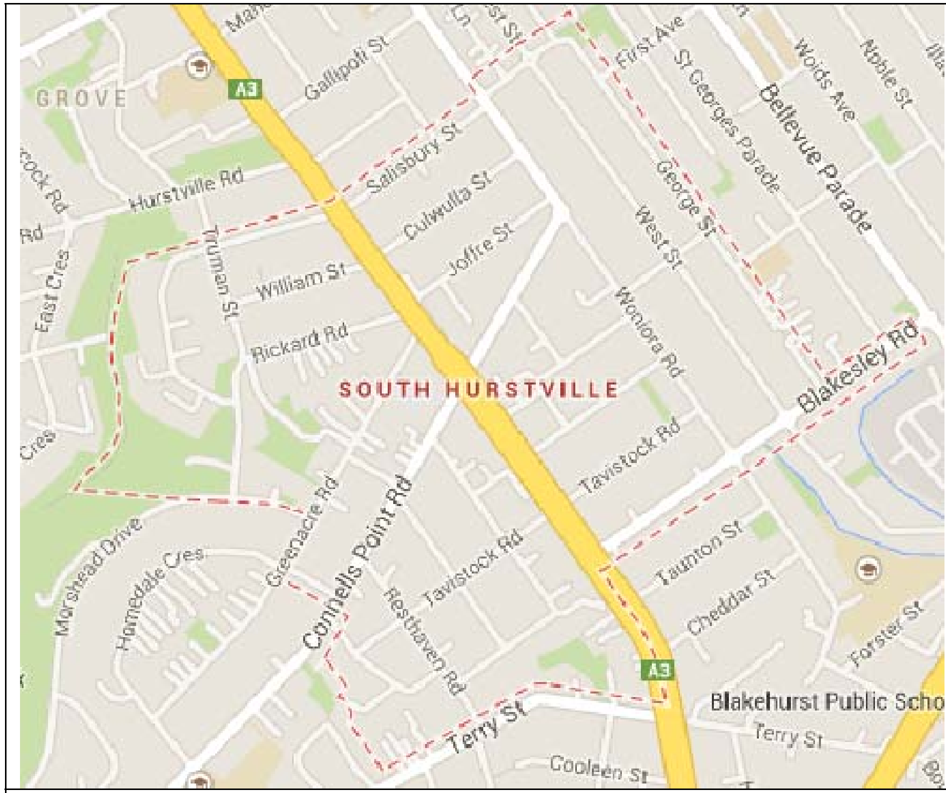


Figure 1. South Hurstville Aerial Map

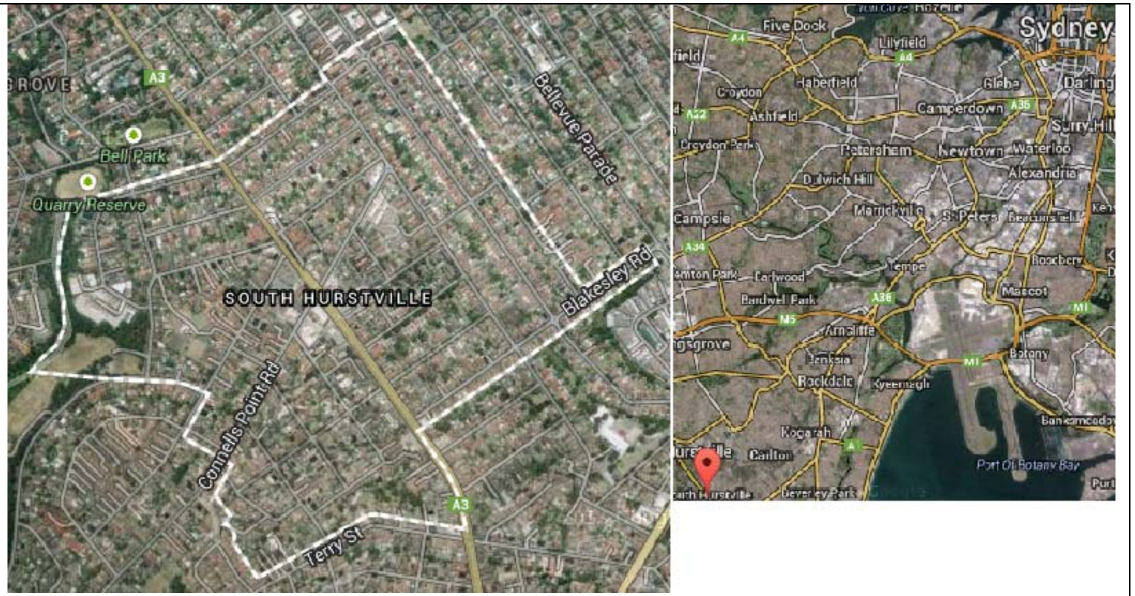
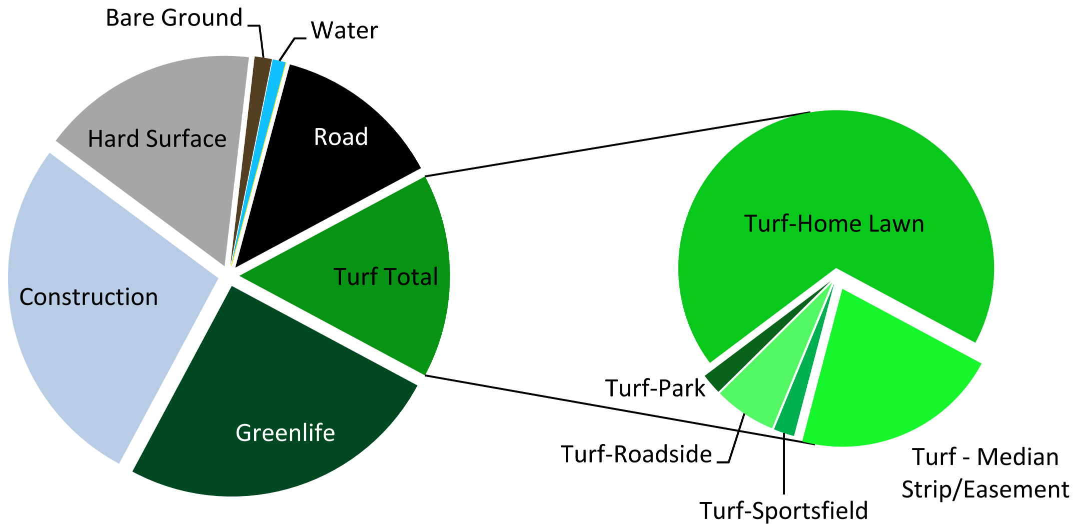


Figure 2. South Hurstville Aerial Photograph

Cover Class	Cover (%)
Greenlife	25.00
Construction	27.33
Hard Surface	16.67
Bare Ground	1.33
Water	1.00
Bushland	0.00
Farm Land	0.00
Road	13.00
Turf-Home Lawn	10.67
Turf-Park	0.33
Turf-Sportsfield	0.33
Turf - Median Strip/Easement	3.33
Turf-Roadside	1.00
Turf TOTAL	15.67

South Hurstville is in the south of Sydney situated 15km from the Sydney CBD. It is the administrative centre for the local government area of the Municipality of Kogarah. In the 2011 Census of Population and Housing, the population of South Hurstville stood at 4,928 people, with a median age of 37 years. South Hurstville's population is on par with the Australian average, with a median weekly household income of $1,305, compared with $1,234 in Australia. Total area of the suburb is 1.08km^2 which means that the population density is 45.63 people per hectare.

Percentage Cover in South Hurstville



Suburb Case File: Sutherland

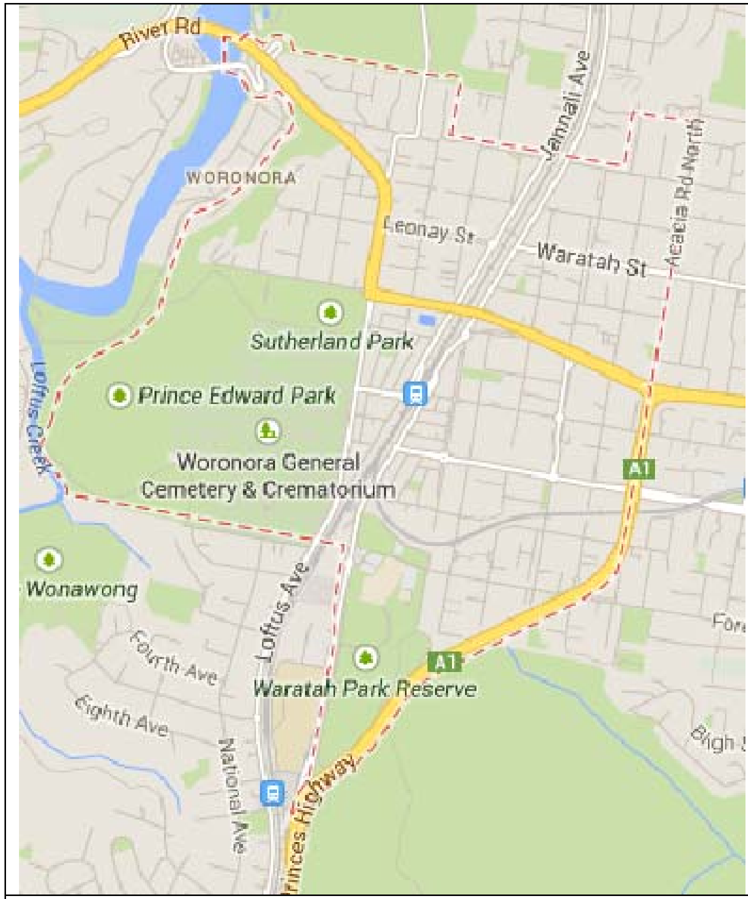


Figure 1. Sutherland Aerial Map

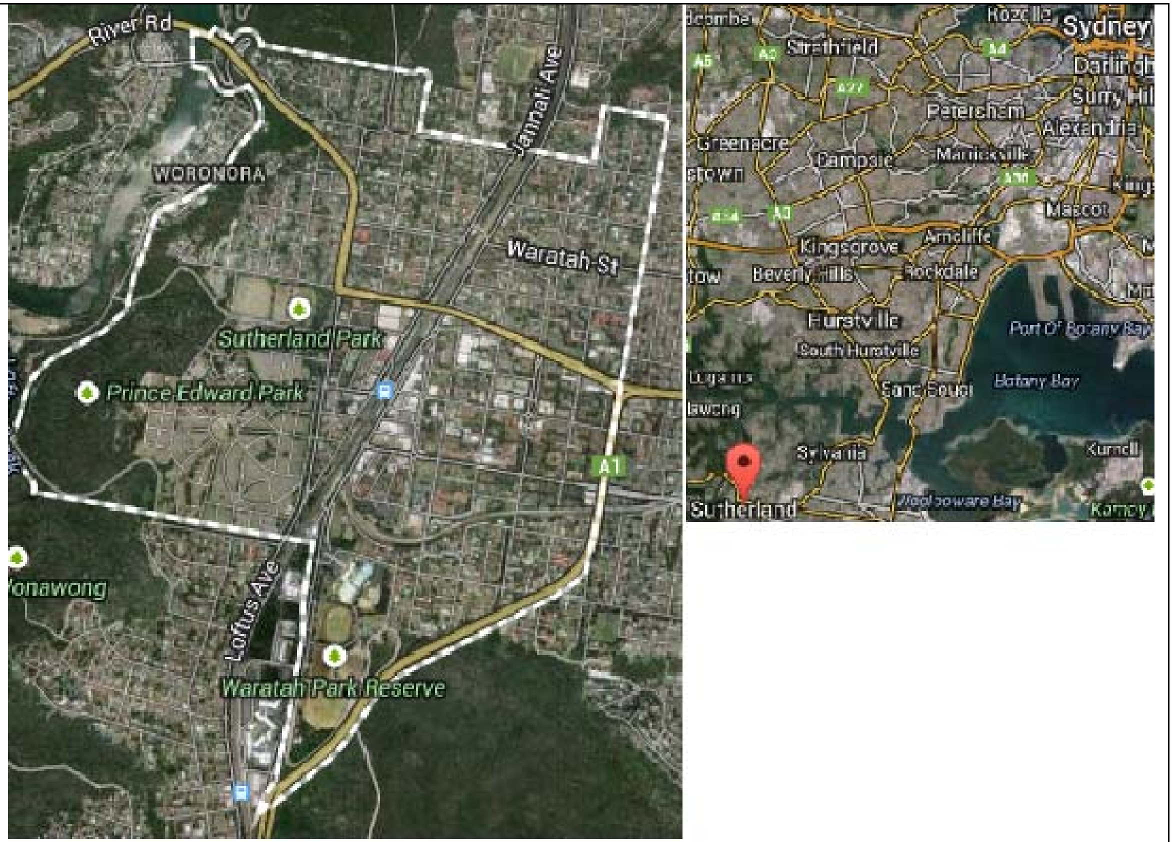
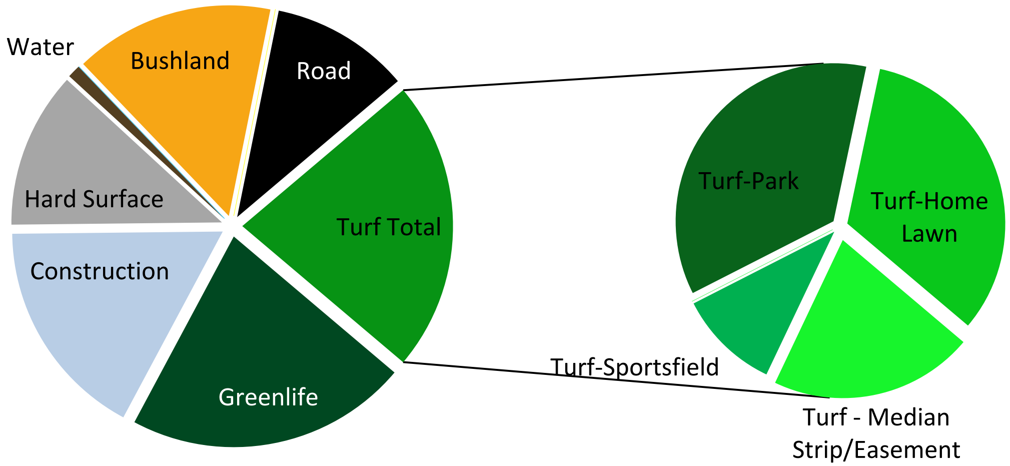


Figure 2. Sutherland Aerial Photograph

Cover Class	Cover (%)
Greenlife	21.67
Construction	17.00
Hard Surface	12.00
Bare Ground	1.00
Water	0.00
Bushland	15.33
Farm Land	0.00
Road	10.67
Turf-Home Lawn	7.33
Turf-Park	8.00
Turf-Sportsfield	2.33
Turf - Median Strip/Easement	4.67
Turf-Roadside	0.00
Turf TOTAL	22.33

Sutherland is in the south outskirts of Sydney situated 20km from the Sydney CBD. It is the administrative centre for the local government area of Sutherland Shire. In the 2011 Census of Population and Housing, the population of Sutherland stood at 9,923 people, with a median age of 36 years. Sutherland's population is on par with the Australian average, with a median weekly household income of $1,375, compared with $1,234 in Australia. Total area of the suburb is 3.73km^2 which means that the population density is 26.6 people per hectare.

Percentage Cover in Sutherland



Appendix 6 – Melbourne suburbs included in the i-Tree Canopy assessment.

Suburb Case File: Melbourne CBD

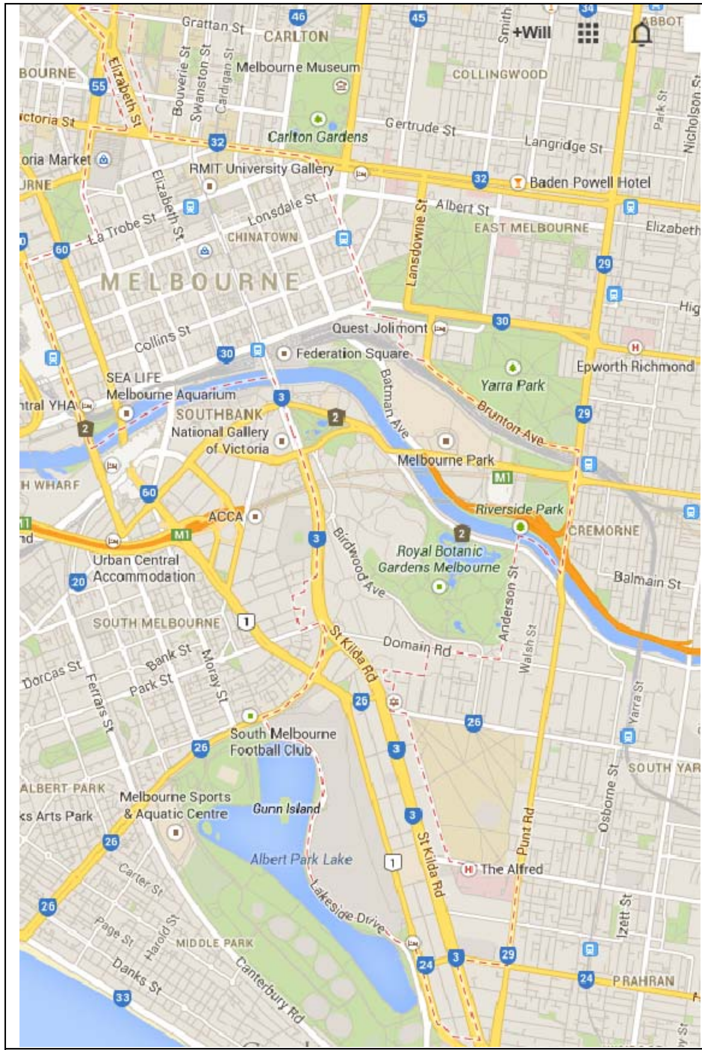


Figure 1. Melbourne CBD Aerial Map

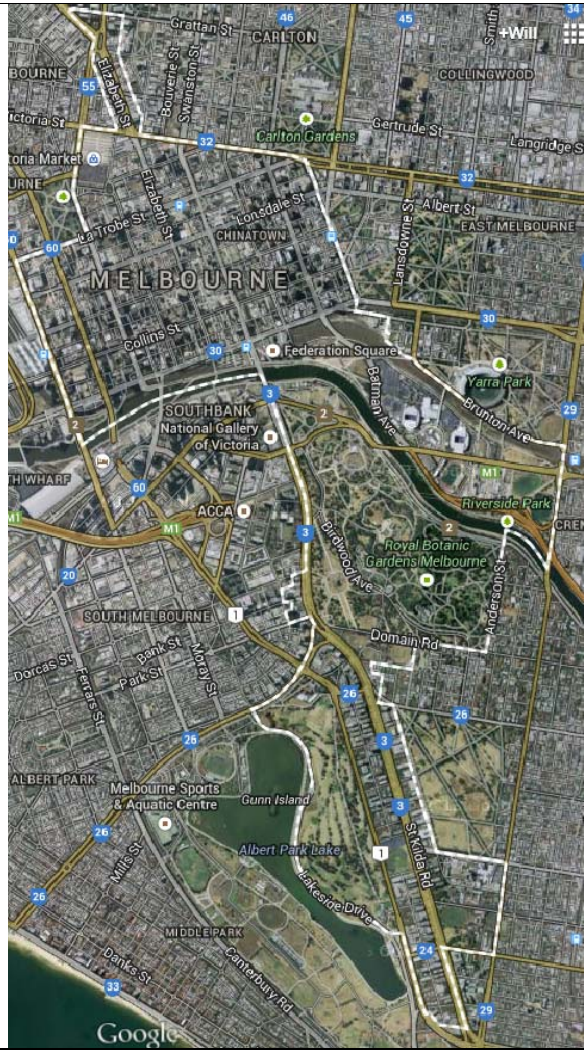
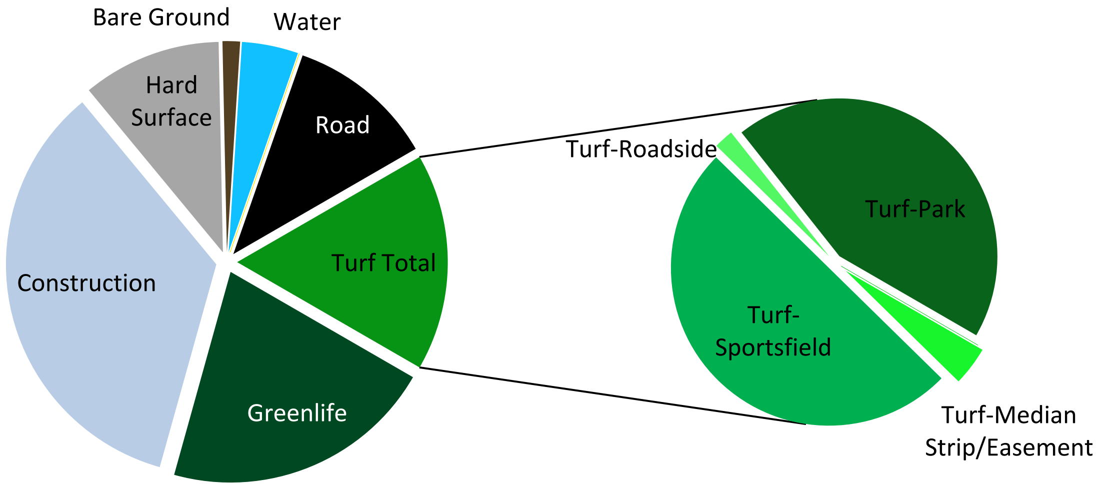


Figure 2. Melbourne CBD Aerial Photograph

Cover Class	Cover (%)
Greenlife	21.00
Construction	34.67
Hard Surface	10.67
Bare Ground	1.33
Water	4.33
Bushland	0.00
Farm Land	0.00
Road	11.33
Turf-Home Lawn	0.00
Turf-Park	7.33
Turf-Sportsfield	8.33
Turf - Median Strip/Easement	0.67
Turf-Roadside	0.33
Turf TOTAL	16.67

Melbourne CBD is in the local government area of the City of Melbourne. In the 2011 Census of Population and Housing, the population of Melbourne stood at 28,371 people, with a median age of 28 years. Melbourne's household income is similar to the Australian average, with a median weekly household income of $1,230, compared with $1,234 in Australia. The total area of the suburb is 6.48km^2 which means that the population density is 43.78 people per hectare.

Percentage Cover in Melbourne CBD



Suburb Case File: Footscray

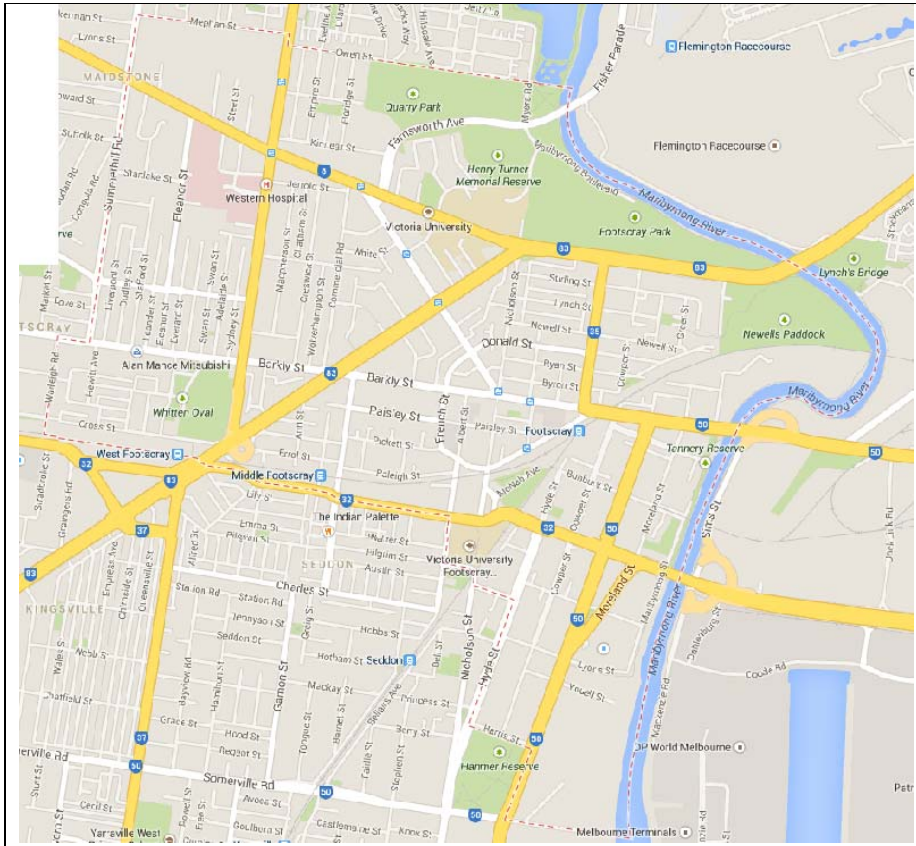


Figure 1. Footscray Aerial Map

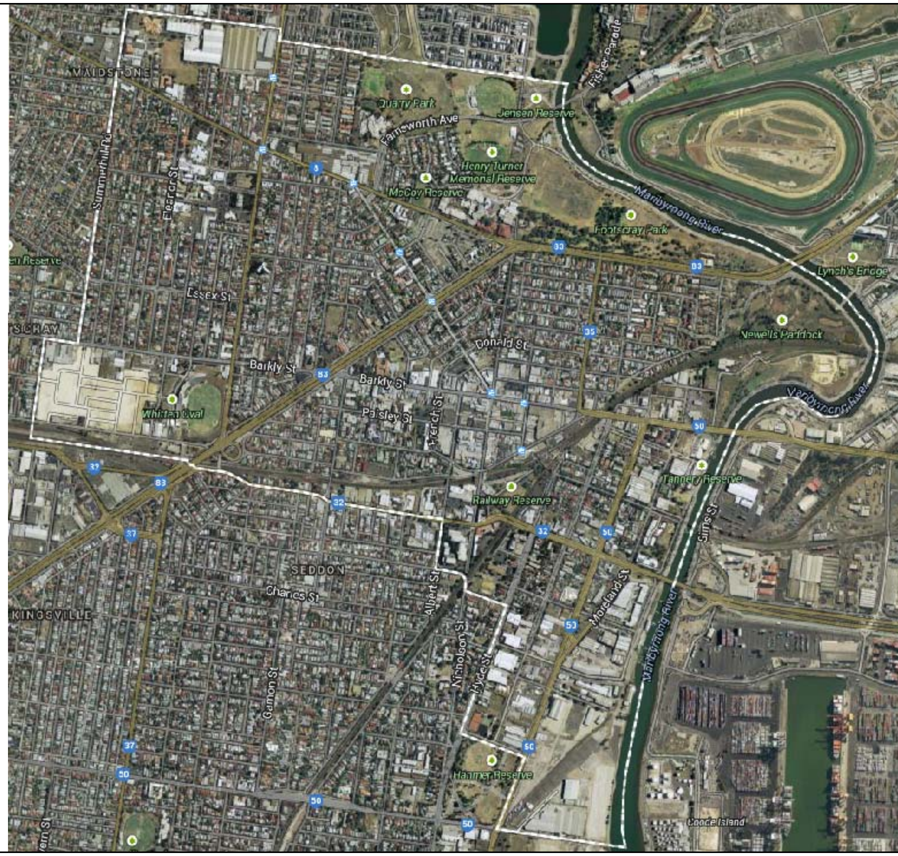
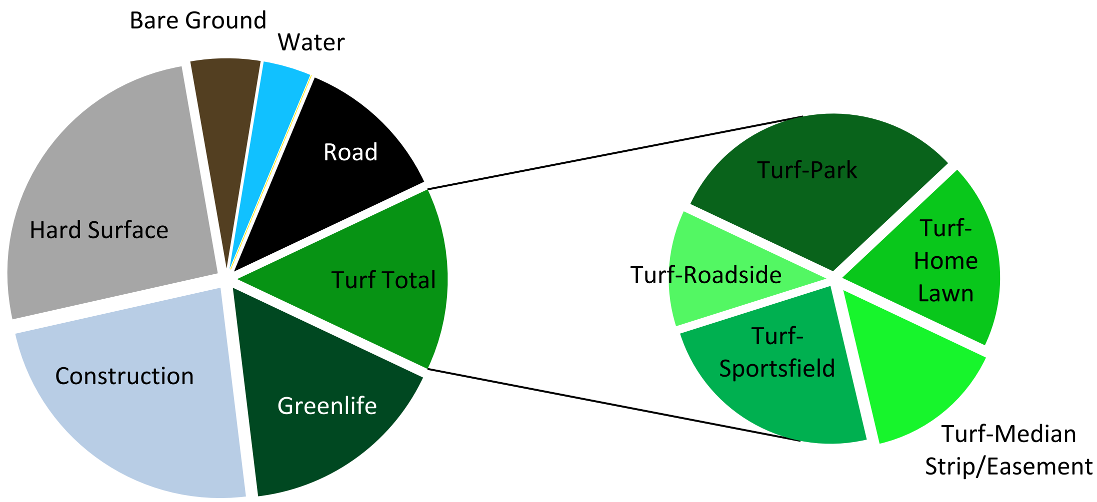


Figure 2. Footscray Aerial Photograph

Cover Class	Cover (%)
Greenlife	16.00
Construction	23.33
Hard Surface	25.67
Bare Ground	5.33
Water	3.67
Bushland	0.00
Farm Land	0.00
Road	11.67
Turf-Home Lawn	2.67
Turf-Park	4.33
Turf-Sportsfield	3.33
Turf - Median Strip/Easement	2.00
Turf-Roadside	1.67
Turf TOTAL	14.00

The local government area of Footscray is the City of Maribyrnong. In the 2011 Census of Population and Housing, the population of Footscray stood at 13,203 people, with a median age of 32 years. Footscray's household income is lower than the Australian average, with a median weekly household income of $1,059, compared with $1,234 in Australia. The total area of the suburb is 5.02km^2 which means that the population density 26.3 is people per hectare.

Percentage Cover in Footscray



Suburb Case File: Braybrook

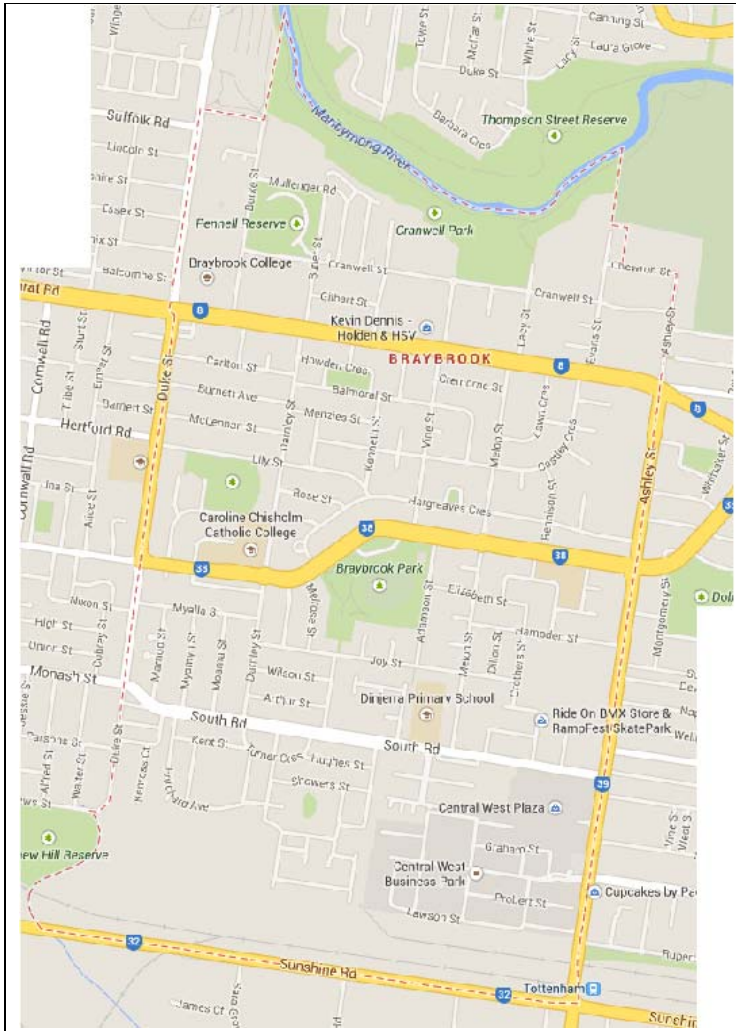


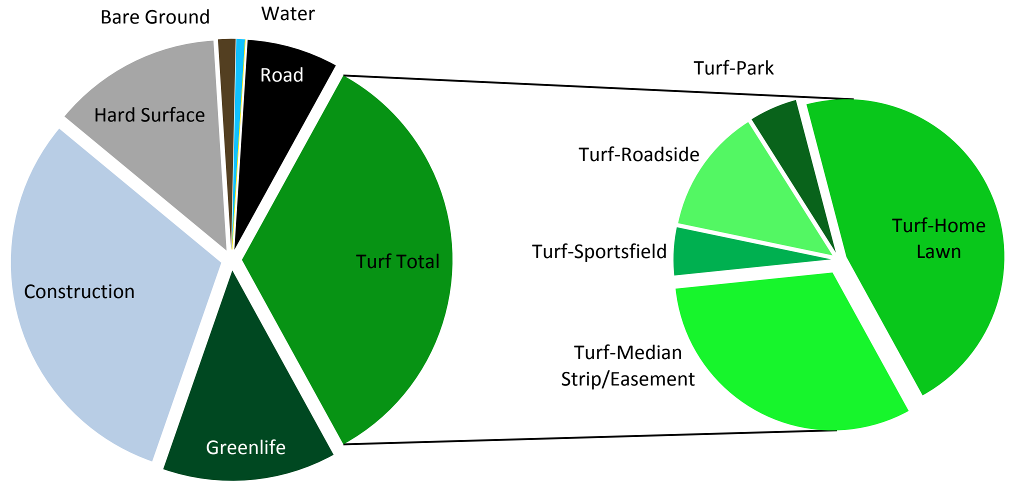
Figure 1. Aerial Map

Figure 2. Braybrook Aerial Photograph

Cover Class	Cover (%)
Greenlife	13.33
Construction	30.67
Hard Surface	13.00
Bare Ground	1.33
Water	0.67
Bushland	0.00
Farm Land	0.00
Road	7.00
Turf-Home Lawn	10.67
Turf-Park	1.67
Turf-Sportsfield	4.33
Turf - Median Strip/Easement	1.67
Turf-Roadside	15.67
Turf TOTAL	34.00

Braybrook is in the local government area of City of Maribyrnong. In the 2011 Census of Population and Housing, the population of Braybrook stood at 8,180 people, with a median age of 32 years. Braybrook's household income is lower than the Australian average, with a median weekly household income of $792, compared with $1,234 in Australia. The total area of the suburb is 4.32km^2 which means that the population density 18.94 is people per hectare.

Percentage Cover in Braybrook



Suburb Case File: Ardeer

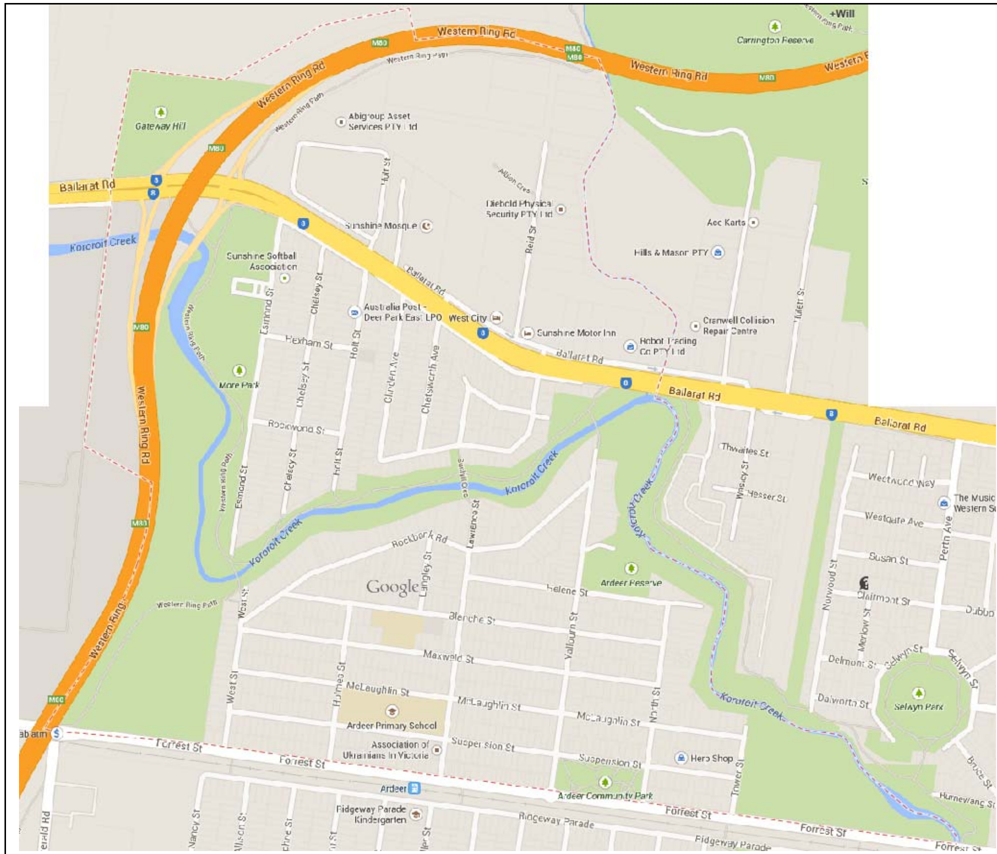


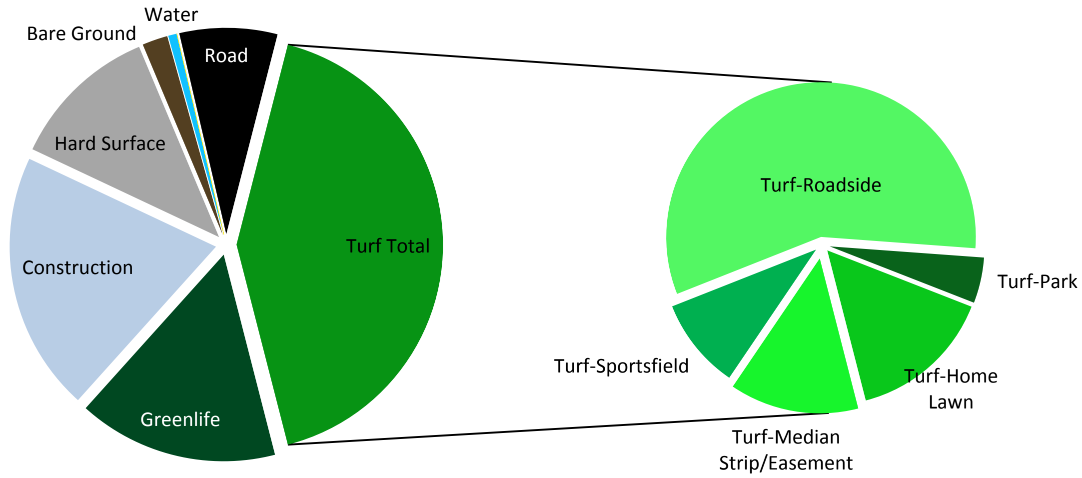
Figure 1. Aerial Map

Figure 2. Ardeer Aerial Photograph

Cover Class	Cover (%)
Greenlife	15.67
Construction	20.33
Hard Surface	11.67
Bare Ground	2.00
Water	0.67
Bushland	0.00
Farm Land	0.00
Road	7.67
Turf-Home Lawn	6.33
Turf-Park	2.00
Turf-Sportsfield	4.00
Turf - Median Strip/Easement	5.67
Turf-Roadside	24.00
Turf TOTAL	42.00

Ardeer is in the local government area of the City of Brimbank. In the 2011 Census of Population and Housing, the population of Ardeer stood at 2,823 people, with a median age of 37 years. Ardeer's household income is lower than the Australian average, with a median weekly household income of $891, compared with $1,234 in Australia. The total area of the suburb is 2.21km^2 which means that the population density is 12.77 people per hectare.

Percentage Cover in Ardeer



Suburb Case File: Caroline Springs

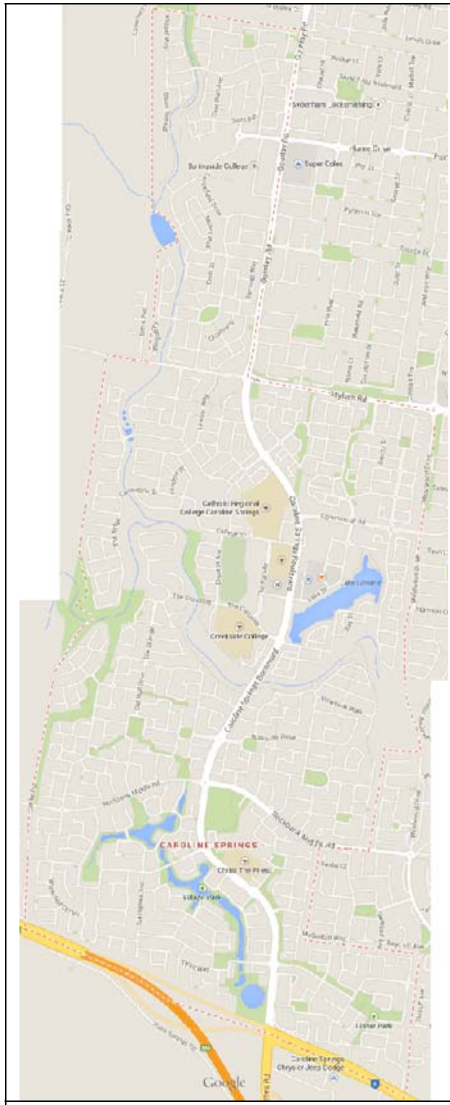


Figure 1. Caroline Spings Aerial Map

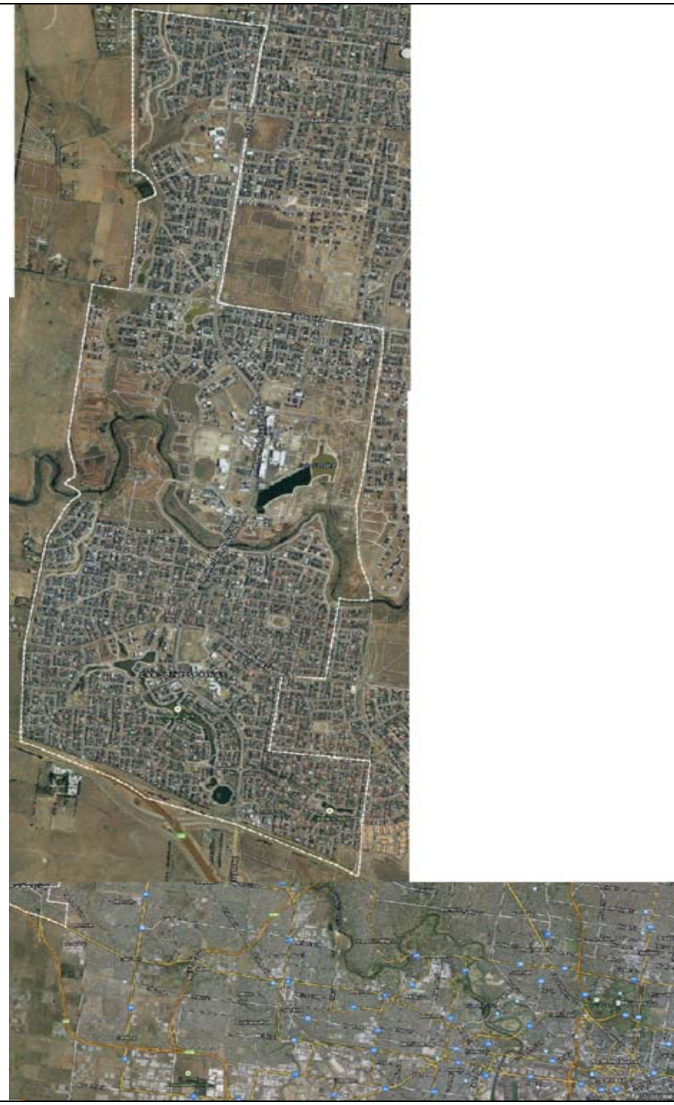
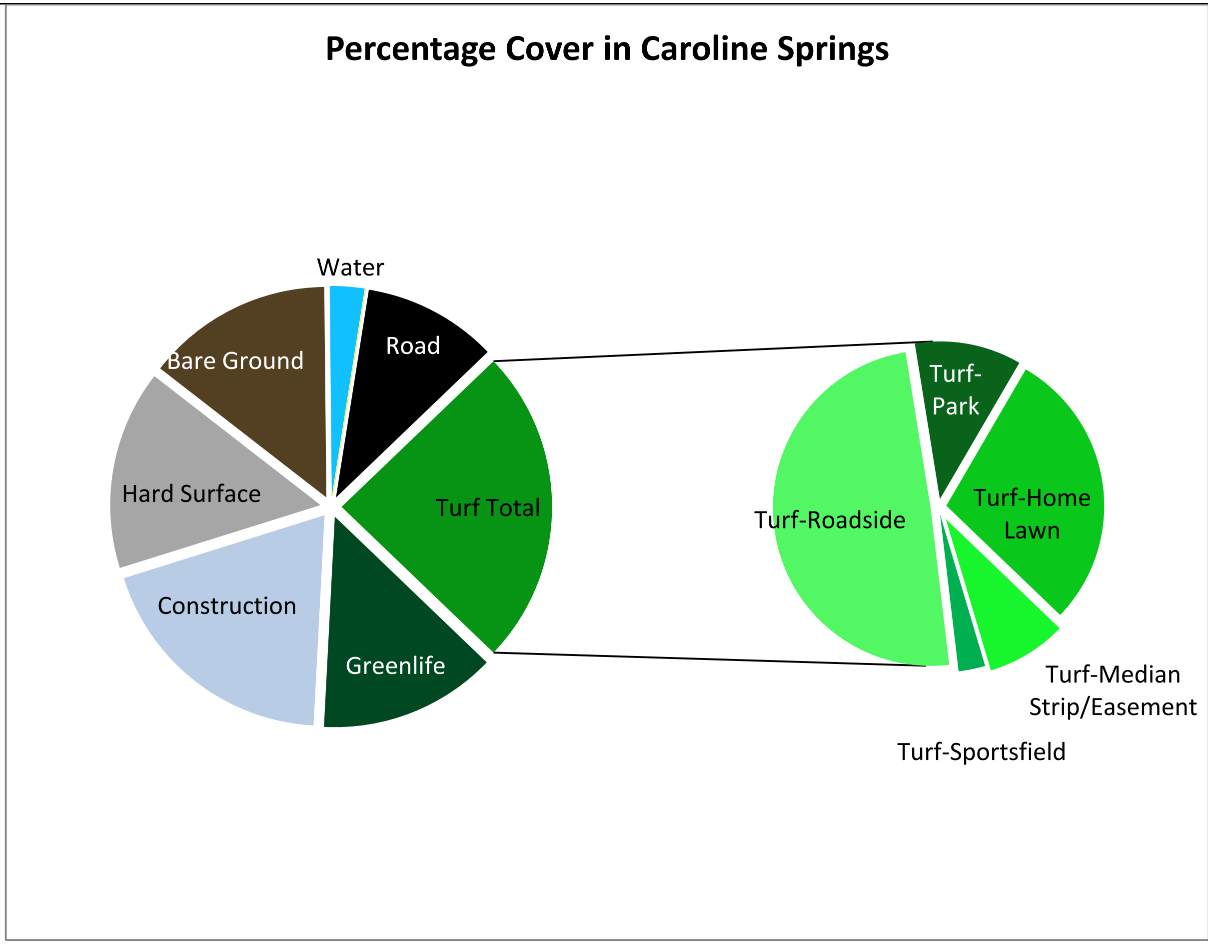


Figure 2. Caroline Spings Aerial Photograph

Cover Class	Cover (%)
Greenlife	13.67
Construction	19.33
Hard Surface	15.33
Bare Ground	14.33
Water	2.67
Bushland	0.00
Farm Land	0.00
Road	10.33
Turf-Home Lawn	7.00
Turf-Park	2.67
Turf-Sportsfield	0.67
Turf - Median Strip/Easement	2.00
Turf-Roadside	12.00
Turf TOTAL	24.33

Caroline Springs is in the local government area of Shire of Melton. In the 2011 Census of Population and Housing, the population of Caroline Springs stood at 20,366 people, with a median age of 31 years. Caroline Spring's household income is higher than the Australian average, with a median weekly household income of $1,653, compared with $1,234 in Australia. The total area of the suburb is 8.42km^2 which means that the population density is 24.19 people per hectare.



Suburb Case File: Rockbank

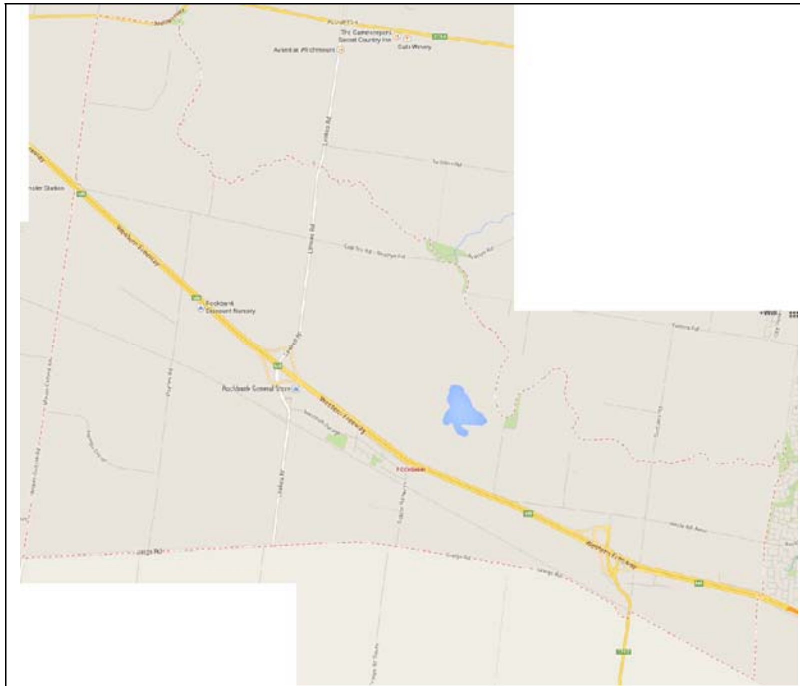
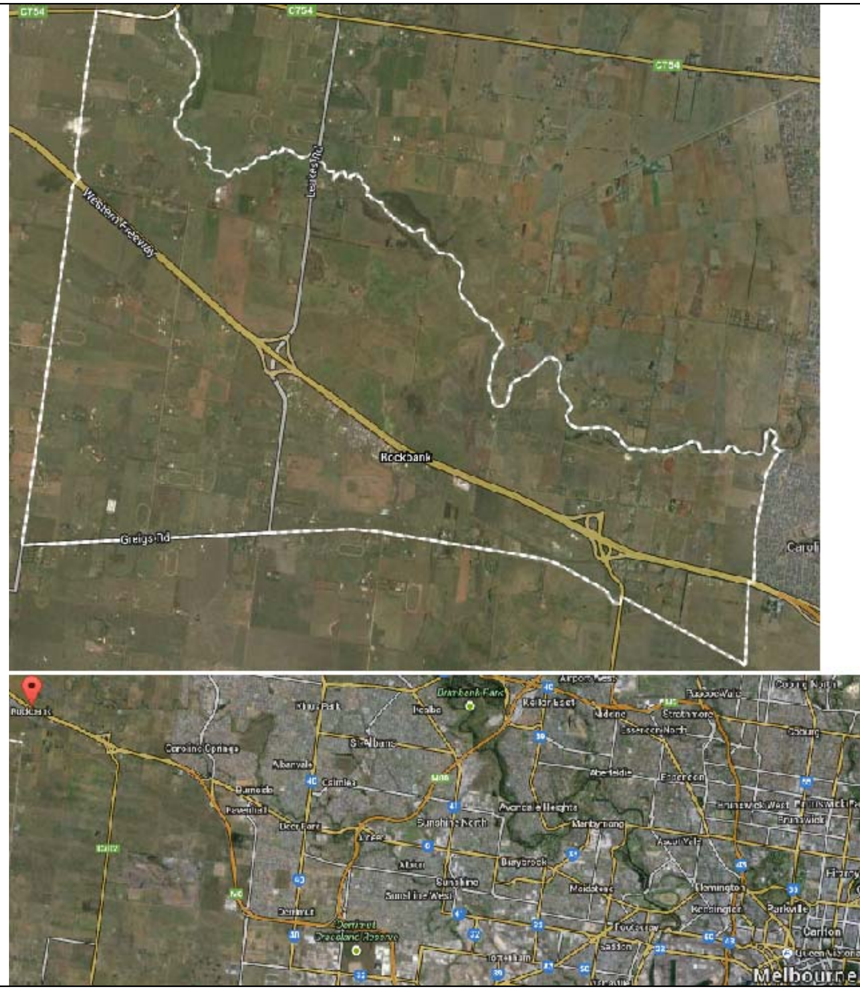
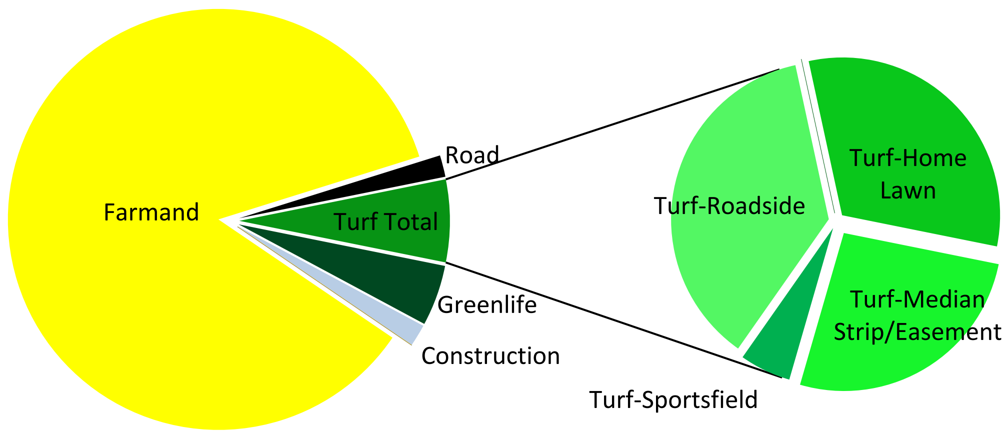
	

Figure 1. Rockbank Aerial Map	**Figure 2.** Rockbank Aerial Photograph

Cover Class	Cover (%)
Greenlife	4.67
Construction	1.67
Hard Surface	0.00
Bare Ground	0.00
Water	0.00
Bushland	0.00
Farm Land	85.67
Road	1.67
Turf-Home Lawn	2.00
Turf-Park	0.00
Turf-Sportsfield	0.33
Turf - Median Strip/Easement	1.67
Turf-Roadside	2.33
Turf TOTAL	6.33

Rockbank is in the local government area of Shire of Melton. In the 2011 Census of Population and Housing, the population of Rockbank stood at 1,349 people, with a median age of 39 years. Rockbank household income is lower than the Australian average, with a median weekly household income of $964, compared with $1,234 in Australia. The total area of the suburb is 38.3km^2 which means that the population density is .35 people per hectare.

Percentage Cover in Rockbank



Suburb Case File: Brookfield

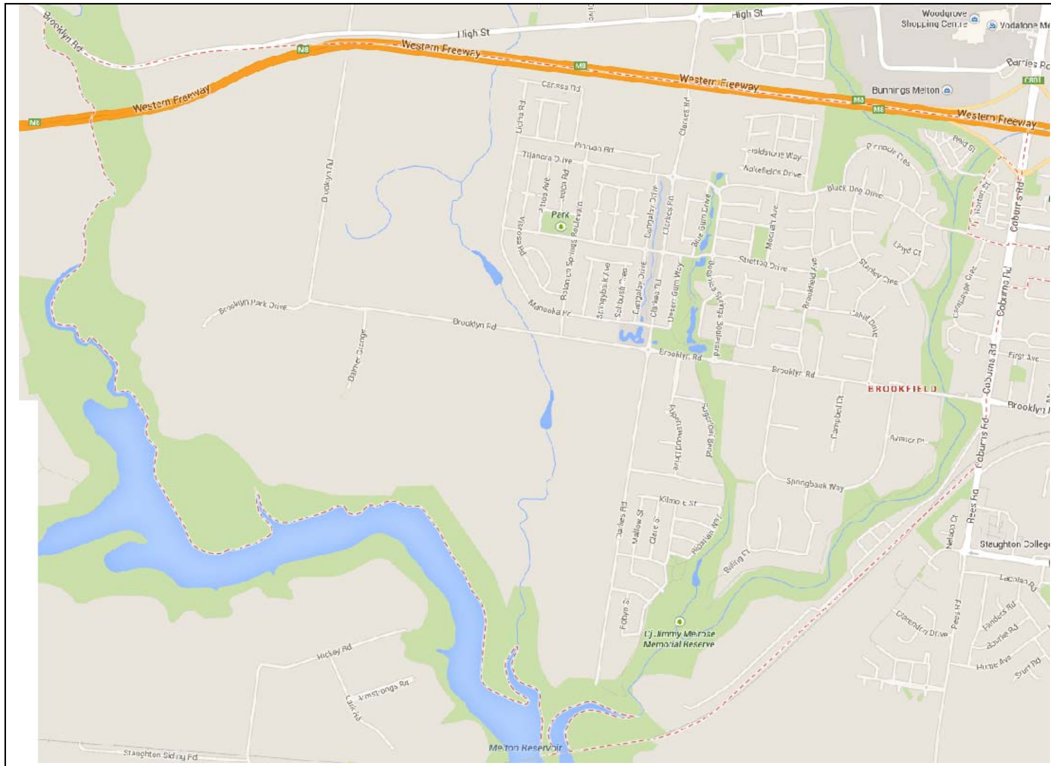


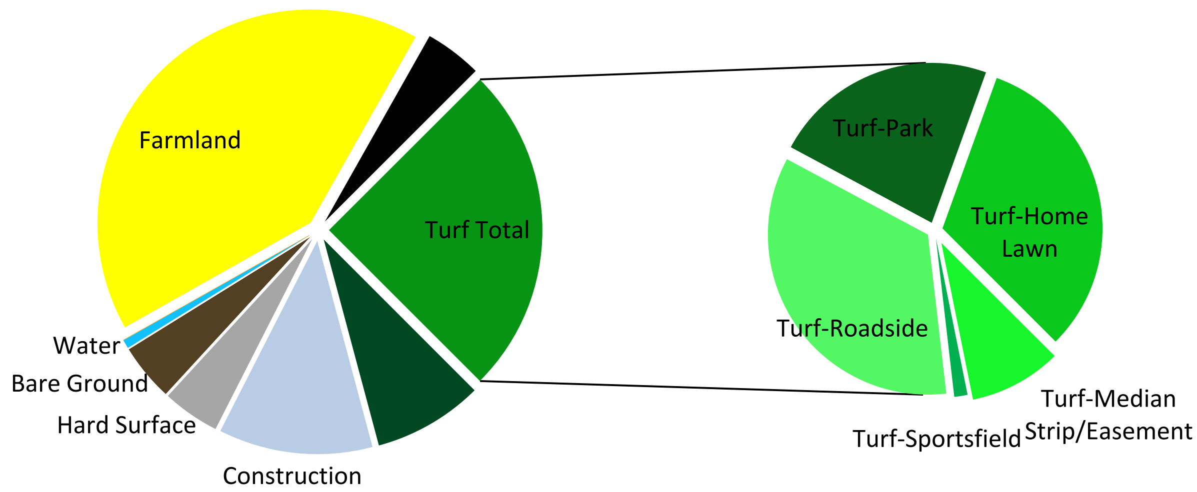
Figure 1. Brookfield Aerial Map

Figure 2. Brookfield Aerial Photograph

Cover Class	Cover (%)
Greenlife	8.33
Construction	11.67
Hard Surface	4.33
Bare Ground	4.33
Water	0.67
Bushland	0.00
Farm Land	41.33
Road	4.33
Turf-Home Lawn	8.00
Turf-Park	5.67
Turf-Sportsfield	0.33
Turf - Median Strip/Easement	2.33
Turf-Roadside	8.67
Turf TOTAL	25.00

Brookfield is in the local government area of Shire of Melton. In the 2011 Census of Population and Housing, the population of Brookfield stood at 6,104 people, with a median age of 31 years. Brookfield household income is close to the Australian average, with a median weekly household income of $1,377, compared with $1,234 in Australia. The total area of the suburb is 10.22km^2 which means that the population density is 5.97 people per hectare.

Percentage Cover in Brookfield



Suburb Case File: Bacchus Marsh

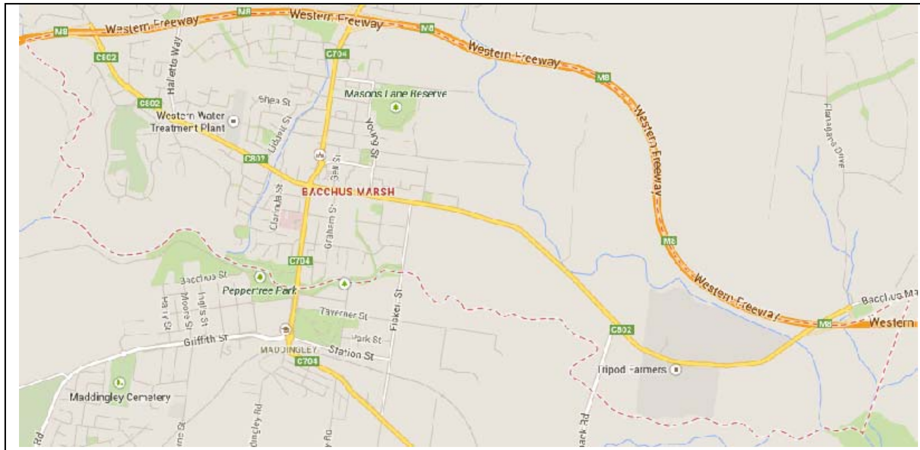
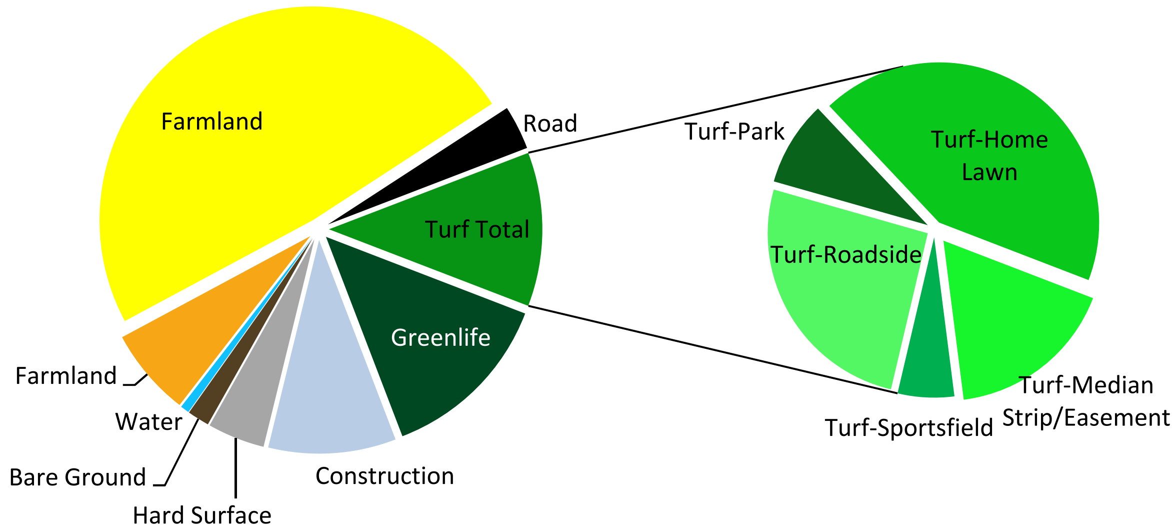


Figure 1. Bacchus Marsh Aerial Map	**Figure 2.** Bacchus Marsh Aerial Photograph

Cover Class	Cover (%)
Greenlife	13.33
Construction	9.67
Hard Surface	4.33
Bare Ground	1.67
Water	0.67
Bushland	6.67
Farm Land	48.67
Road	3.33
Turf-Home Lawn	5.00
Turf-Park	1.00
Turf-Sportsfield	0.67
Turf - Median Strip/Easement	2.00
Turf-Roadside	3.00
Turf TOTAL	11.67

Bacchus Marsh is in the local government area of the Shire of Moorabool. In the 2011 Census of Population and Housing, the population of Bacchus Marsh stood at 5,760 people, with a median age of 41 years. Bacchus Marsh household income is lower than the Australian average, with a median weekly household income of $972, compared with $1,234 in Australia. The total area of the suburb is 11.36km^2 which means that the population density is 5.07 people per hectare.

Percentage Cover in Bacchus Marsh



Suburb Case File: Brunswick East

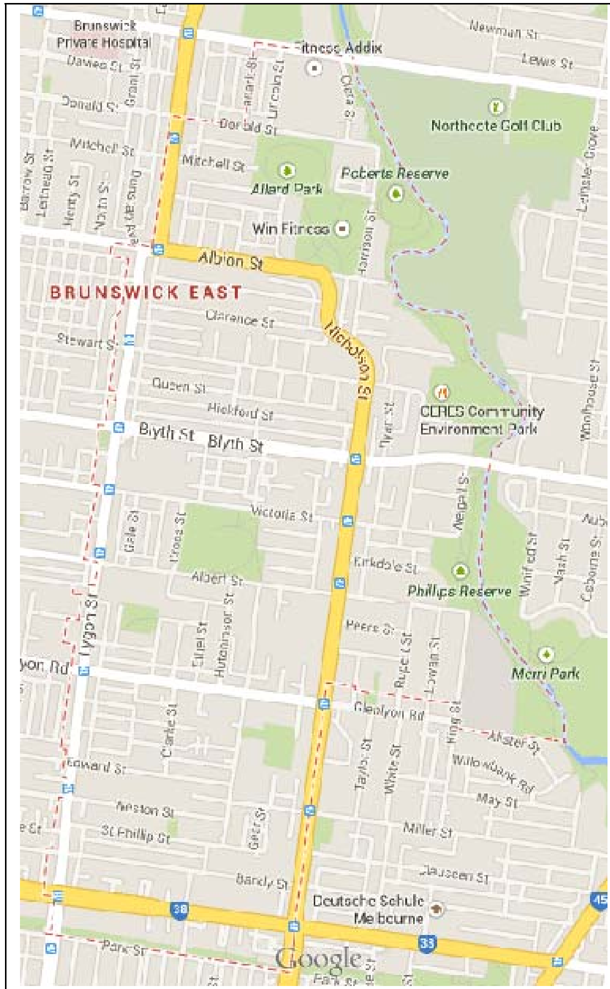


Figure 1. Brunswick East Aerial Map

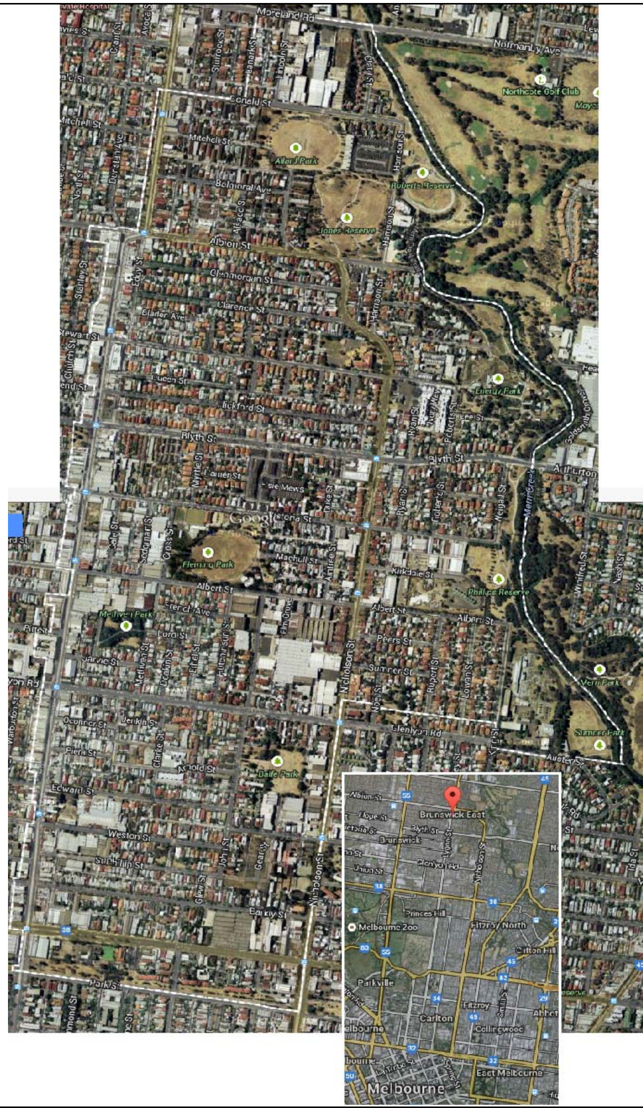
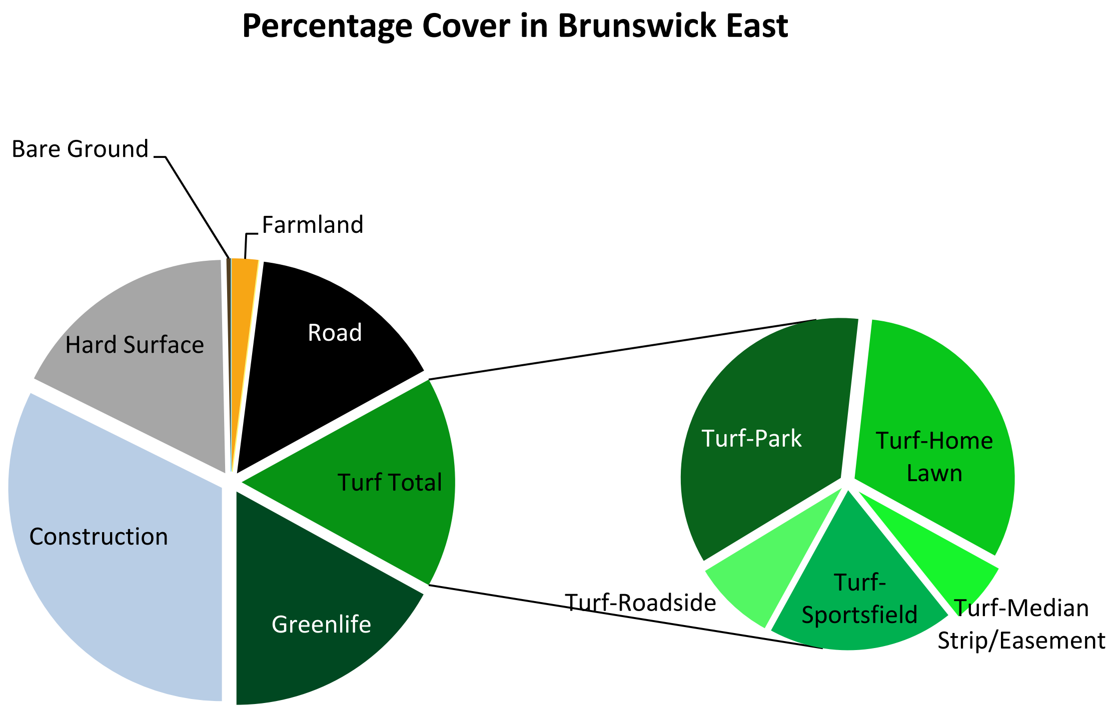


Figure 2. Brunswick Easts Aerial Photograph

Cover Class	Cover (%)
Greenlife	17.00
Construction	32.33
Hard Surface	17.33
Bare Ground	0.33
Water	0.00
Bushland	2.00
Farm Land	0.00
Road	15.00
Turf-Home Lawn	5.00
Turf-Park	5.67
Turf-Sportsfield	3.00
Turf - Median Strip/Easement	1.00
Turf-Roadside	1.33
Turf TOTAL	16.00

Brunswick East is in the local government area of the City of Moreland. In the 2011 Census of Population and Housing, the population of Brunswick East stood at 8,476 people, with a median age of 33 years. Brunswick East's household income is slightly higher than the Australian average, with a median weekly household income of $1,468, compared with $1,234 in Australia. The total area of the suburb is 2.22km^2 which means that the population density is 38.18 people per hectare.



Suburb Case File: Reservoir

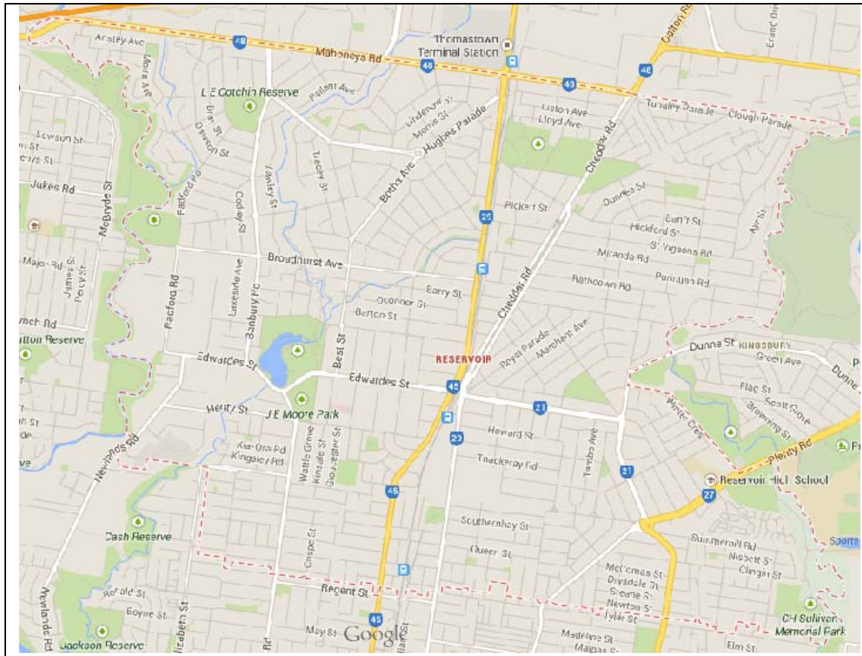


Figure 1. Reservoir Aerial Map

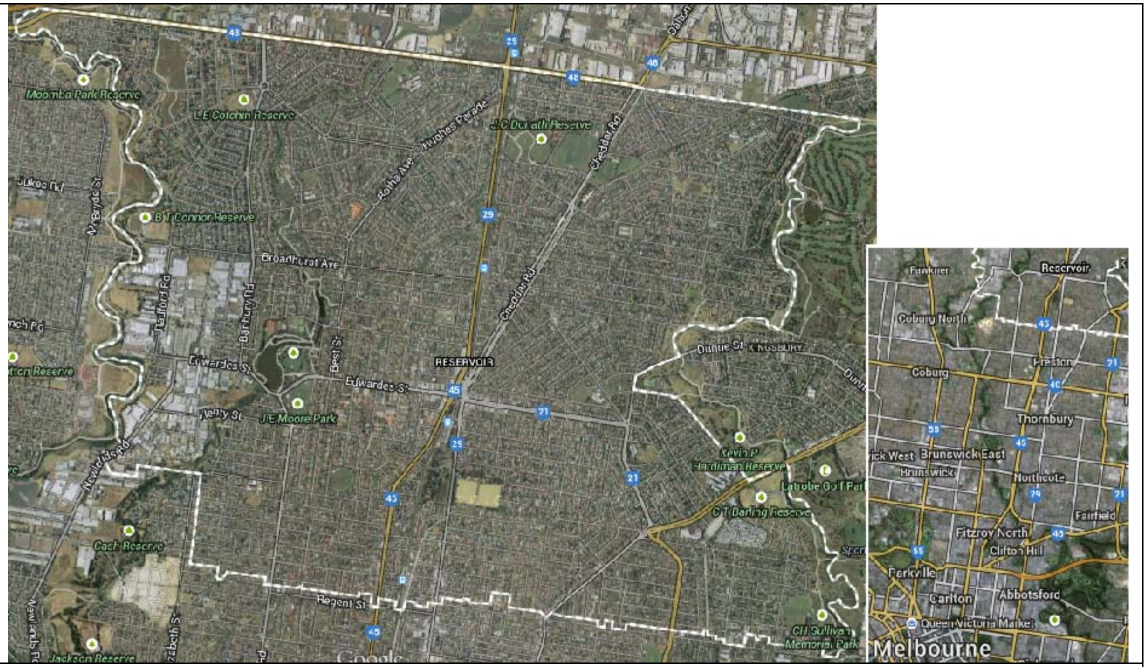
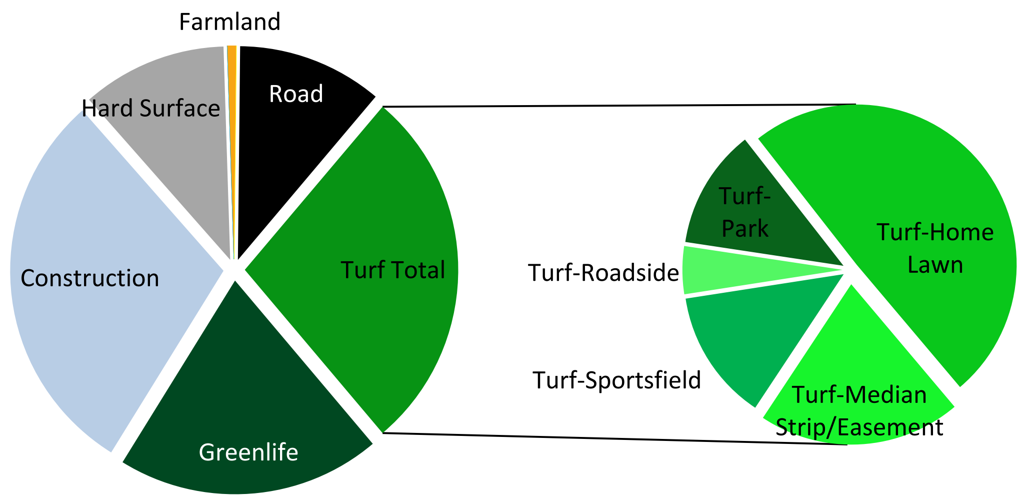


Figure 2. Reservoir Aerial Photograph

Cover Class	Cover (%)
Greenlife	20.00
Construction	29.67
Hard Surface	11.00
Bare Ground	0.00
Water	0.00
Bushland	0.67
Farm Land	0.00
Road	11.00
Turf-Home Lawn	13.67
Turf-Park	3.33
Turf-Sportsfield	3.67
Turf - Median Strip/Easement	5.67
Turf-Roadside	1.33
Turf TOTAL	27.67

Reservoir is in the local government area of City of Darebin. In the 2011 Census of Population and Housing, the population of Reservoir stood at 47,637 people, with a median age of 38 years. Reservoir's household income is lower than the Australian average, with a median weekly household income of $972, compared with $1,234 in Australia. The total area of the suburb is 18.88km^2 which means that the population density is 25.23 people per hectare.

Percentage Cover in Reservoir



Suburb Case File: Thomastown

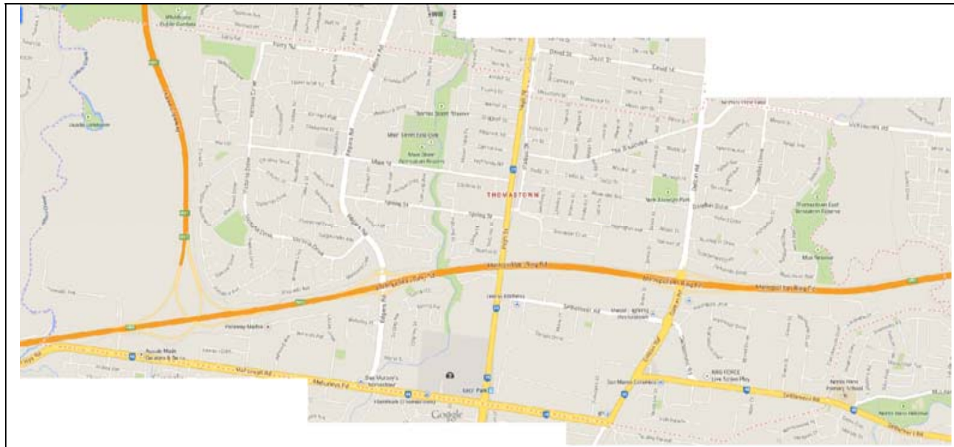
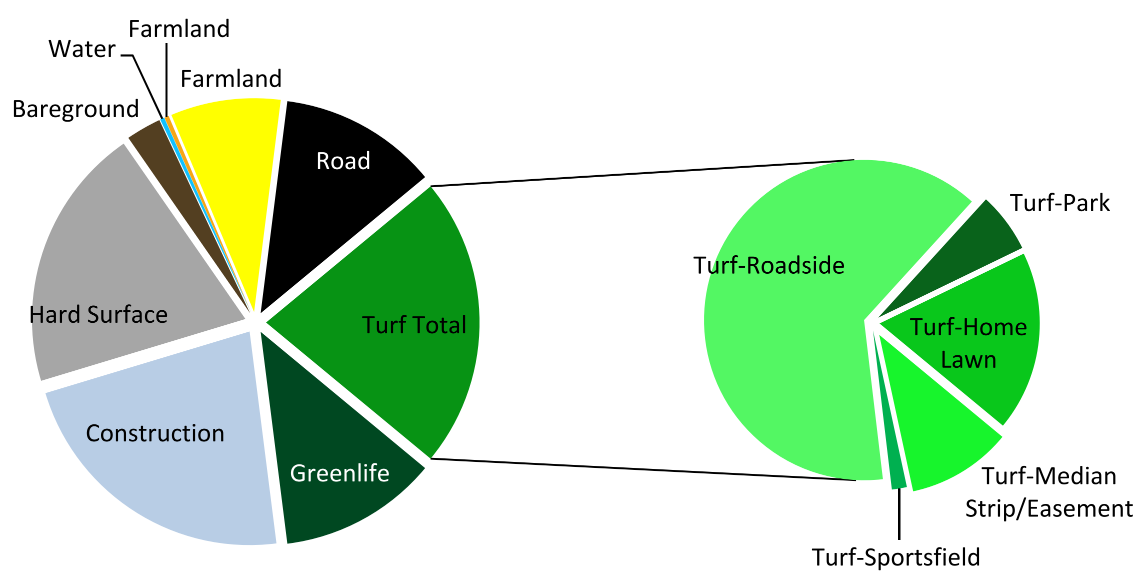


Figure 1. Thomastown Aerial Map	**Figure 2.** Thomastown Aerial Photograph

Cover Class	Cover (%)
Greenlife	12.00
Construction	22.33
Hard Surface	20.00
Bare Ground	2.67
Water	0.33
Bushland	0.33
Farm Land	8.33
Road	12.00
Turf-Home Lawn	4.00
Turf-Park	1.33
Turf-Sportsfield	0.33
Turf - Median Strip/Easement	2.33
Turf-Roadside	14.00
Turf TOTAL	22.00

Thomastown is in the local government area of City of Whittlesea. In the 2011 Census of Population and Housing, the population of Thomastown stood at 20,331 people, with a median age of 38 years. Thomastown's household income is lower than the Australian average, with a median weekly household income of $900, compared with $1,234 in Australia. The total area of the suburb is 14.85km^2 which means that the population density is 13.69 people per hectare.

Percentage Cover in Thomastown



Suburb Case File: Epping

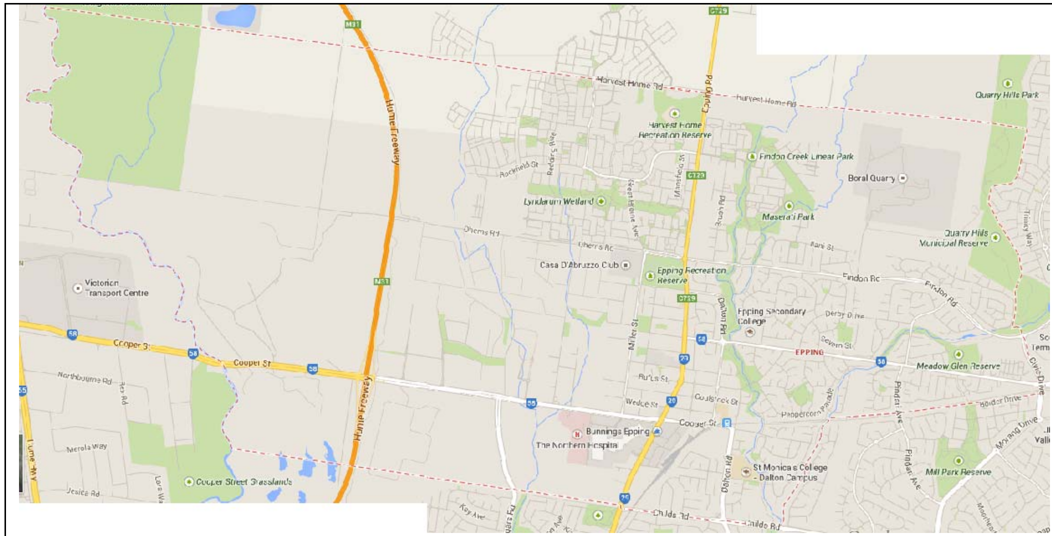


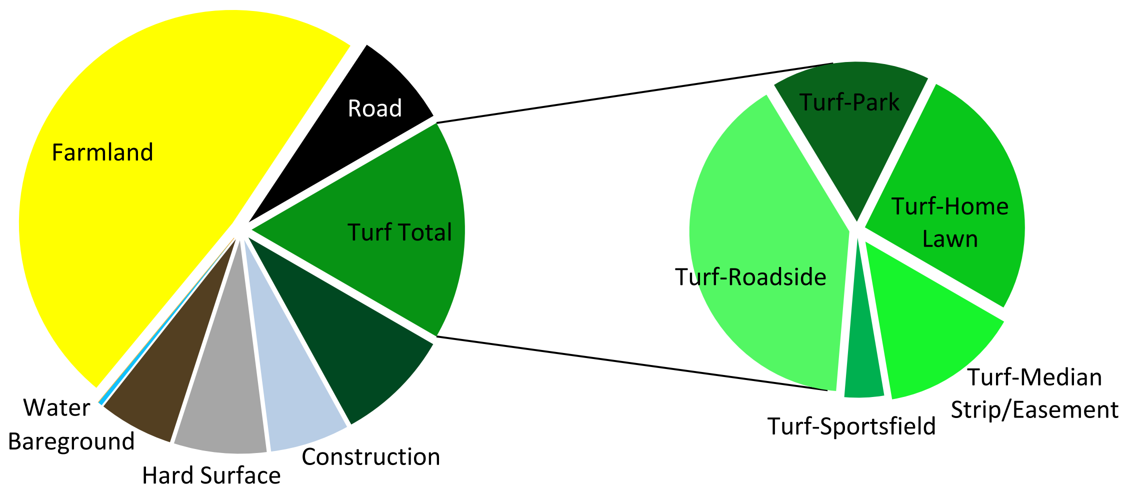
Figure 1. Epping Aerial Map

Figure 2. Epping Aerial Photograph

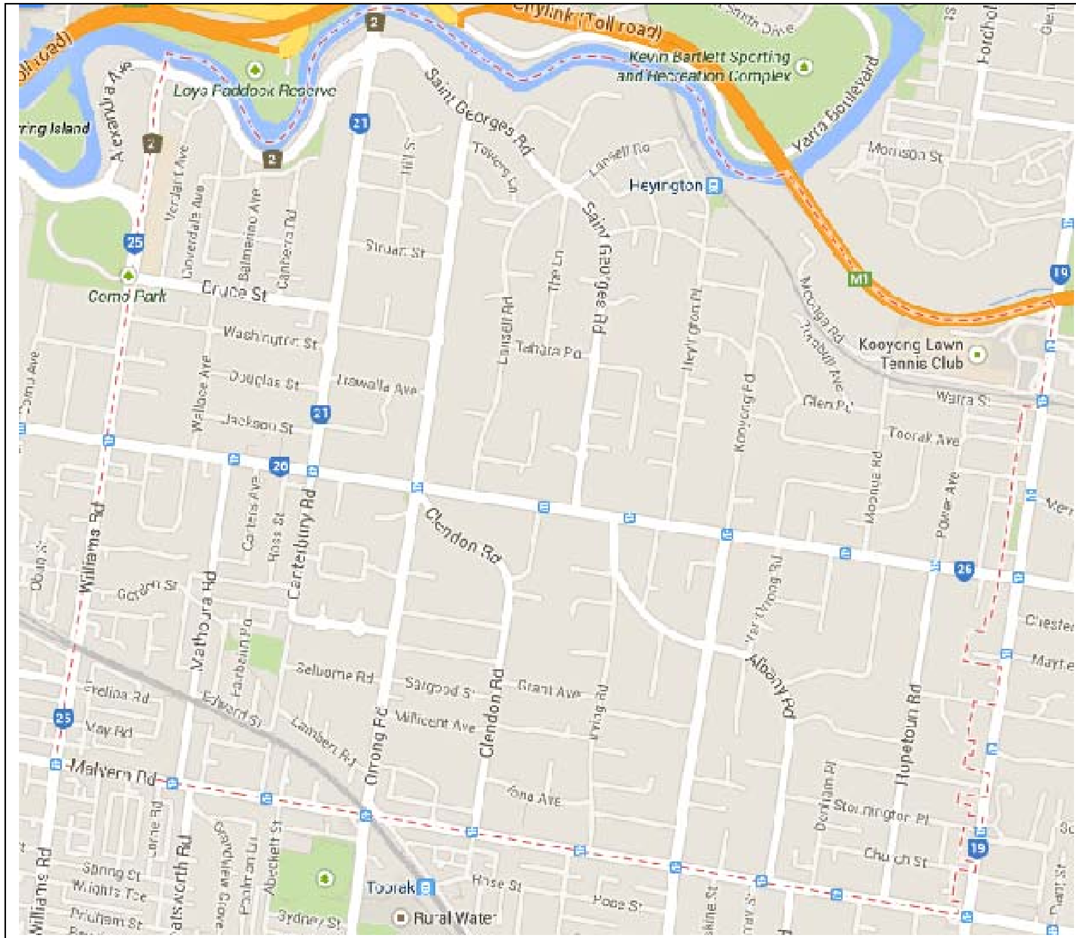
Cover Class	Cover (%)
Greenlife	8.67
Construction	6.00
Hard Surface	7.00
Bare Ground	5.67
Water	0.33
Bushland	0.00
Farm Land	48.33
Road	7.33
Turf-Home Lawn	4.33
Turf-Park	2.67
Turf-Sportsfield	0.67
Turf - Median Strip/Easement	2.33
Turf-Roadside	6.67
Turf TOTAL	16.67

Epping is in the local government area of City of Whittlesea. In the 2011 Census of Population and Housing, the population of Epping stood at 26,346 people, with a median age of 32 years. Epping's household income is similar to the Australian average, with a median weekly household income of $1,283 compared with $1,234 in Australia. The total area of the suburb is 33.71km^2 which means that the population density is 7.82 people per hectare.

Percentage Cover in Epping



Suburb Case File: Toorak



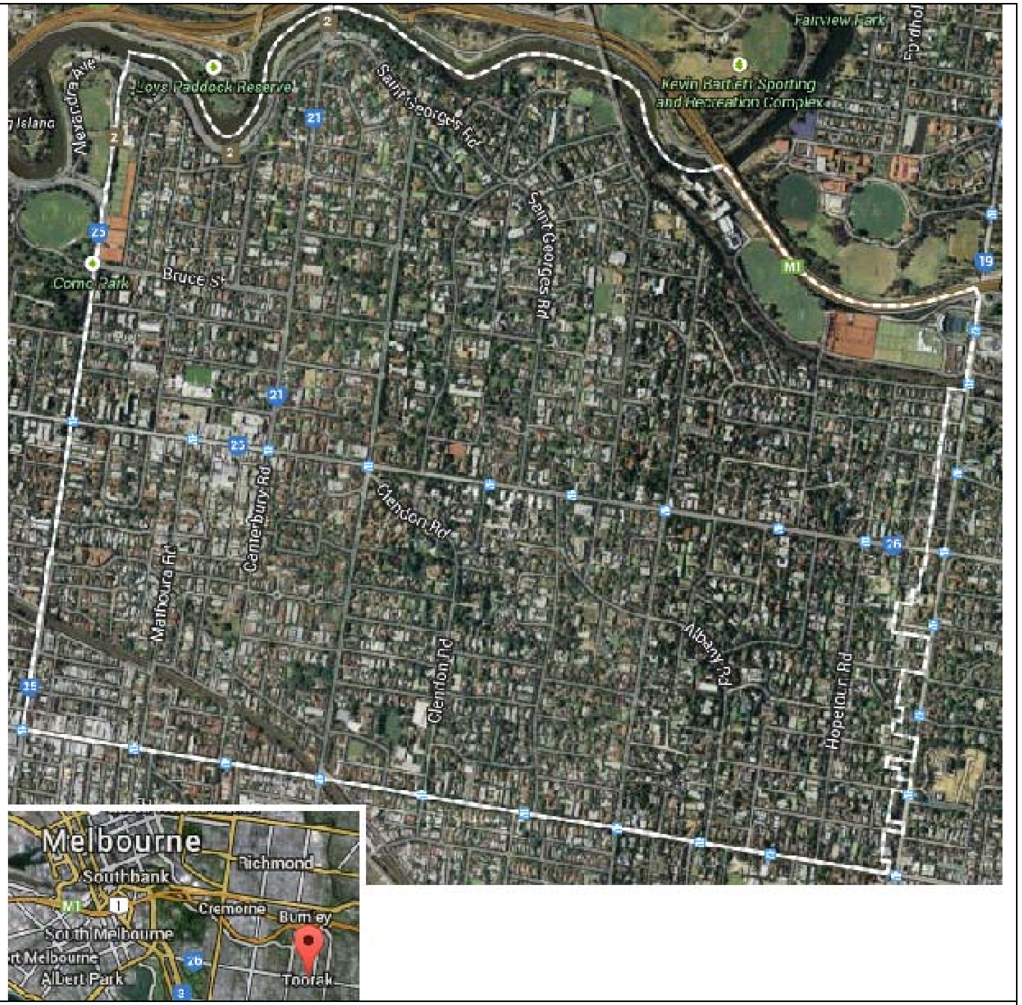


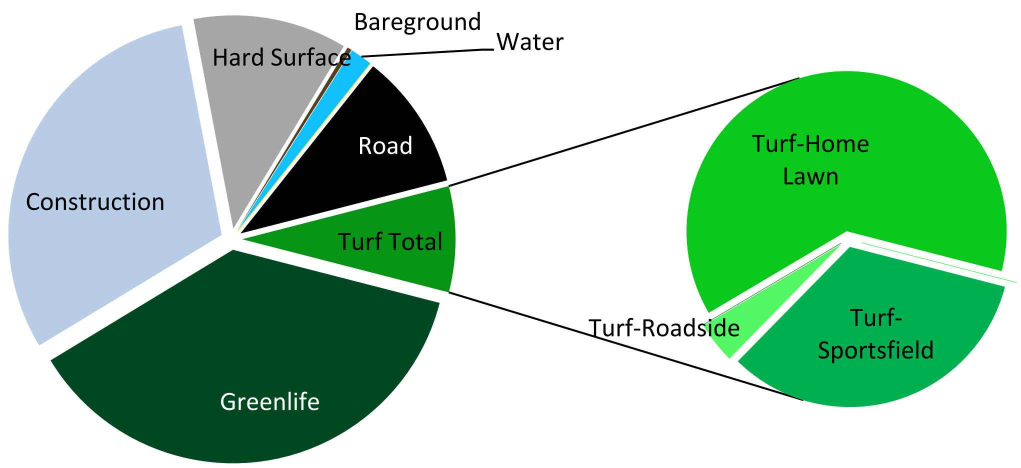
Figure 1. Toorak Aerial Map

Figure 2. Toorak Aerial Photograph

Cover Class	Cover (%)
Greenlife	37.33
Construction	30.67
Hard Surface	11.67
Bare Ground	0.33
Water	1.67
Bushland	0.00
Farm Land	0.00
Road	10.33
Turf-Home Lawn	5.00
Turf-Park	0.00
Turf-Sportsfield	2.67
Turf - Median Strip/Easement	0.00
Turf-Roadside	0.33
Turf TOTAL	8.00

Toorak is in the local government area of City of Stonnington. In the 2011 Census of Population and Housing, the population of Toorak stood at 12,871 people, with a median age of 43 years. Epping's household income is higher than the Australian average, with a median weekly household income of $1,977 compared with $1,234 in Australia. The total area of the suburb is 4.29km^2 which means that the population density is 30 people per hectare.

Percentage Cover in Toorak



Suburb Case File: Malvern East

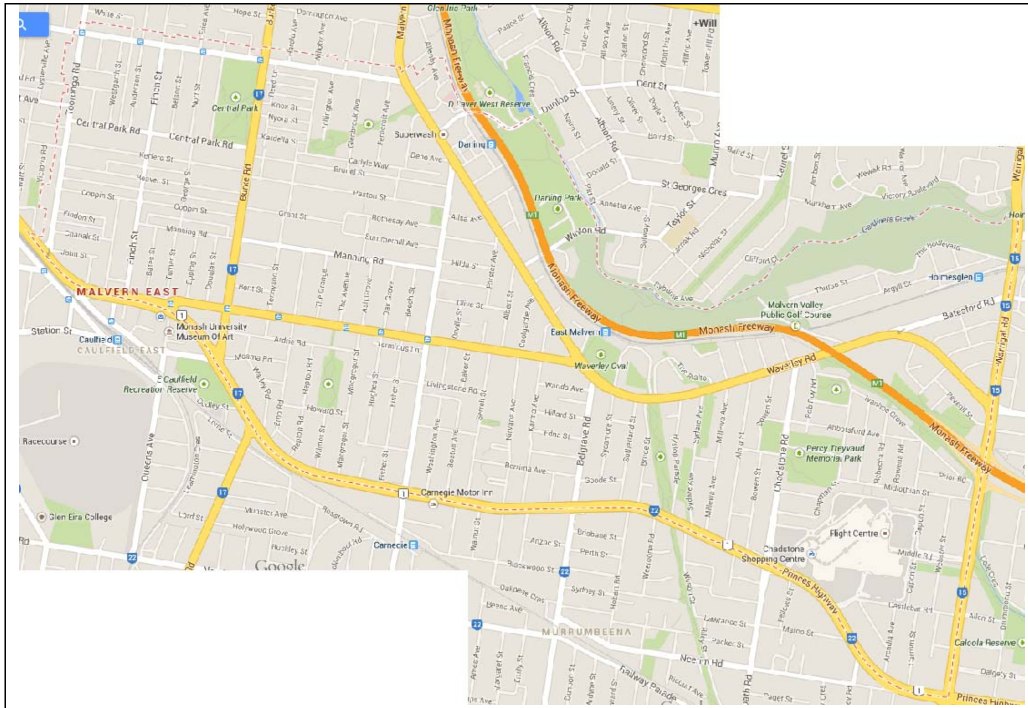


Figure 1. Malvern East Aerial Map

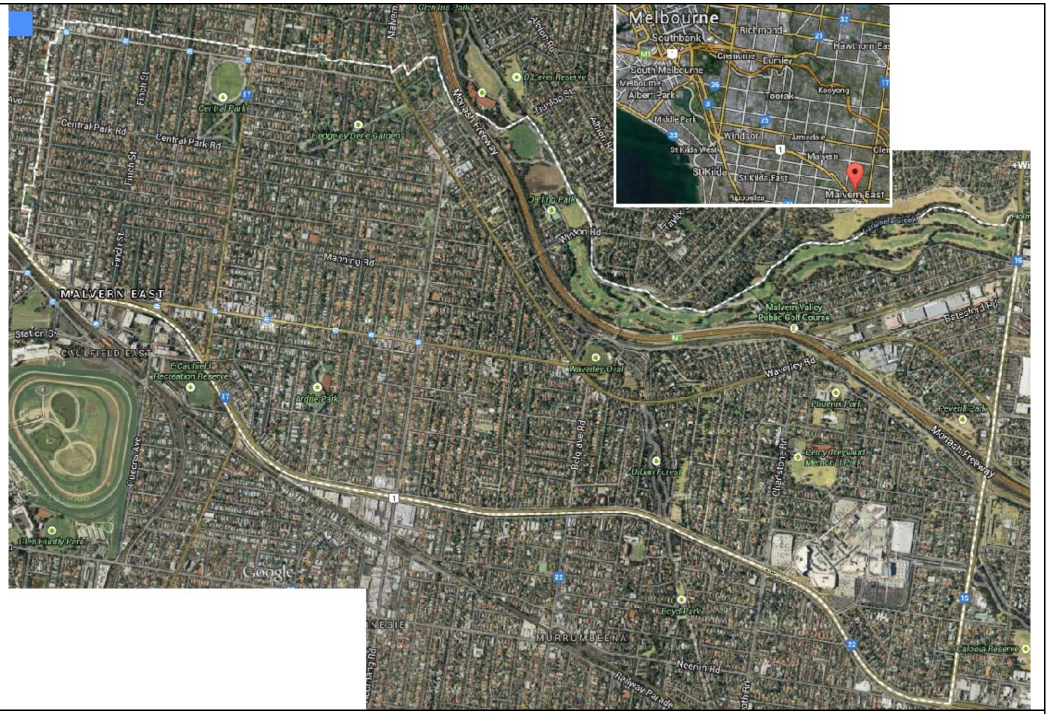
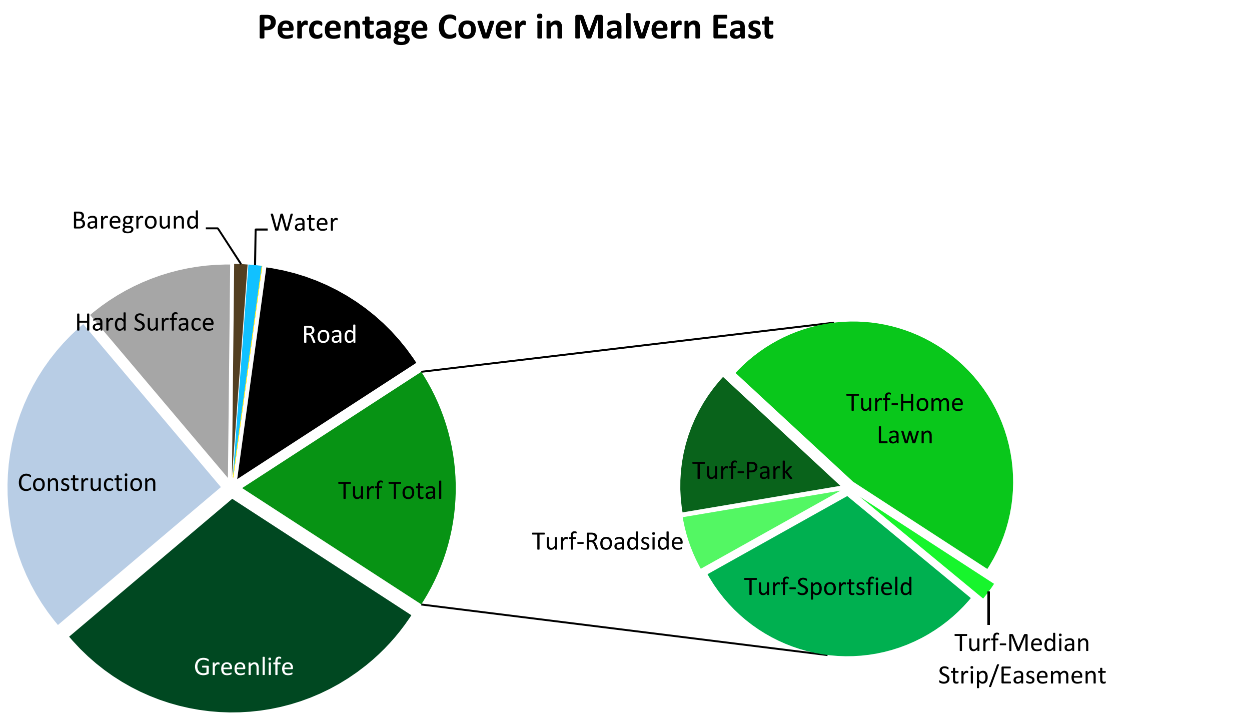


Figure 2. Malvern East Aerial Photograph

Cover Class	Cover (%)
Greenlife	29.67
Construction	25.00
Hard Surface	11.33
Bare Ground	1.00
Water	1.00
Bushland	0.00
Farm Land	0.00
Road	13.67
Turf-Home Lawn	8.67
Turf-Park	2.67
Turf-Sportsfield	5.67
Turf - Median Strip/Easement	0.33
Turf-Roadside	1.00
Turf TOTAL	18.33

Malvern East is in the local government area of City of Stonnington. In the 2011 Census of Population and Housing, the population of Malvern East stood at 20,066 people, with a median age of 43 years. Malvern East9's household income is higher than the Australian average, with a median weekly household income of $1,715 compared with $1,234 in Australia. The total area of the suburb is 7.78km^2 which means that the population density is 25.79 people per hectare.



Suburb Case File: Oakleigh

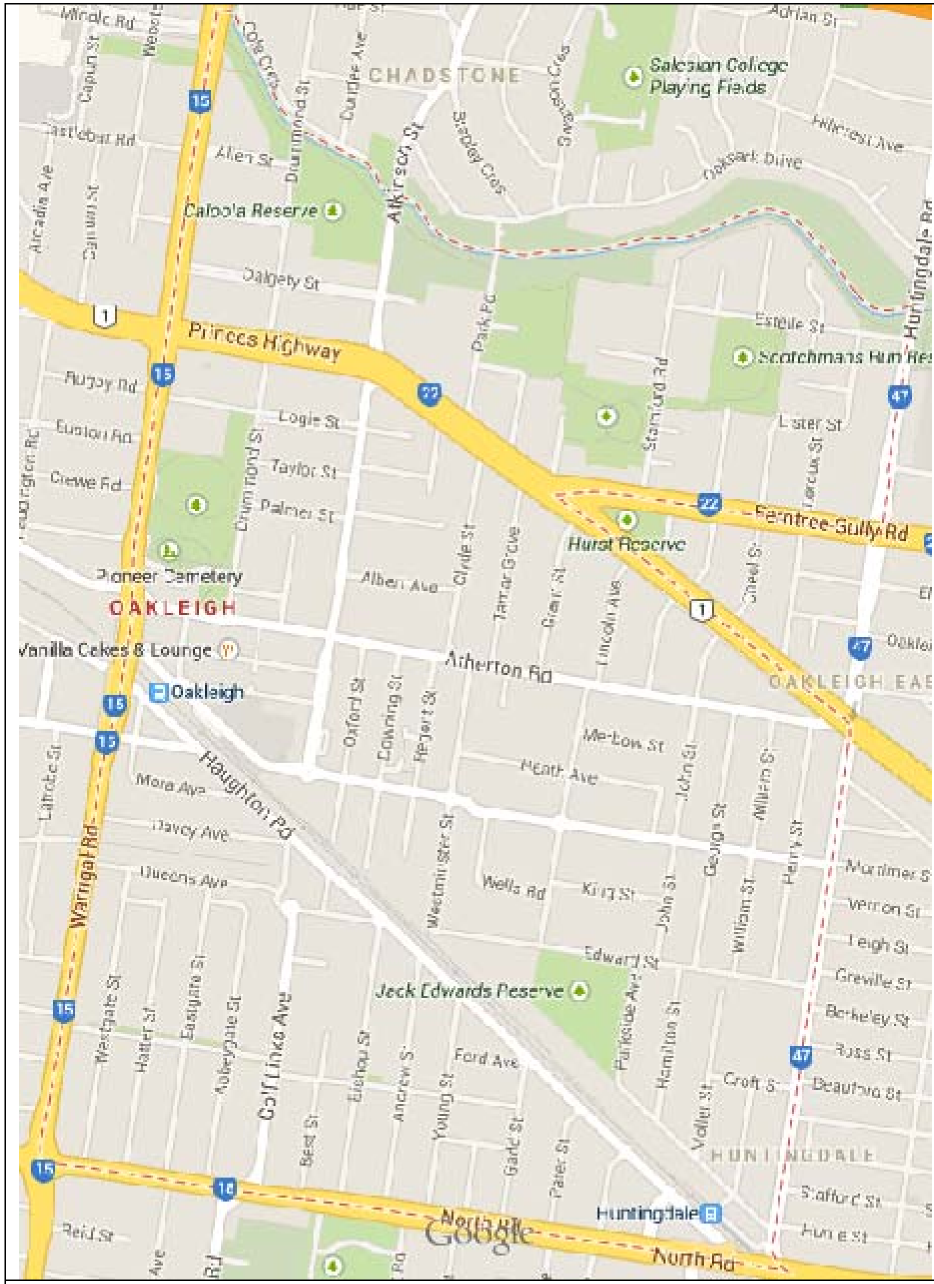


Figure 1. Oakleigh East Aerial Map

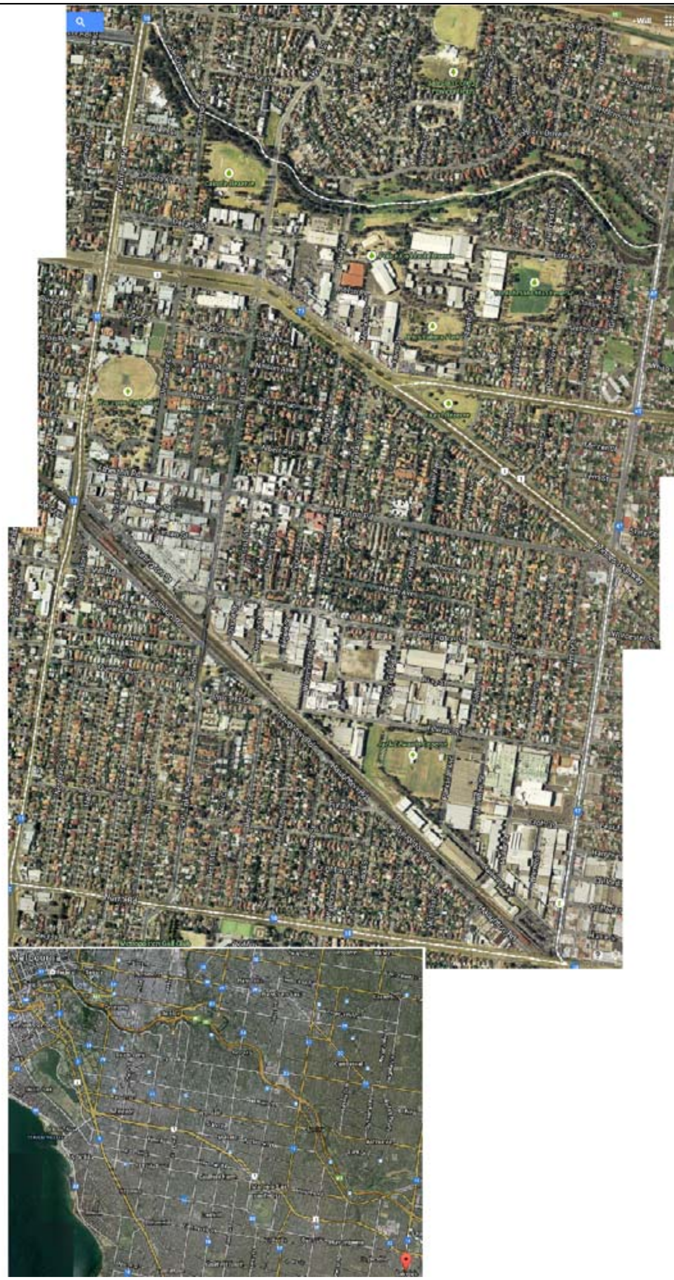
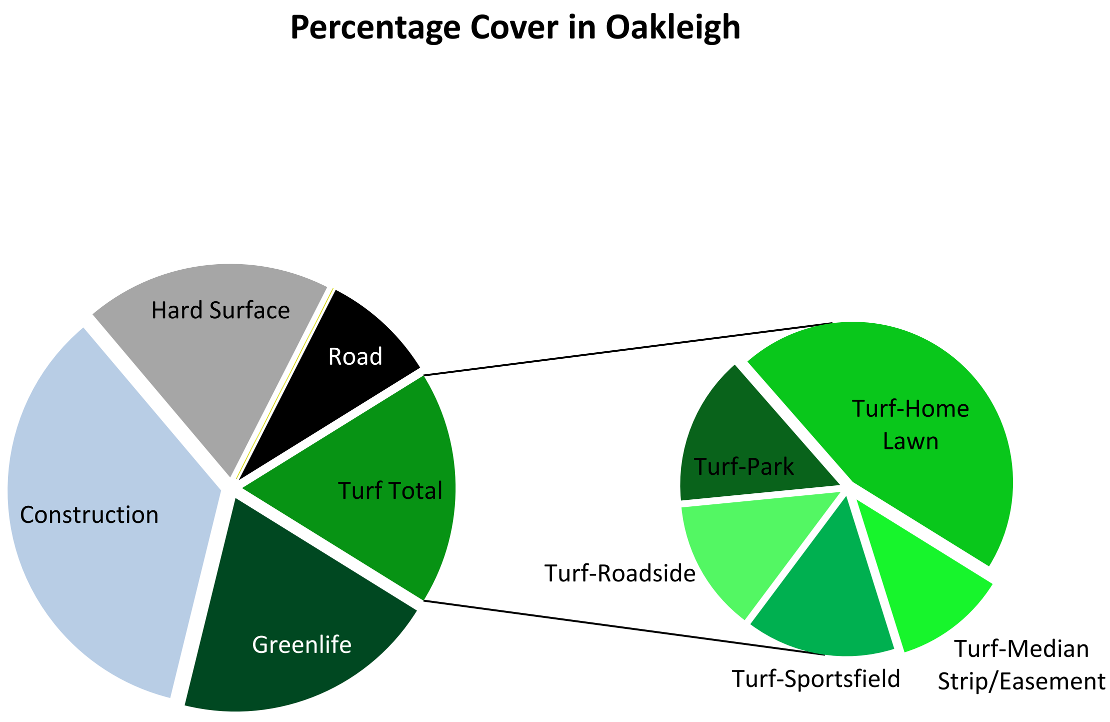


Figure 2. Oakleigh Aerial Photograph

Cover Class	Cover (%)
Greenlife	20.00
Construction	35.00
Hard Surface	18.67
Bare Ground	0.00
Water	0.00
Bushland	0.00
Farm Land	0.00
Road	8.67
Turf-Home Lawn	8.00
Turf-Park	2.67
Turf-Sportsfield	2.67
Turf - Median Strip/Easement	2.00
Turf-Roadside	2.33
Turf TOTAL	17.67

Oakleigh is in the local government area of City of Stonnington. In the 2011 Census of Population and Housing, the population of Oakleigh stood at 7,535 people, with a median age of 43 years. Epping's household income is slightly higher than the Australian average, with a median weekly household income of $1,393 compared with $1,234 in Australia. The total area of the suburb is 3.51 km^2 which means that the population density is 21.47 people per hectare.



Suburb Case File: Clayton

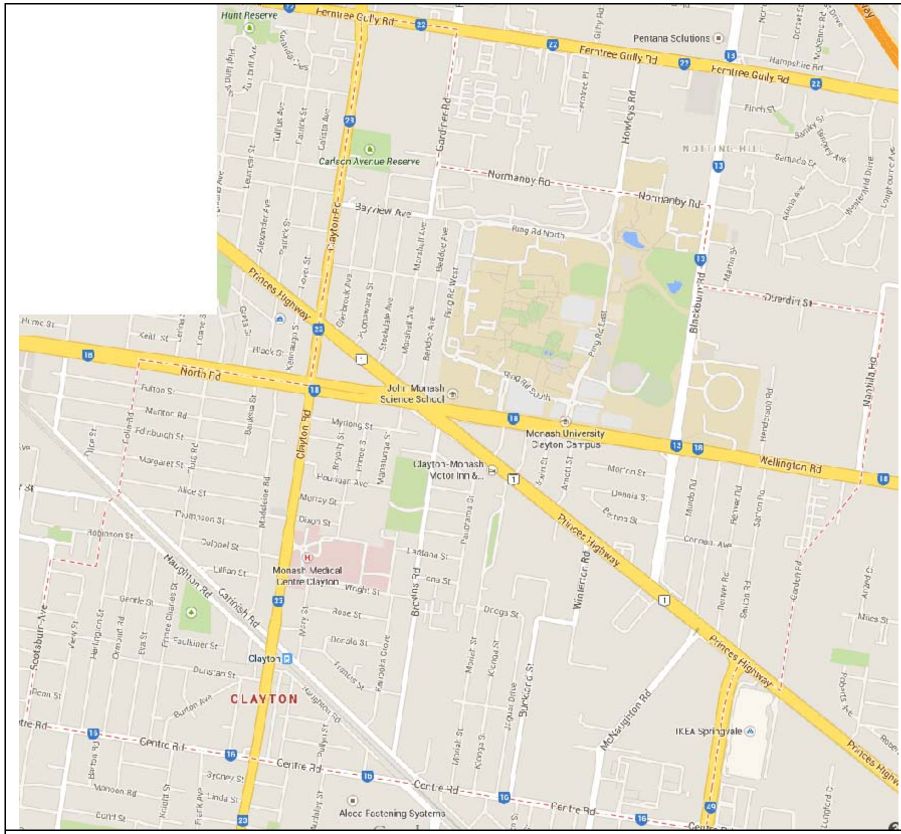


Figure 1. Clayton Aerial Map

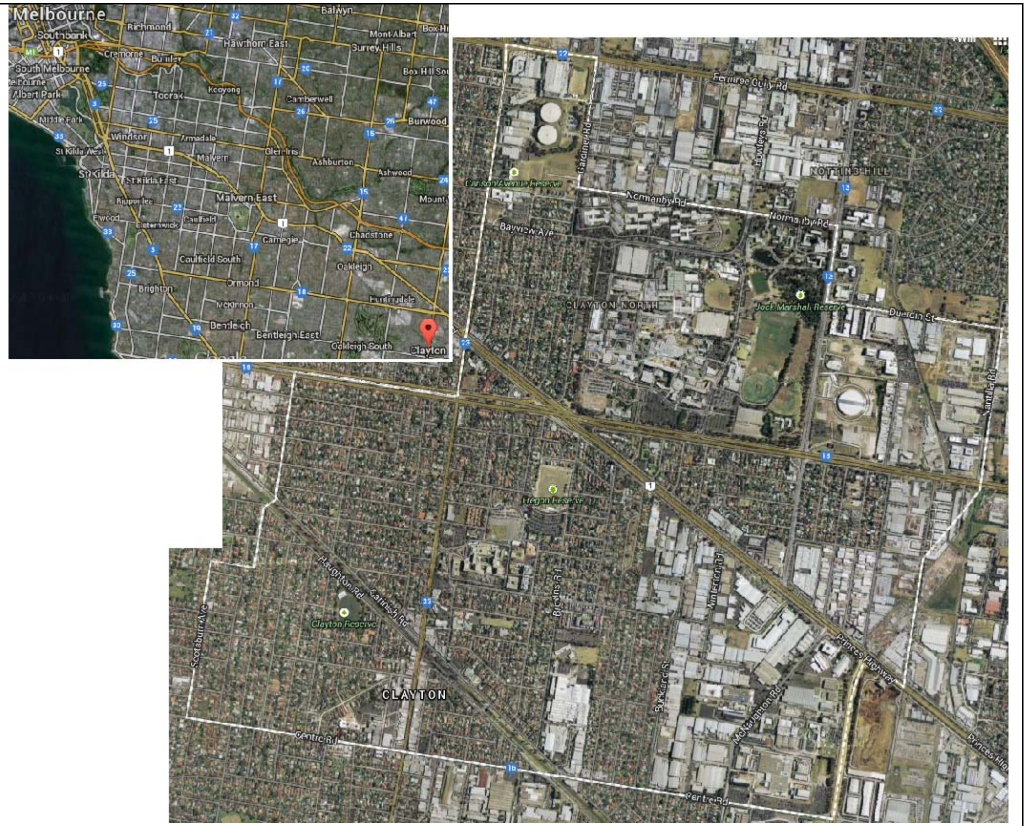
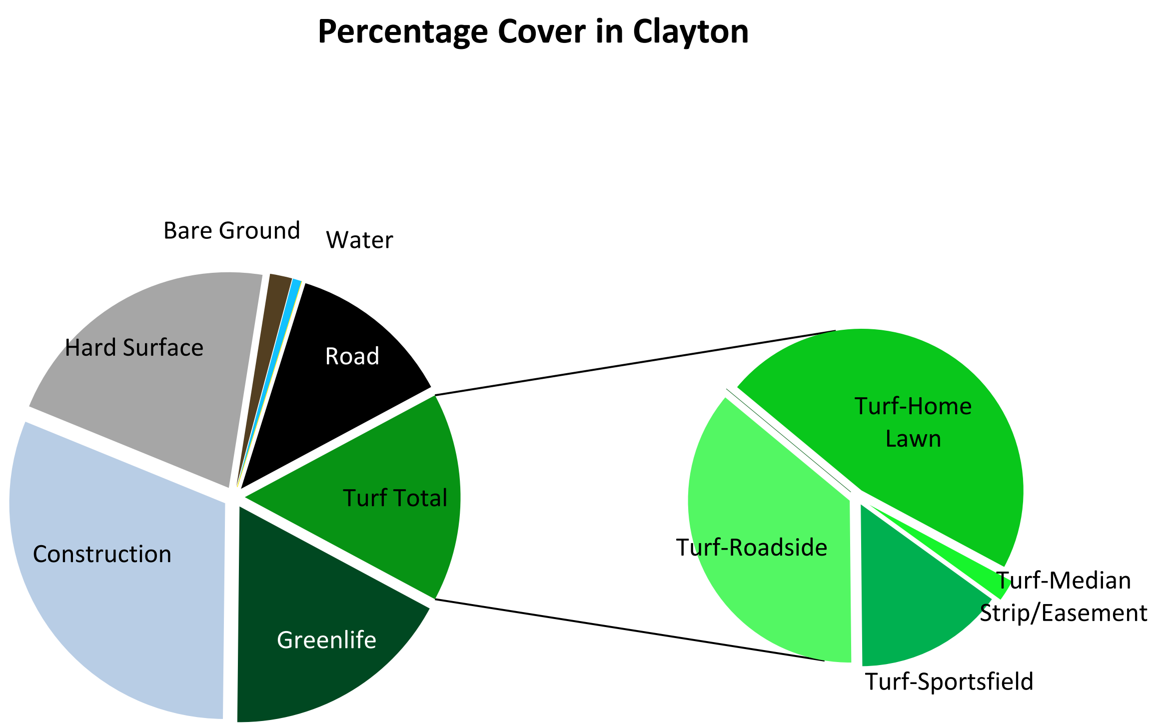


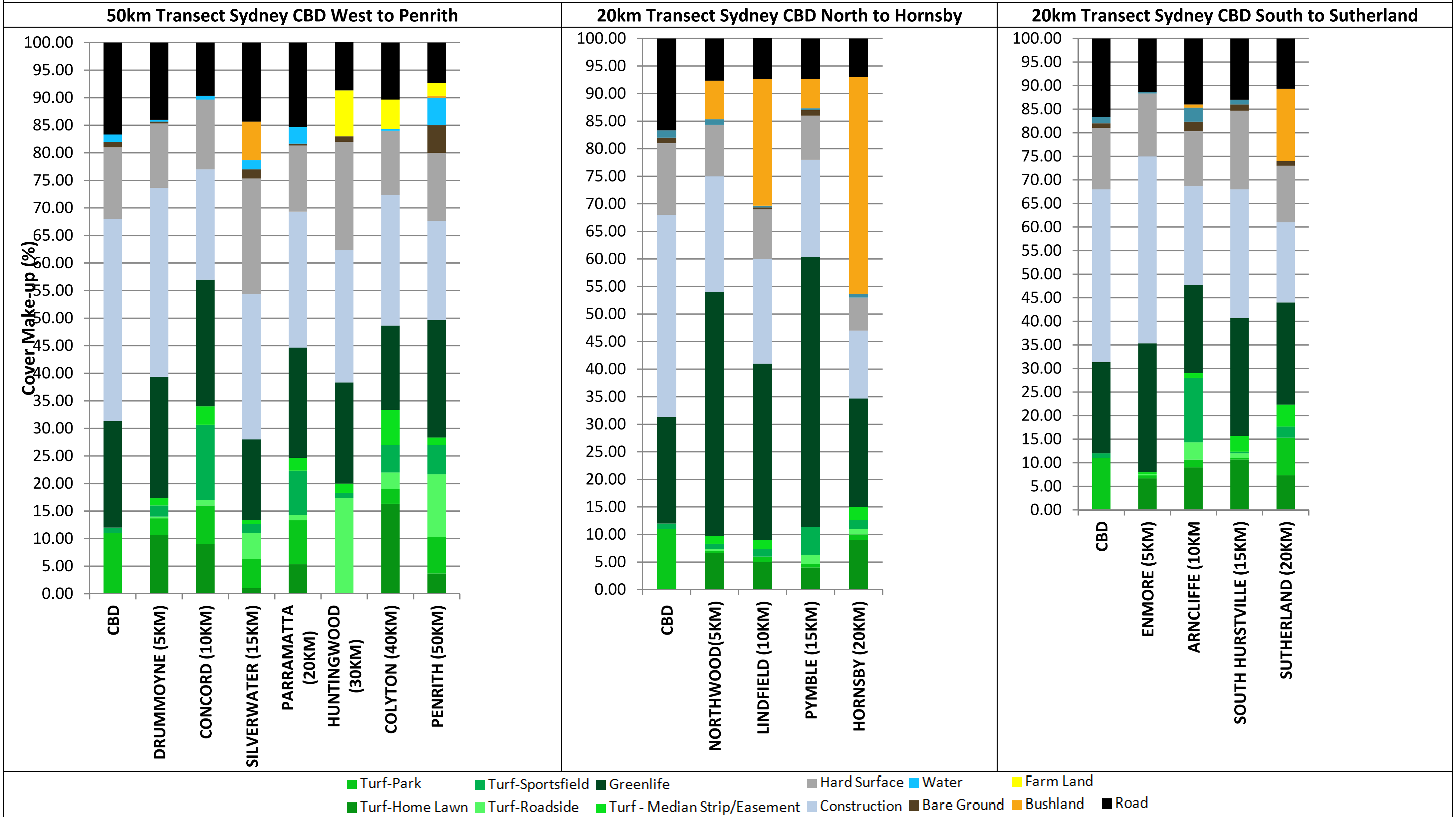
Figure 2. Clayton Aerial Photograph

Cover Class	Cover (%)
Greenlife	17.33
Construction	31.00
Hard Surface	21.33
Bare Ground	1.67
Water	0.67
Bushland	0.00
Farm Land	0.00
Road	12.33
Turf-Home Lawn	7.33
Turf-Park	0.00
Turf-Sportsfield	2.33
Turf - Median Strip/Easement	0.33
Turf-Roadside	5.67
Turf TOTAL	15.67

Clayton is in the local government area of the City of Monash. In the 2011 Census of Population and Housing, the population of Clayton stood at 15,543 people, with a median age of 43 years. Clayton's household income is lower than the Australian average, with a median weekly household income of $953 compared with $1,234 in Australia. The total area of the suburb is 7.79 km^2 which means that the population density is 19.95 people per hectare.



Appendix 7- Percentage cover make-up of each suburb along Transects 1, 2 and 3 for Sydney



Appendix 8 - Percentage cover make-up of each suburb along Transects 1, 2 and 3 for Melbourne