CAMPBELLTOWN
CITY COUNCIL

Canopy Cover Change in Campbelltown City Council

2006-2016

27 July 2018

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Canopy Cover Change in Campbelltown City Council, 2006-2016

A report prepared for Campbelltown City Council

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1. Campbelltown City Council trees (Photo by: Jenni Garden, 2018);

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Executive Summary

Green infrastructure is increasingly recognised and implemented as a key mechanism for improving the liveability, prosperity, and resilience of urban areas. In particular, trees – located in parks, public and private gardens, and lining streets and waterways – are valued for the multiple benefits they provide to people, wildlife, and the environment.

Despite the recognition of the multiple benefits offered by trees, barriers to increasing tree cover in urban areas persist, with urban development and in-fill being the most significant. Further compounding the issue is that local councils managing the “urban forest” are largely restricted to actions within public and council owned land. This is particularly problematic in Campbelltown given that the majority of land in the Council area is privately owned and managed.

Being able to measure and monitor changes (trends) in land cover, particularly tree canopy cover on public and private land will be important for informing decision-making, assessing the success of greening objectives and activity, and prioritising the type and location of activities to best promote desired outcomes.

Based on the findings from this project, the **headline trends in land cover between 2006 and 2016** are shown below. Percent tree (canopy), impervious, and plantable space cover are shown for each time period relative to the whole city area, private land area, and public land area (stars indicate a statistically significant change over time).

	Tree (canopy) cover		Impervious cover		Plantable space cover	
	2006	**2016**	**2006**	**2016**	**2006**	**2016**
Total city trends	25.19%	18.76% ☆	50.43%	56.62% ☆	21.71%	21.90%
Private land trends	14.38%	9.57% ☆	35.67%	40.19% ☆	15.29%	15.43%
Public land trends	10.81%	9.19%	14.76%	16.43%	6.43%	6.48%

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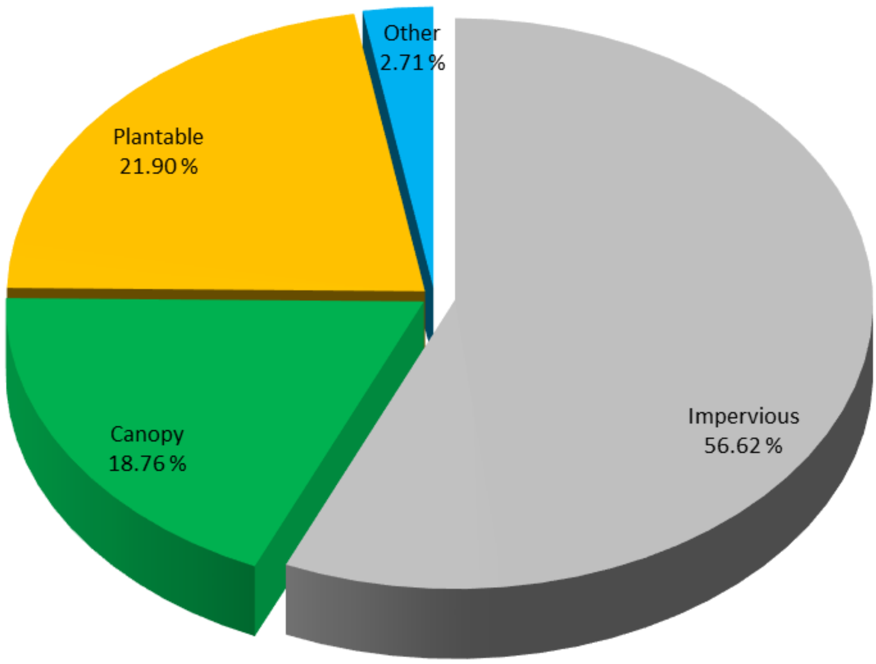
An assessment of current (2016) land cover within Campbelltown City Council was conducted using the i-Tree Canopy software. Land cover was assessed for all suburbs comprising the Council area. In each suburb, land cover was assessed in two time periods (2006 and 2016), and across private and public land tenures. Based on these assessments the key findings were as follows:

- current land cover across the City is dominated by impervious surfaces, followed by plantable space, tree canopy cover, and other land covers (e.g. water);
  - percent impervious cover is highest in Newton and lowest in Athelstone;
  - percent tree canopy cover is highest in Athelstone and lowest in Newton;
  - percent plantable space cover is highest in Athelstone and lowest in Newton;



- compared to 2006 cover levels, impervious cover has increased significantly across the City, tree canopy cover has decreased significantly, and plantable space has remained relatively unchanged;
- changes in land cover across the City are driven primarily by changes on private land;
- tenure-specific information can be valuable in refining the type and location of programs and activities, for example:
  - Athelstone currently provides the most plantable space opportunity for implementing Council planting programs, with this suburb containing the highest percent plantable space on public land; and
  - Campbelltown may be best targeted with community education and incentives programs, as this suburb provides the most plantable space opportunity on private land.

These findings show that tree canopy cover has been declining in Campbelltown City Council on all private land and most public land. Such declines present a major challenge for Council meeting future liveability, prosperity, and resilience targets, especially given projected rates and extents of on-going urban in-fill. Mitigating future tree loss and moving towards overall canopy cover gain across the City will require complimentary greening actions on public and private land.

The implications of on-going declining tree cover will be wide and varied, with substantial negative impacts on the liveability, prosperity, and long-term resilience of the City. Specific examples include:

- **lower air quality** (e.g. dust and pollutants), which will compromise human health and well-being;
- **hotter average day and night temperatures**, contributing further to the urban heat island effect;
- **decreased shading**, leading to lower use of parks and gardens and higher maintenance costs, as well as increased building cooling costs;
- **increased winds**, which will decrease air quality and the overall liveability and attractiveness of the City;
- **increase localised flooding**, which will directly impact infrastructure and communities and decrease water quality;
- **decreased biodiversity**, which will compromise the functioning of natural and dependent ecosystems; and
- **decreased amenity**, which will decrease property values, liveability, and local economic prosperity, and potentially increase crime rates.

The information derived from this assessment can be used to immediately inform a range of Council decision-making relating to, for example:

- what actions to take and which locations to target in order to achieve the best outcome for resources;
- how local policies and strategies may be amended in order to facilitate urban greening objectives; and
- future spatial analyses to help further refine priority activities and locations, such as planting programs targeted to benefit vulnerable members of the community living in thermal hotspots.

1 Introduction

Urban trees are widely recognised for the multiple benefits that they provide, for example to human health and well-being, environmental health, climate change adaptation, local economy, infrastructure maintenance, and real estate values. The benefits provided by healthy trees increase as they grow, making trees the only urban asset to appreciate in value over time. Accordingly, there is growing momentum by local governments to understand, maintain, and enhance their urban forests, including on public and private land.

Despite the recognition of the multiple benefits offered by trees, and the recent drive to increase canopy cover in urban areas, substantial barriers to increasing tree cover in urban areas persist, including:

- competition for space from opposing land-uses (e.g. residential in-fill development, sporting fields);
- the difficulty in valuing their worth as an urban asset, such as may be done for built infrastructure (e.g. roads, buildings); and
- community perception relating to trees often skewed towards trees being “dangerous”, “messy” or “inconvenient”.

Further compounding the issue is that local councils managing the “urban forest” are restricted to actions within public and council owned land. This is particularly problematic given that the majority of land in most metropolitan Council areas are privately owned and managed. Encouraging tree plantings on private land and eliciting support for additional plantings on public land will be important for achieving increases in tree (canopy) cover across local council areas.

The i-Tree Canopy software provides a user-friendly, repeatable way to measure and value urban trees. Though not all services provided by trees are able to be readily valued (e.g. benefits for biodiversity and human health), i-Tree assessments provide an initial baseline on which to build the business-case for increasing tree cover in urban areas and to examine drivers of land cover change and identify priority areas for action.

Campbelltown City Council undertook an initial baseline i-Tree Canopy assessment of land cover within each of their suburbs based on 2016 aerial imagery. Seed Consulting Services (Seed) was then engaged to assess land cover in 2006 and land cover change over time across the whole Council area, within each suburb, and across private versus public tenures.

1.1 City of Campbelltown overview

Campbelltown City Council (“Council”) covers a land area of approximately 29km^2 to the north-east of Adelaide City Council (Figure 1). It shares boundaries with five other local government areas: Burnside, Adelaide Hills, Tea Tree Gully, Port Adelaide Enfield, and Norwood, Payneham & St Peters. The River Torrens runs along its northern boundary, and much of its eastern boundary merges with the foothills of the Adelaide hills.

Since its proclamation of a City in 1960, the area has been heavily modified and is now comprised of the eight suburbs of: Athelstone, Campbelltown, Hectorville, Magill, Newton, Paradise, Rostrevor, and Tranmere (Table 1).

Table 1. Council's eight suburbs and their areas.

SUBURB	AREA (km^2)
Athelstone	7.58
Campbelltown	4.25
Hectorville	1.77
Magill	2.97
Newton	2.65
Paradise	4.37
Rostrevor	4.34
Tranmere	1.80

1.2 Objectives

The primary objective of this project was to investigate historical change in canopy cover on public and private land which can then be used to consider drivers of land cover change, establish a benchmark of tree canopy cover, and inform future decision-making regarding tree management, the efficacy of tree planting programs, and action prioritisation.

This report will:

- detail the methods used for the assessment;
- summarise key findings of land cover across the Council area and within each suburb in 2006 and 2016;
- summarise trends in land cover change across the Council area, within each suburb, and between public and private land; and
- provide recommendations for future priority actions with regard to maintaining and increasing canopy cover in the region.

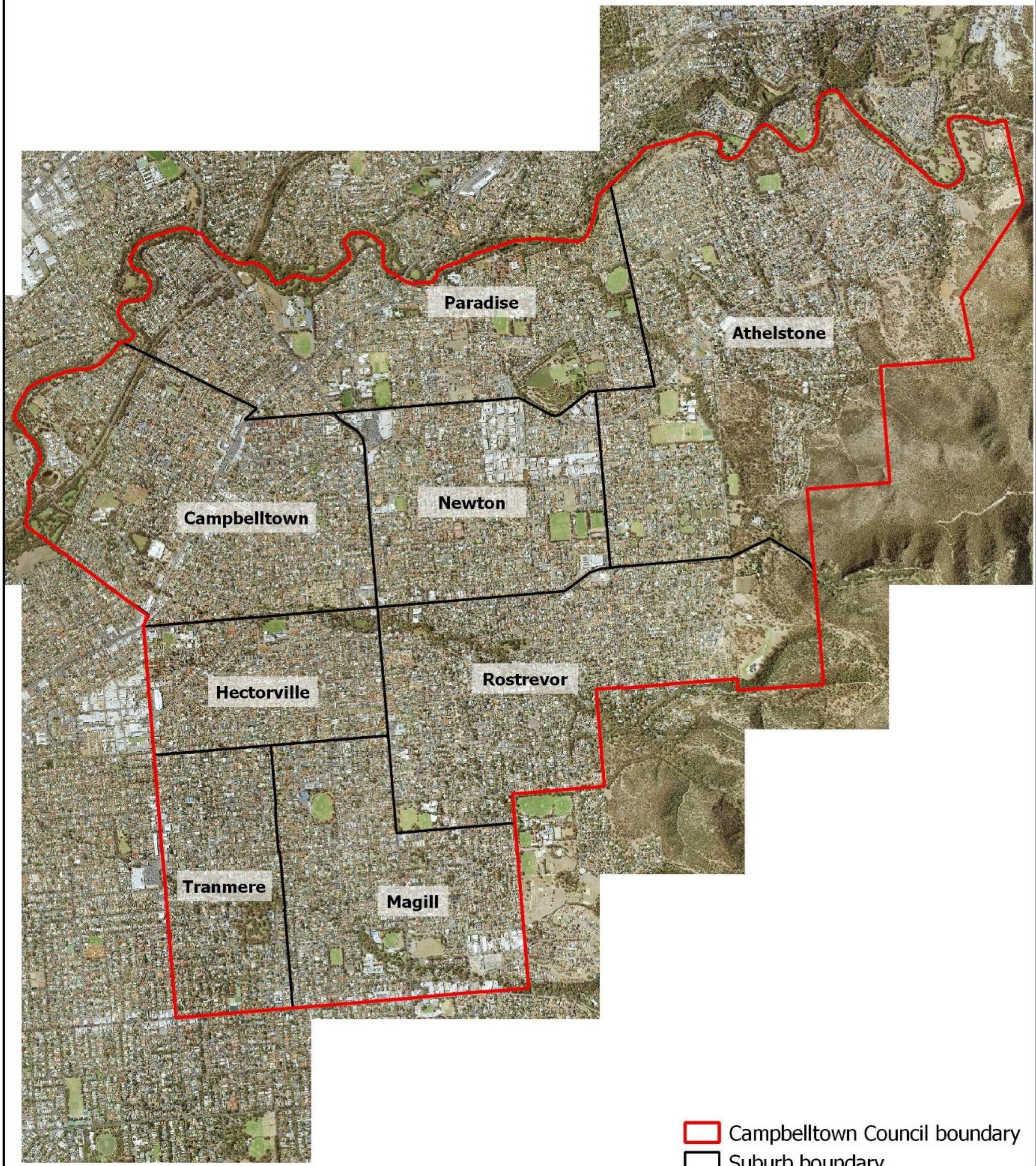


Figure 2. Campbelltown City Council and suburb boundaries.

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2 Method

2.1 Survey area and selection of points

All suburbs (Table 1, Figure 1) were assessed using the same approach. Council undertook the initial assessment of land cover for the year 2016 using the i-Tree Canopy software[1] which allows a user to readily, and statistically rigorously, classify land cover amounts within a user-defined area overlaid on Google Earth imagery. As each point is classified, i-Tree Canopy provides automated running statistical estimates for land cover categories of the estimate total area (km^2) and percent cover (%) within the study area, as well as an uncertainty estimate (i.e. standard error, SE). Accordingly, the more points that are classified, the lower the standard error and the more precise the estimated result should be. However, the more land-cover categories defined, the more points that need to be classified in order to achieve statistical stabilisation of estimates (Jacobs, et al., 2014).

For this project, Council assessed 250 points in each suburb except Athelstone, in which 350 points were assessed, giving a total of 2,100 points across the whole Council area. For each suburb, except Athelstone, this gave a minimum confidence interval of 6.2% at a 95% confidence level. Suburb points were collated to provide assessment across the whole Council area of 2,100 points which gave a 2.14% confidence interval at a 95% confidence level.

The way to relate these power analyses to the assessment outputs is, for example: based on the 2,100 points surveyed across the City of Campbelltown, if the assessment outputs estimate a canopy cover of 25% then we are at least 95% confident that the actual canopy cover across the city is between 19.76% and 30.24% (i.e. estimated output plus or minus the 5.24% confidence interval). To greatly improve on these confidence levels and intervals significantly more points would need to be surveyed. However, statistically and for the requirements of this project, this level of power is considered acceptable.

[1] https://canopy.itreetools.org/

2.2 Land cover categories

Nine land cover categories were used to assess each of the points. These categories were defined by Council and were based on similar assessments conducted for other local Council areas in the region (Table 2; Plate 1).

Table 2. Land cover categories used for i-Tree Canopy analysis. Categories used in this analysis were consistently applied irrespective of tenure (i.e. public or private land).

LAND COVER CATEGORY	DESCRIPTION
Impervious	
Building impervious	A building or permanent structure.
Impervious other	Building envelope, carparks (concrete), driveways, footpaths, gutters, paving, tennis courts, pools etc.
Impervious road	A sealed road.
Canopy	
Tree impervious	Generally where a tree is directly adjacent to at least 2 impervious surfaces such as road, building, footpath, carpark, etc.
Tree other	Trees that do not fit the description of "Tree impervious".
Plantable space	
Bare ground	Non-vegetated pervious surface.
Grass other	Grass areas that are not "Grass sporting". Includes small shrubs.
Other (unplantable) space	
Grass sporting	Grass areas used primarily for sporting purposes, including school ovals and golf courses. Also includes grass areas associated with airports.
Water	Aquatic or marine water body; does not include pools.

Plate 1. Aerial images showing randomly allocated points (yellow dots) over examples of each land cover category assessed.

2.3 Historical land cover assessment

A combination of GIS and i-Tree Canopy was used for historical assessments. Whilst a range of approaches are available for assessing land cover and change over time (Appendix A), the approach applied here is considered statistically sound and rigorous, and was selected over other approaches as it is readily repeated in the future without the need for specialist spatial analysis skills, or expensive software/tools/equipment.

Council provided historical aerial imagery for the year 2006 as well as i-Tree Canopy assessments undertaken for the year 2016 for each of the eight suburbs. The points for each suburb were converted to a GIS shapefile and overlaid on the historical imagery. 2016 classified land cover categories were then compared to land cover in the 2006 aerial imagery. Using the i-Tree Canopy “change survey” function, land cover classifications for each point were reclassified as required to match 2006 land cover. The revised classifications in i-Tree Canopy were saved as new project files to enable future comparisons.

2.3.1 Assessment errors and considerations

The interpretation of satellite imagery and aerial photos is open to interpretation by the user, which may lead to an inherent level of error in the land cover classification, particularly if the quality of the imagery/photo is poor. Such error was minimized as much as possible by considering the surrounding land use context and comparing images in other time periods. Key interpretation issues that may be faced in such analyses include:

- Non-anthropogenic land-cover changes:
    - seasonal variations may result in a point’s land-cover category changing between different assessment dates. For example, a point classified as “grass other” in one year/month may be classified as “bare ground” in another year/month due to changes only caused by seasonal influences. Other similar changes may occur due to fluctuations in water levels in waterways and water bodies;
- Inferred points:
    - user-rationale was used to interpret land cover under points where shadows impeded a clear view; where necessary, comparison with imagery from other time periods and Google street view were also assessed;
    - where a point fell over a temporary cover (e.g. cars, junkyard debris), the more permanent land cover is classified. For example, a point falling over a car parked on a grassy area, would be classified as “grass other” not “impervious other”. Similarly, a point falling over a boat on the water would be classified as “water”;
- Photo skew and quality:
    - the quality of aerial photos and satellite imagery (particularly older images) can vary substantially in quality and resolution and influence the ability to clearly identify land cover; and
    - aerial photos can appear displaced or skewed due to variation in the capture angles of the aircraft/satellite relative to the feature. This displacement increases as the look angle moves away from a vertical capture angle, and so features at the edge of an image will have more displacement than those directly below the sensor at the time of acquisition. When these photos are georeferenced, this skew can impact on where certain points appear to fall. User interpretation is required in these cases to infer how the photo would appear if not displaced/skewed.

2.4 Change over time and tenure analyses

Examination of percent land cover change over time and tenure was conducted using a GIS and Excel to conduct additional spatial and statistical analyses based on the i-Tree Canopy land cover assessments.

Change in percent land cover between tenure was assessed using a tenure GIS layer developed specifically for this project which classified all land within the Council boundary as either public or private. Public tenure was the public road network as well as any additional land area owned or managed by the Council; by default, private land was all other land not covered by the public tenure definition. Approximately 64% of land was classified as private, and 36% as public (Figure 3). A spatial analysis was conducted by overlaying the i-Tree Canopy classified land cover points with the tenure layer and calculating the percent of points within each land cover category falling within public versus private land. This assessment was conducted for the 2006 and 2016 time periods.

Change in percent land cover over time was assessed by comparing in Excel the difference in percent land cover between 2006 and 2016, and between tenures.

2.5 Calculating statistical significance

Statistical significance of changes in percent land cover were calculated using t-tests, which is a statistical hypothesis test used to determine if two data sets differ significantly from each other. When comparing percentages, a one-sample t-test is used if comparing values from a single data set and a two-sample t-test is used if comparing values from different data sets. For the purposes of this project a one-sample t-test was applied to determine if land cover changes observed over time for the same area were statistically significant, and a two-sample t-test was applied to determine if percent cover on public land was significantly different to that on private land.

Differences were considered statistically significant if p-values were less than or equal to the 0.05 critical alpha level (see Attachment B for further details).

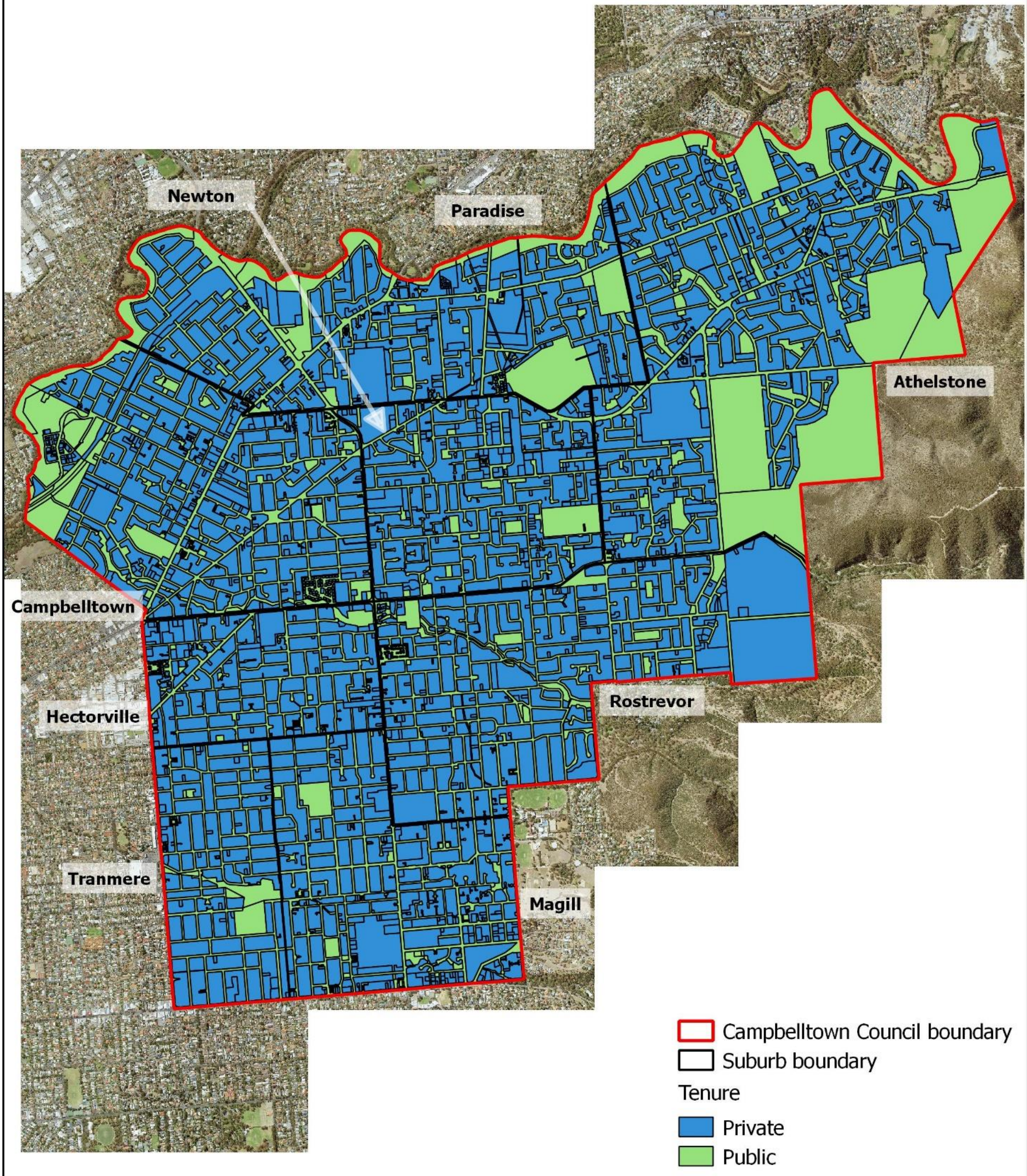

Figure 2. Tenure layer of private and public land in Campbelltown City Council.

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3 Results – 2016 Land Cover

3.1 Across Campbelltown City Council

In 2016, the majority of land cover across the Council area was impervious surfaces, with half of this cover being buildings, and roads comprising the lowest percentage (Figure 3). Tree canopy covered just under 19% of the Council area, with almost twice as much considered to occur over pervious surfaces than impervious surfaces. Plantable space covered nearly 22% of the Council area, with most of this being bare ground (Figure 3). The remaining Council area (2.71%) was primarily unplantable grassed sporting areas, and a small proportion of water (0.33%) (Figure 3). There was no apparent spatial pattern in land cover across the Council area (Figure 4), and although the 2016 estimated canopy cover of 18.76% is slightly lower than the 19.4% reported in the National Benchmarking Report[2] for the year 2013, this difference is not statistically significant ($p = 0.671$).

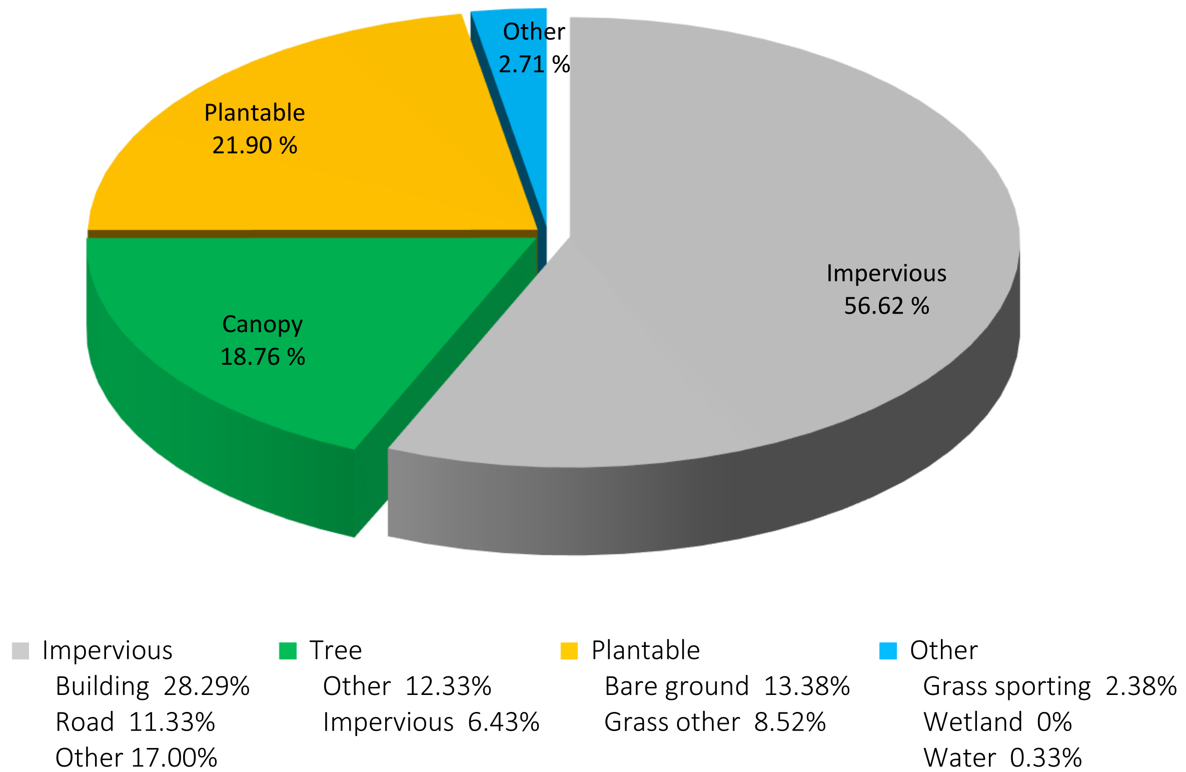

Figure 3. Estimated land cover across Campbelltown City Council in 2016.

[2] Jacobs, B., Mikhailovich, N. & Delaney, C., 2014. *Benchmarking Australia's Urban Tree Canopy: An i-Tree Assessment, prepared for Horticulture Australia Limited by the Institute for Sustainable Futures,* NSW: University of Technology Sydney.

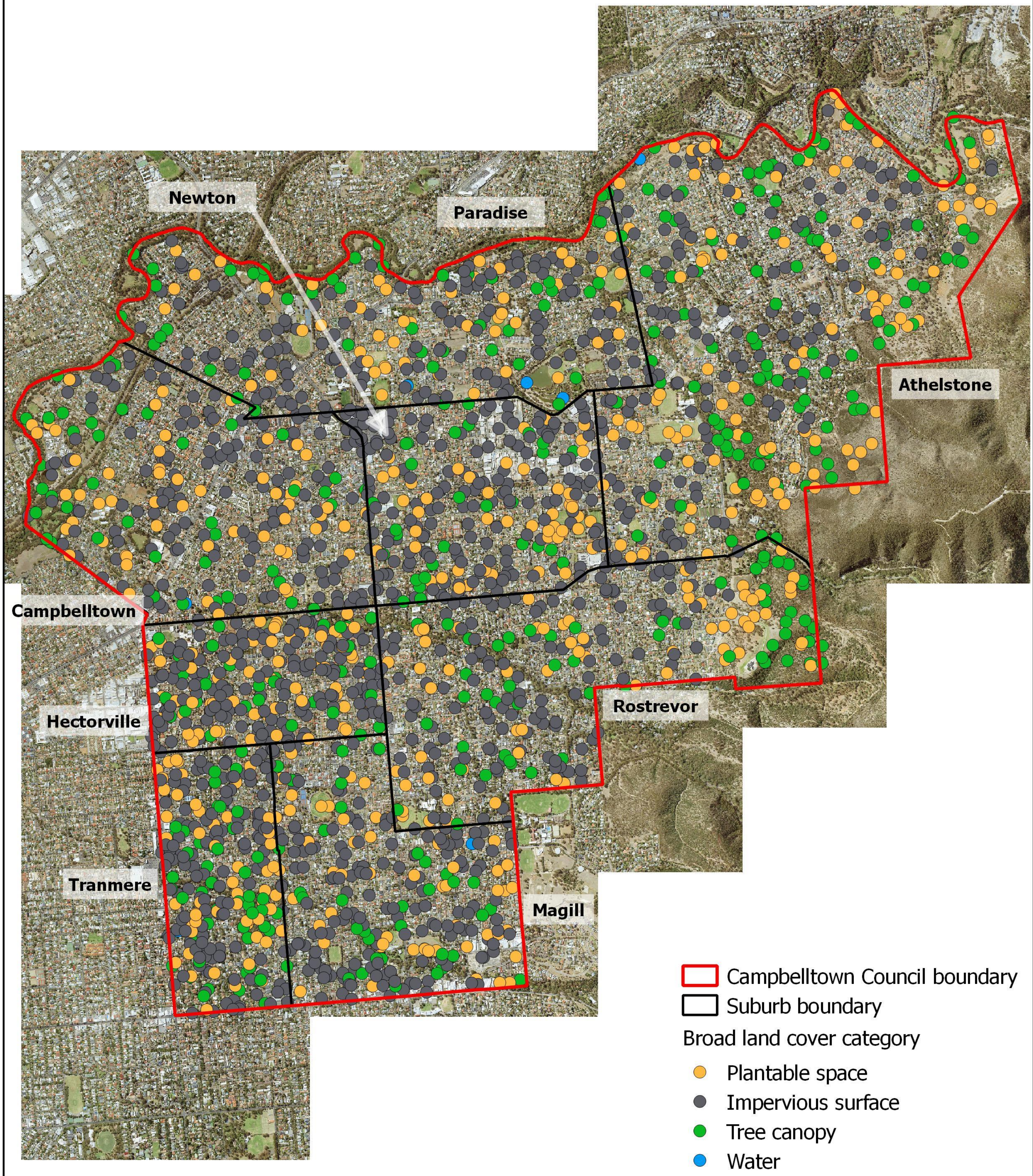

Figure 4. Points located across Campbelltown City Council, classified by broad land cover category in 2016.

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Imagery: 2016 Aerial

3.1.1 Public versus private land

Impervious cover across the City occurred significantly more ($p = < 0.001$) on private land than public land, with more than twice as much occurring on private than public land (40.19% versus 16.43%, respectively) (Figure 5). This was driven primarily by significantly more buildings and other impervious cover occurring on private lands, though significantly more roads occurred on public lands ($p<0.001$ for all) (Figure 5).

Canopy cover amounts did not vary significantly in 2016 between public and private land, with 9.19% on public land and 9.57% on private land (Figure 5). Between tenures, slightly more canopy cover occurred over pervious surfaces on private land, whereas slightly more occurred over impervious surfaces on public land (Figure 5). Whilst none of these differences were statistically significant, they are likely indicative of more canopy occurring over gardens on private land and more over roads and footpaths on public land.

Plantable space comprised significantly more ($p = <0.001$) private land than public land in 2016, both for bare ground and non-sporting grass areas (Figure 5).

Unplantable other cover did not vary significantly between private and public tenures in 2016 (Figure 5).

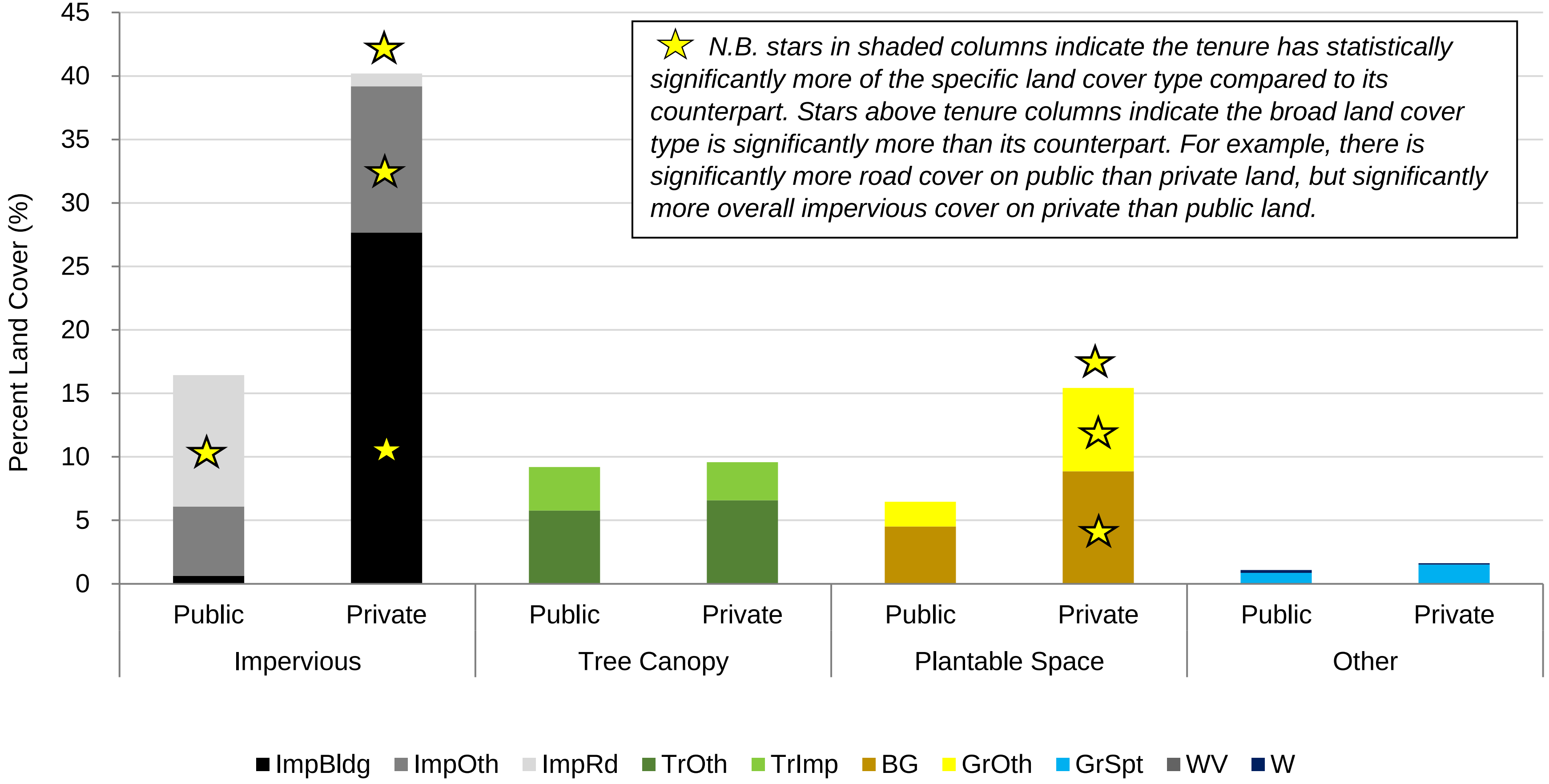

Figure 5. Percent land cover in 2016 between public and private land tenures. Stars sitting above columns indicate significantly more of the broad category. Land cover categories: Impervious = road (ImpRd), building (ImpBld), other (ImpOth); Tree canopy = over impervious surface (TrImp), over pervious surface (TrPer); Plantable space = bare ground (BG), non-sporting grass (GrOth); Other = sports grass (GrSpt), wetland vegetation (WV), water (W).

3.2 Across Suburbs

2016 land cover varied among suburbs (Table 3; Figure 6). All suburbs contained a mixture of impervious, canopy, plantable space, and unplantable other cover, though the proportions varied (Table 3; Figure 6) (Appendix D).

Impervious cover ranged from 40% in Athelstone to 67.6% in Newton (Table 3; Figure 6). All suburbs except for Athelstone contained impervious surfaces that covered more than 50% of their areas. As well as having the lowest overall percent impervious cover, Athelstone also had the lowest percent cover of buildings and other impervious surfaces, and the second lowest road cover (after Hectorville). Comparatively, Hectorville had the highest percent building cover, Magill the highest other impervious surfaces cover, and Newton the highest road cover.

Canopy cover ranged from 11.6% in Newton to 28.29% in Athelstone (Table 3; Figure 6). The amount of canopy cover closely correlated with the amount of impervious cover, with suburbs containing higher impervious cover generally having lower canopy cover. All suburbs except for Tranmere, Rostrevor, and Athelstone contained less than 20% canopy cover (Table 3; Figure 6). Athelstone contained the highest percent cover of canopy over both impervious and other (pervious) surfaces. The lowest percent cover of canopy over impervious surfaces occurred in Newton, and over pervious surfaces in Magill.

Plantable space ranged from 16% in Newton and Paradise to 29.43% in Athelstone (Table 3; Figure 6). Percent bare ground was highest in Athelstone and lowest in Paradise, whereas percent non-sporting grass cover was highest in Rostrevor and lowest in Newton. Newton also had the lowest percent canopy cover, and whilst it had the lowest overall percent plantable space, it is potentially a priority suburb for increasing canopy cover. The level of planting opportunities on private versus public land will need to be carefully considered, as to how feasible such actions are for Council.

Unplantable other cover ranged from 0.8% in Tranmere to 5.6% in Paradise (Table 3; Figure 6). Whilst Newton had the highest percent sporting grass cover (4.8%) followed by Paradise (4.4%), Paradise also had the highest percent water cover (1.2%) which overall gave it the highest percent unplantable other cover. Newton had no other unplantable cover categories detected. Similarly, the unplantable other cover in Hectorville and Rostrevor was also comprised only of sporting grass cover. Tranmere had the lowest sporting grass cover at just 0.4%, with the remaining 0.4% of unplantable other cover being water. Although wetland vegetation is known to occur in the Council area, wetland vegetation was not recorded for any of the suburbs. This reflects the very low percent cover of this type compared to other land cover types. It is reasonable to assume wetland vegetation in any suburb is less than 0.02km^2, which equates to the lowest amount of land cover identified for a suburb (i.e. 0.29% water cover in Athelstone).

Table 3. Land cover in each suburb. For each suburb, land cover is shown as percent cover (%) and equivalent land area (km2). Imp. = impervious cover; Can. = canopy cover; Pla. = plantable space cover; Oth. = other unplantable cover.

	Percent cover (%)				Land area (km²)			
Suburb	**Imp.**	**Can.**	**Pla.**	**Oth.**	**Imp.**	**Can.**	**Pla.**	**Oth.**
Athelstone	40.00	28.29	29.43	2.29	3.03	2.14	2.23	0.17
Campbelltown	58.80	17.20	22.40	1.60	2.50	0.73	0.95	0.07
Hectorville	61.60	13.60	23.60	1.20	1.09	0.24	0.42	0.02
Magill	65.20	13.60	17.60	3.60	1.94	0.40	0.52	0.11
Newton	67.60	11.60	16.00	4.80	1.79	0.31	0.42	0.13
Paradise	59.20	19.20	16.00	5.60	2.59	0.84	0.70	0.24
Rostrevor	50.80	22.80	24.40	2.00	2.21	0.99	1.06	0.09
Tranmere	56.40	20.00	22.80	0.80	1.02	0.36	0.41	0.01

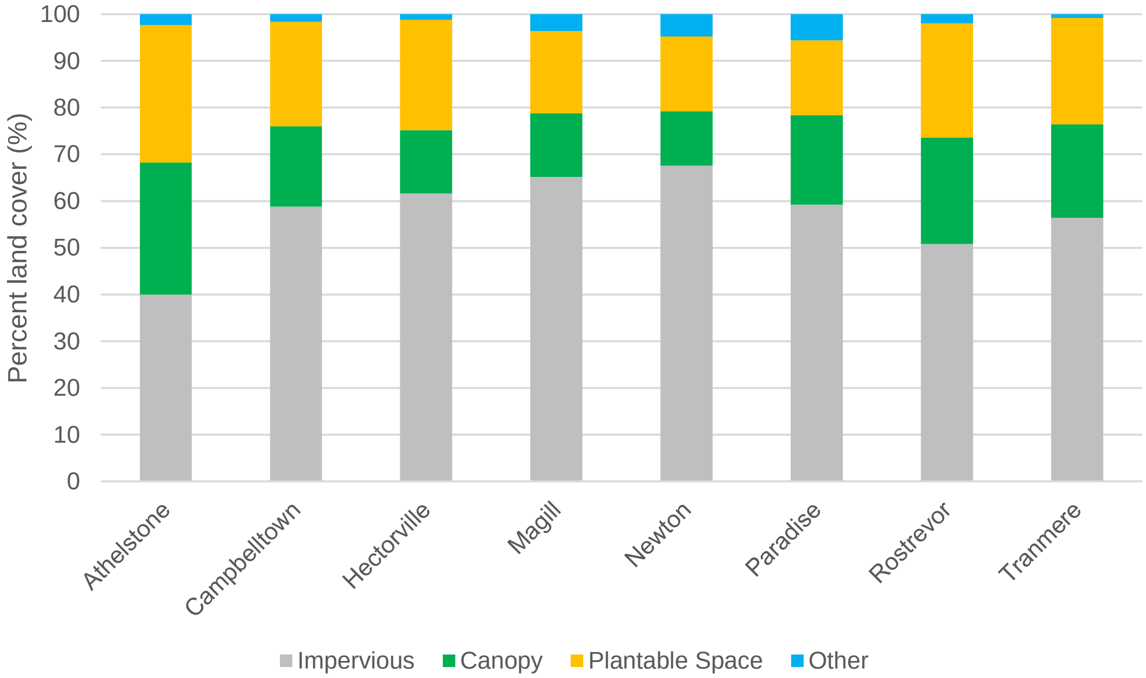

Figure 6. Percent land cover in 2016 for each suburb. Refer to Table 3 for further details on percentages and equivalent land areas.

3.2.1 Public versus private land

Within each suburb, the proportions of the various land cover types on public versus private land varied substantially, though trends generally were consistent among suburbs.

Impervious cover occurred significantly more on private than public land (all p = 0.001 or less) (Figure 7a). This was despite road cover being significantly higher on public land in all suburbs (Table 4). Instead, the trend was driven by significantly more building cover on private land in all suburbs and also significantly more other impervious cover in all suburbs except Campbelltown, where other impervious cover did not differ significantly between public and private land (Table 4).

Canopy cover occurred significantly more on public land in Athelstone and Campbelltown (p = <0.001 and 0.047, respectively), but significantly more on private land in Magill and Rostrevor (p = 0.006 and <0.0001) (Figure 7b). The drivers of these differences were not as clear as differences in impervious cover (Table 4). In Athelstone, the higher canopy cover on private land was driven by significantly more canopy over other (pervious) surfaces, but for Campbelltown neither canopy over impervious or pervious surfaces was a main driver (i.e. both contributed to the significant difference overall) (Table 4). The significantly higher canopy cover on private land in Magill was driven by canopy over other (pervious) surfaces (Table 4). This trend was also true for Newton and Tranmere, though overall canopy cover was not significantly different across tenures (Table 4). In Rostrevor, canopy over both pervious and impervious surfaces were the drivers of the significantly higher cover on private than public land (Table 4). No significant differences between tenures were found in other suburbs.

Plantable space was significantly higher on private land in all suburbs except Athelstone (Figure 7c, Table 4). Hectorville, Magill, Newton, Paradise, and Rostrevor all had significantly more bare ground and non-sporting grass areas on private than public land (Table 4). Comparatively, the higher cover on private land in Campbelltown and Tranmere was driven by significantly more non-sporting grass areas. In Athelstone, significantly more plantable space occurred on public land (p = 0.013), due primarily to significantly more bare ground (p = 0.001) (Table 4).

Unplantable other cover was only significantly different between tenures in Newton and Rostrevor (Figure 7d), due to significantly differences in the amount of sporting grass areas. In Newton, this occurred more on public land, but in Rostrevor more occurred on private land (Table 4). Significantly more sporting grass on private land also occurred in Paradise, but the higher water cover on public land, though not significant, meant overall unplantable other cover was not significantly different between tenures in this suburb (Table 4).

Table 4. Percent (%) land cover on public and private land in each suburb. IMPERVIOUS COVER = impervious building (ImpBldg), impervious other (ImpOth); and impervious road (ImpRd); CANOPY COVER = Tree over other/pervious surface (TrOth), and Tree over impervious surface (TrImp); PLANTABLE SPACE COVER = bare ground (BG), and grass other (non-sporting) (GrOth); OTHER COVER (unplantable) = grass sporting (GrSpt), wetland vegetation (WV), and water (W). Percentages of land cover types shown in red are statistically significantly different from their tenure counterparts (e.g. Athelstone has significantly more impervious cover on private than public land, but significantly more bare ground cover on public than private land).

LAND COVER	ATHELSTONE		CAMPBELLTOWN		HECTORVILLE		MAGILL		NEWTON		PARADISE		ROSTEVOR		TRANMERE	
	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private
IMPERVIOUS	**12.00**	**28.00**	**21.60**	**37.20**	**4.80**	**46.80**	**16.80**	**48.40**	**19.60**	**48.00**	**16.80**	**42.40**	**14.00**	**36.80**	**17.60**	**38.80**
ImpBldg	0.00	18.29	2.40	26.80	0.80	36.00	0.80	31.60	1.20	32.40	0.00	28.00	0.00	27.20	0.00	24.80
ImpOth	3.71	9.60	6.00	9.60	5.60	10.80	7.20	16.00	6.00	11.60	6.80	12.40	3.60	9.60	5.60	13.60
ImpRd	8.29	0.29	13.20	0.80	8.40	0.00	8.80	0.80	12.40	4.00	10.00	2.00	10.40	0.00	12.00	0.40
CANOPY	**21.71**	**6.57**	**11.20**	**6.00**	**4.80**	**8.80**	**3.60**	**10.00**	**4.40**	**7.20**	**10.80**	**8.40**	**4.00**	**18.80**	**8.00**	**12.00**
TrOth	17.14	3.43	7.20	4.00	2.00	6.40	0.00	8.80	0.80	3.60	7.60	4.00	2.40	13.20	4.40	10.40
TrImp	4.57	3.14	4.00	2.00	2.80	2.40	3.60	1.20	3.60	3.60	3.20	4.40	1.60	5.60	3.60	1.60
PLANTABLE SPACE	**18.29**	**11.14**	**6.00**	**16.40**	**3.60**	**20.00**	**2.80**	**14.80**	**2.40**	**13.60**	**4.40**	**11.60**	**4.00**	**20.40**	**5.60**	**17.20**
BG	14.29	6.57	4.40	8.00	2.80	14.40	1.60	8.40	2.00	9.60	2.40	6.00	1.20	11.20	3.60	7.60
GrOth	4.00	4.57	1.60	8.40	0.80	5.60	1.20	6.40	0.40	4.00	2.00	5.60	2.80	9.20	2.00	9.60
OTHER	**0.86**	**1.43**	**0.80**	**0.80**	**0.00**	**1.20**	**0.80**	**2.80**	**4.40**	**0.40**	**2.00**	**3.60**	**0.00**	**2.00**	**0.00**	**0.80**
GrSpt	0.57	1.43	0.40	0.80	0.00	1.20	0.80	2.40	4.40	0.40	0.80	3.60	0.00	2.00	0.00	0.40
WV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W	0.29	0.00	0.40	0.00	0.00	0.00	0.00	0.40	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0.40

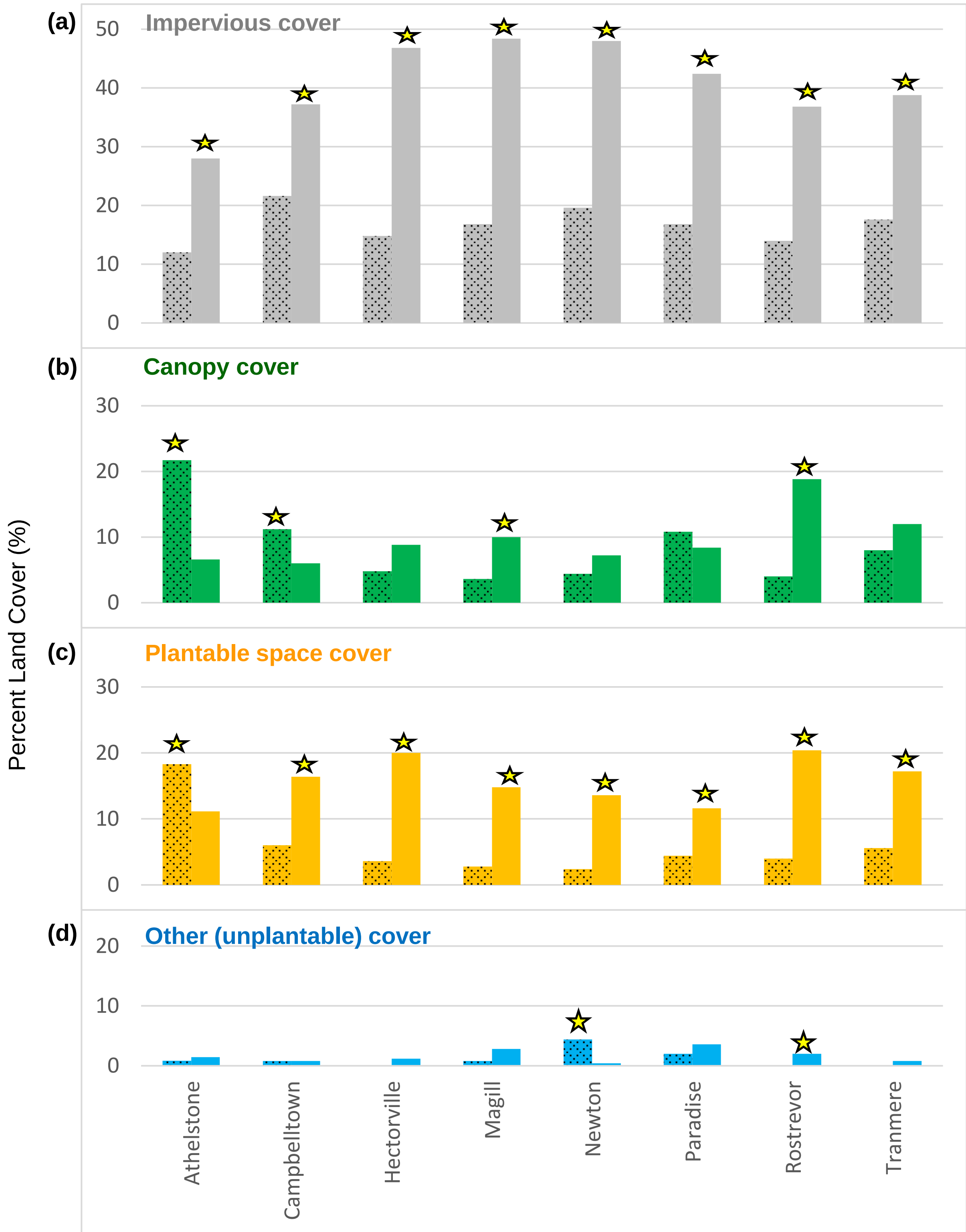

Figure 7. Percent broad land cover types (a-d) in 2016 on public and private land in each suburb. Stars indicate statistically significant more land cover compared to the tenure counterpart in that suburbs. Refer to Table 4 for further details on percentage values for detailed land cover categories.

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4 Results – Change in Land Cover 2006-2016

4.1 Across Campbelltown City Council

Impervious cover increased significantly (p = 0.006) over the decade to 2016, from just over 50% cover in 2006 (50.43%) to 56.62% cover in 2016. (Figure 8). Whilst their combined effect was significant, when considered in isolation, increases in building, road and other impervious cover were not significant (ranging between 1.76% and 2.43%). This indicates that there is no one key driver of impervious cover change, rather, the impact of general urban development process have been significant in the City (Figure 8).

Canopy cover has decreased significantly (p = 0.001) across the Council area, from just over a quarter of the City area covered in 2006 (25.19%) to less than one-fifth in 2016 (18.76%) (Figure 8). The declining canopy cover trend was driven entirely by a loss of canopy cover over other (pervious) surfaces, with cover over impervious surfaces remaining the same. It is also of interest to note that the 6.43% decline in canopy cover is almost accounted for entirely by the 6.19% increase in impervious cover.

Plantable space cover increased slightly between 2006 and 2016, though the 0.19% increase was not statistically significant (p=0.895) (Figure 8). Although the overall change in plantable space was not significant, changes in the composite plantable space categories were. Percent bare ground increased significantly by 4.29% (p = 0.001), whilst non-sporting grass cover decreased significantly by almost the same amount (4.10%, p = 0.001). These respective patterns of increased and decreased cover effectively offset each other, resulting in the observed insignificant change in overall plantable space.

Other land cover (i.e. grass sporting areas, water, and wetland vegetation) overall remained relatively constant over time, with a non-significant increase of 0.05% (p=0.937) (Figure 8). The component land cover types also showed insignificantly changes in cover over time, with grass sporting areas and wetland vegetation having a 0.05% decline (p = 0.917 and p = 0.306, respectively), and percent water cover increasing by 0.14% (p = 0.374).

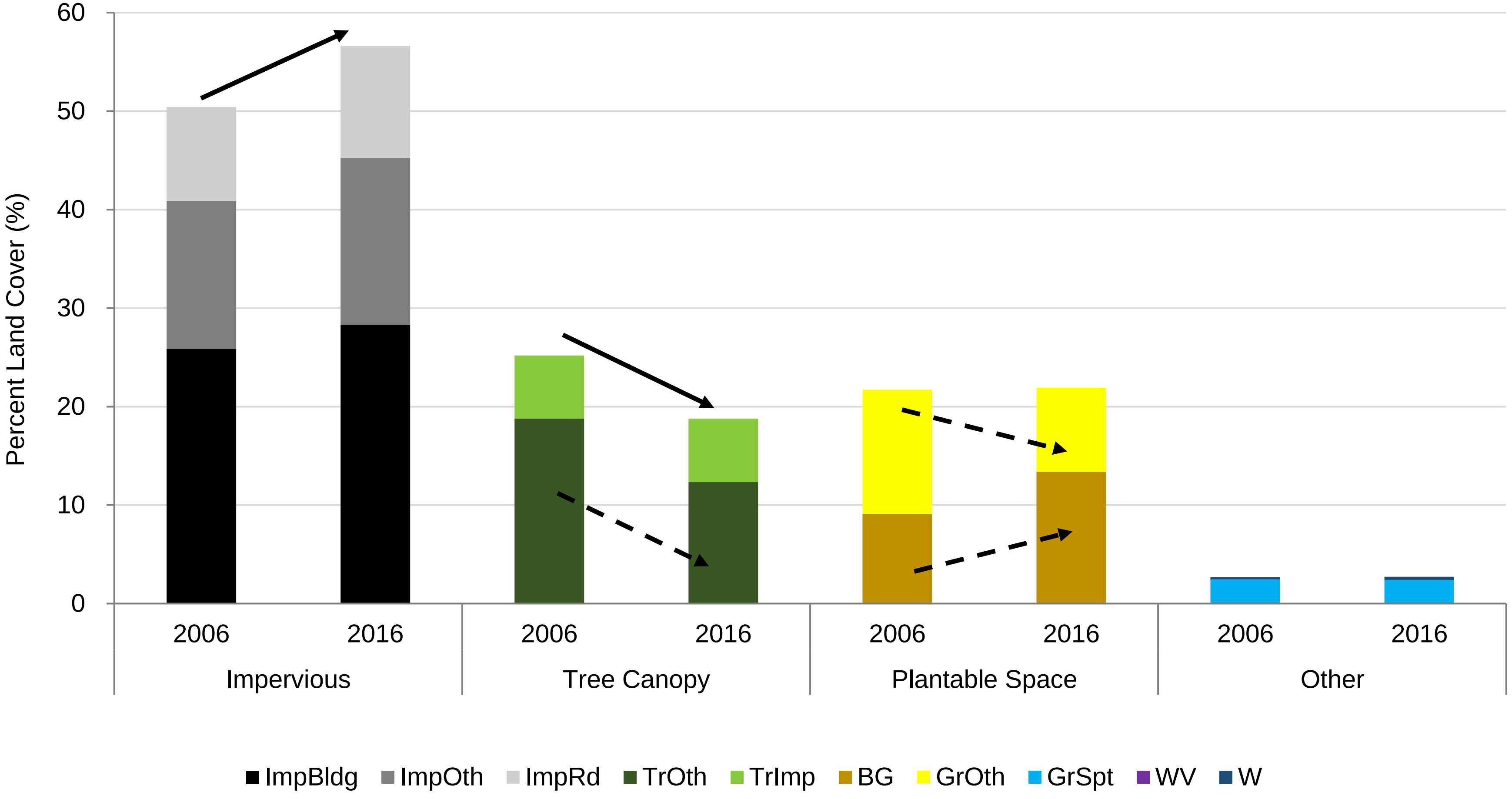

Figure 8. Percent land cover across the City between 2006-2016. Arrows indicate direction of statistically significant changes over time either for broad land cover categories (solid line) and/or composite land cover types (dotted line). Land cover categories: Impervious = road (ImpRd), building (ImpBld), other (ImpOth); Tree canopy = over impervious surface (TrImp), over pervious surface (TrPer); Plantable space = bare ground (BG), non-sporting grass (GrOth); Other = sports grass (GrSpt), wetland vegetation (WV), water (W).

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4.1.1 Public versus private land

Across the City there were substantial differences in land cover changes over time between private and public tenure, with generally more and significant changes occurring on private than public land (Figure 9). The following summarises key trends in land cover change relative to tenure areas, with further details provided in Attachment C.

Impervious cover increased on both public and private land between 2006 and 2016, from 14.76% to 16.43% on public land and 35.67% to 40.19% on private land (Figure 9). Only the change on private land was statistically significant ($p = 0.017$). Whilst all impervious cover categories increased on both public and private land, only the increase in roads on private land was significant ($p = < 0.001$). This is indicative of urban development and expanding communities requiring increase infrastructure.

Canopy cover followed a similar though opposite trend to impervious cover, decreasing on both public and private land between 2006 and 2016; from 10.81% to 9.19% on public land and 14.38% to 9.57% on private land (Figure 9). Only the 4.81% loss of cover on private land though was statistically significant, being driven by a significant loss of canopy cover over other (pervious) surfaces from 11.62% to 6.57% ($p = < 0.001$) (Figure 9).

Plantable space cover increased on public and private land between 2006 and 2016, though neither change was significant (Figure 9). However, the changes on private land in both bare ground and non-sporting grass cover were significant ($p = < 0.001$ for both). However, as bare ground cover increased by 3.1% and non-sporting grass decreased by 2.95%, the changes countered each other when considering overall plantable space cover change. Both the loss of non-sporting grass cover and the increase of bare ground on private land can be viewed as indicators of urban in-fill processes, with grassy areas being cleared to bare ground prior to construction works commencing. Accordingly, the actual amount of plantable space may be overestimated in this assessment, if a significant amount of bare ground is realistically unplantable due to urban development activities.

Unplantable other cover increased slightly on private land and decreased slightly on public land, though none of the changes were significantly across the City (Figure 9).

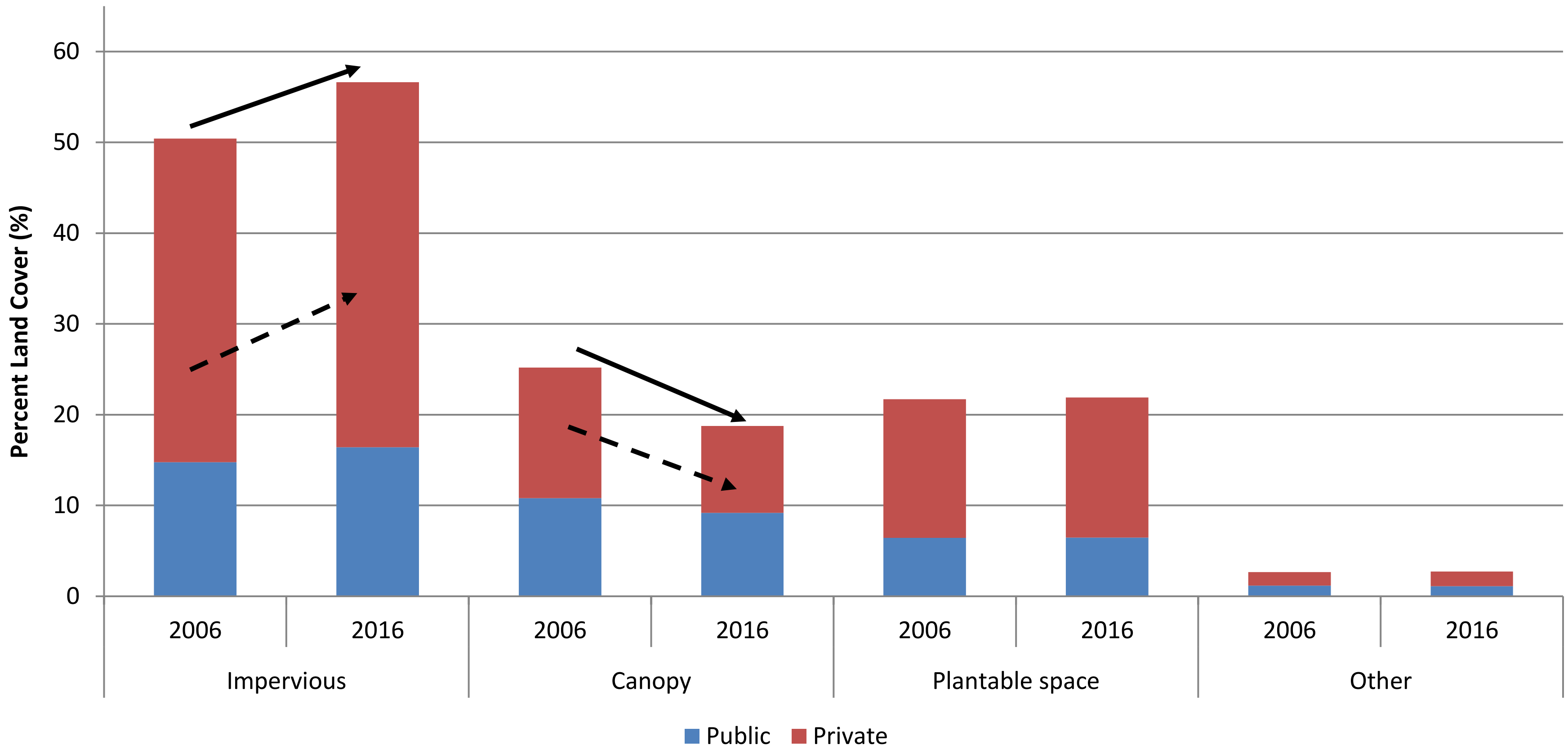

Figure 9. Percent land cover on public and private land across the City in 2006 and 2016. Arrows indicate direction of statistically significant changes over time either for broad land cover categories (solid line) and/or composite land cover types (dotted line). Land cover categories: Impervious = road (ImpRd), building (ImpBld), other (ImpOth); Tree canopy = over impervious surface (TrImp), over pervious surface (TrPer); Plantable space = bare ground (BG), non-sporting grass (GrOth); Other = sports grass (GrSpt), wetland vegetation (WV), water (W).

4.2 Across suburbs

Changes in land cover between 2006 and 2016 varied among suburbs, though trends tended to follow those observed across the whole City. For the purposes of this section, only change in impervious, tree, and plantable space cover are discussed. Further details of land cover change for each suburb are provided in Attachment D.

Impervious cover increased in all suburbs, between 1.6% and 9.2%, though none of these changes were significant at the suburb level (Figure 10). However, when combined across suburbs, the changes result in a significant increase at the City scale. The greatest increase (9.20%) occurred in Tranmere, with this change pushing the total impervious cover in the suburb to over 50% (47.20% to 56.40%). The lowest increase of 1.6% occurred in Hectorville, with Hectorville also being the suburb with the second highest total amount of impervious cover in 2016 (61.6%).

When considering the composite land cover categories, building, road, and other impervious covers also generally increased in all suburbs, though in Hectorville and Newton, the amount of other impervious cover decreased by 0.4% and 3.2%, respectively. None of these changes though were significant. Campbelltown experienced the greatest increase in building cover (5.2%), Newton the great increase in road cover (4.8%) and Magill the greatest increase in other impervious cover (4.8%). Conversely, the least increases in building, road, and other impervious cover occurred in Paradise (0.8%), Athelstone (0.29%), and Campbelltown (0.8%).

Canopy cover trends were generally inversely related to impervious cover trends, with all suburbs experiencing a loss of canopy cover between 2006 and 2016 (Figure 10). The greatest losses of cover occurred in Tranmere (10%) and Rostrevor (9.6%), both of which were statistically significant changes ($p = 0.025$ and 0.04, respectively) and reduced the suburbs' total canopy cover to less than 30%. No other canopy losses were significant at the suburb-scale, though the total canopy loss across all suburbs resulted in the overall significant loss of canopy across the City. The lowest amount of canopy loss of 2% occurred in Newton, which was also the suburb with the overall lowest canopy cover in both 2006 and 2016.

The amount of canopy cover over impervious surfaces increased in five suburbs and decreased in the other three, with the greatest increase in Paradise, the greatest loss in Campbelltown, and no change in Athelstone. None of these changes were significant. Comparatively, canopy cover over other (pervious) surfaces decreased in all suburbs, with some of these changes being significant. This suggests that these changes in particular drove the overall significant losses of canopy cover at suburb and City scales. The greatest losses of canopy over pervious surfaces were in: Rostrevor (10.4%), Tranmere (8.8%), Paradise (8.4%), and Hectorville and Athelstone (both 6%). With the exception of Athelstone, all of these changes were significant. The lowest loss of canopy over pervious surfaces was in Newton (2.8%), though this change was not significant.

Plantable space trends varied, with four suburbs showing cover losses, and the other four suburbs showing cover gains (Figure 10). Together, these changes resulted in relatively little overall plantable space change across the City, and none of the changes were statistically significant. The greatest gain in plantable space was in Hectorville (4%), and the greatest loss in Magill and Newton (both 2.4%).

However, significant changes were found in some suburbs for the bare ground category. Bare ground increased in all suburbs, with the greatest increases (and the significant increases), being in Hectorville (9.2%, p= 0.004), Athelstone (8%, p = 0.01), and Campbelltown (6%, p = 0.028). As indicated at the City level, these changes again are likely at least partially related to urban in-fill processes and so the area actually available for planting in each suburb may be overestimated (Plate 2). Non-sporting grass cover decreased in all suburbs except Rostrevor which increased by 1.6%. The greatest loss of non-sporting grass cover was in Campbelltown and least in Paradise (1.6%). None of the changes in non-sporting grass cover were significant at the suburb level.

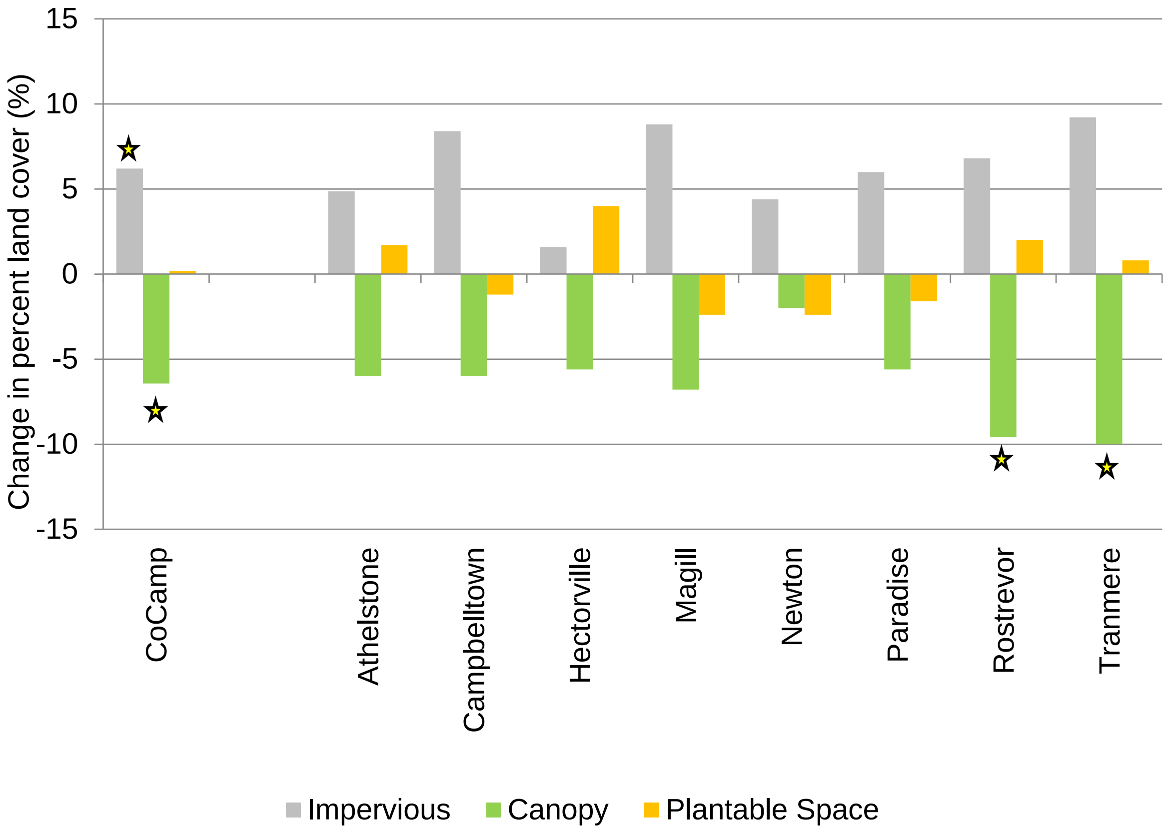

Figure 10. Change in percent land cover (impervious, canopy, plantable space) between 2006 and 2016 within each suburb. City in 2006 and 2016. For comparison, the change in percent land cover is also shown for the whole City (CoCamp). Stars indicate significant changes over time.

Plate 2. Example of land cover changes in Campbelltown showing how land cover under a point can vary over time and how this may lead to potential overestimation if land cover is assessed in one time period only. Examples shown here are of urban in-fill on private land (red circles) and Council landscaping on public land (blue circles).

2006

Tree other (red circle)

Grass other (blue circle)

2015

Bare ground (red circle)

Bare ground (blue circle)

2017

Building impervious (red circle)

Tree other (blue circle)

4.2.1 Public versus private land

There were substantial differences in land cover changes within each suburb between private and public tenure, with generally more changes occurring on private land, but only some changes in canopy cover on private land being significant at the suburb level (Table 5). The following summarises key trends in land cover change in each suburb relative to tenure areas, with further details provided in Table 5.

Impervious cover increased between 2006 and 2016 on private land in all suburbs, with the greatest change occurring in Magill (7.2%), and the least change in Hectorville (1.2%) (Table 5). On public land, percent impervious cover also increased in all suburbs, with the exception of Athelstone which showed no change. The greatest increase on public land was in Campbelltown (3.2%) (Table 5). Whilst none of these changes at the tenure level were statistically significant, they combined to produce a significant increase on private land at the City scale.

Canopy cover decreased over time on **private land** in all suburbs (Table 5). The greatest losses of 7.2% was in Tranmere and Rostrevor, with the loss in Tranmere also being significant ($p = 0.041$). The only other significant loss of canopy cover on private land was in Campbelltown (6%; $p = 0.025$). The least loss on private land was in Newton (2.4%). On **public land** canopy cover also tended to decline, between 0.8% in Hectorville and 3.43% in Athelstone. However, Campbelltown showed no loss of canopy cover on public land and in Newton there was an increase of 0.4%. None of these change on public land were significant at the suburb tenure level (Table 5).

Plantable space trends between 2006 and 2016 varied across suburbs and by tenure. On **private land** percent plantable space increased in four suburbs (between 0.4% and 3.6%) and decreased in the other four suburbs (between 0.4% and 2%) (Table 5). The greatest increase was in Hectorville, and the greatest decrease in Magill. On **public land percent** plantable space cover increased in three suburbs (between 0.4 and 3.43%) and decreased in five suburbs (between 0.4% and 2%) (Table 5). The greatest increase was in Athelstone, and the greatest decrease in Campbelltown. None of the changes on private or public land were statistically significant.

Table 5. Percent land cover in each suburb in 2006 and 2016 and change in land cover percent between 2006 and 2016. Listed alphabetically by suburb. Values in red are statistically significant changes.

	IMPEVIOUS COVER						CANOPY COVER						PLANTABLE SPACE COVER					
	Private			Public			Private			Public			Private			Public		
	2006 %	2016 %	Change	2006 %	2016 %	Change	2006 %	2016 %	Change	2006 %	2016 %	Change	2006 %	2016 %	Change	2006 %	2016 %	Change
Newton	44.40	48.00	3.60	18.80	19.60	0.80	9.60	7.20	-2.40	4.00	4.40	0.40	14.80	13.60	-1.20	3.60	2.40	-1.20
Athelstone	23.14	28.00	4.86	12.00	12.00	0.00	9.14	6.57	-2.57	25.14	21.71	-3.43	12.86	11.14	-1.71	14.86	18.29	3.43
Paradise	39.20	42.40	3.20	14.00	16.80	2.80	12.00	8.40	-3.60	12.80	10.80	-2.00	12.00	11.60	-0.40	5.60	4.40	-1.20
Hectorville	45.60	46.80	1.20	14.40	14.80	0.40	13.60	8.80	-4.80	5.60	4.80	-0.80	16.40	20.00	3.60	3.20	3.60	0.40
Magill	41.20	48.40	7.20	15.20	16.80	1.60	15.60	10.00	-5.60	4.80	3.60	-1.20	16.80	14.80	-2.00	3.20	2.80	-0.40
Campbelltown	32.00	37.20	5.20	18.40	21.60	3.20	12.00	6.00	-6.00	11.20	11.20	0.00	15.60	16.40	0.80	8.00	6.00	-2.00
Rostrevor	32.80	36.80	4.00	11.20	14.00	2.80	26.00	18.80	-7.20	6.40	4.00	-2.40	18.00	20.40	2.40	4.40	4.00	-0.40
Tranmere	32.00	38.80	6.80	15.20	17.60	2.40	19.20	12.00	-7.20	10.80	8.00	-2.80	16.80	17.20	0.40	5.20	5.60	0.40

5 Discussion

Trees are an important component of the urban matrix, not only contributing to a city's character and liveability and helping to create a unique "sense of place", but also providing a suite of beneficial services for the environment, biodiversity, and people. A key challenge for urban land managers is how to maintain and increase tree cover given increasing demands for space and resources to support divergent land-uses, such as urban development. Further complicating this challenge is that much of the land in urban areas is often privately owned, which limits the direct influence that public greening/planting programs can have across the City area as a whole. Developing successful planting programs requires not only a knowledge of current land cover but will also benefit from an understanding of the processes that resulted in the current land cover.

Further, being able to effectively and efficiently measure land cover change over time and across tenures can provide urban land managers with the critical tools and information necessary to monitor the success of greening objectives and prioritise locations for targeting different programs and actions to achieve the best outcomes across the City. The i-Tree Canopy software was used in this project to measure land cover (including tree/canopy) cover at different spatial and temporal scales across Campbelltown City Council. This software provides a consistent, user-friendly and transparent approach to measuring and monitoring land cover change.

5.1 Key findings

The overall finding from this assessment is that the City's current canopy cover of less than 20% is a legacy of urban development, particularly urban in-fill processes on private land. Whilst canopy cover decreased on public and private land in all suburbs, the greatest losses occurred on private land, which is echoed by the greatest increases in impervious cover also occurring on private land. Whilst no suburb showed an increase in canopy cover overall, Newton was the only suburb to show an increase at the tenure level, with approximately 10,601 m^2 of canopy gain on public land being evident over the decade to 2016. This gain however, was outpaced by 6 times as much loss of canopy cover on private land over the same time period (63.61 m^2). Should such trends be permitted to continue unabated, there will be little chance of Council reaching its urban greening and canopy cover targets.

The outputs from this assessment also help to identify where key priorities exist for improving canopy cover. At the suburb level, Athelstone appears to present the best opportunity for planting programs, with approximately 2.2 km^2 of plantable space currently available. What's more, more than half of this area is on public land (1.4 km^2), with the balance on private land. This highlights the usefulness of insights gained from tenure analyses within suburbs to prioritise. For example, at the suburb level, the second highest opportunity for planting appears to be Campbelltown (0.95 km^2 available), however an examination at the tenure level shows that more than 70% of this available planting space falls on private property. Whilst direct Council planting opportunities may therefore be limited in Campbelltown, the suburb instead presents itself as a potential priority location for community engagement and education programs that encourage and/or incentivise plantings on private land. Such investigations also highlight the importance of considering multiple land cover categories (e.g. not just the amount of tree cover).

5.2 Insights from temporal analyses

In addition to understanding current land cover at City, suburb, and tenure scales, understanding trends in land cover change over time at each of these scales can provide important insights about drivers of change. Such insights can identify some mechanisms which may inhibit greening targets and so help to further refine the type of activity that will best achieve urban greening targets and their priority locations (e.g. public land plantings vs community engagement to encourage private land plantings)

The temporal trends observed in land cover at all spatial scales examined provide clear indications of urban development and in-fill effects, particularly on private land, with impervious surfaces replacing canopy and non-sporting grass cover and canopy cover over pervious surfaces. Fluxes in bare ground on private land also fits with the urban development and in-fill explanation, with bare ground being an intermediary stage between the conversion of green infrastructure to built infrastructure.

For example, the greatest increases in impervious land cover occurred in Magill and Tranmere, with increases of approximately 213,763 m^2 and 122,984m^2, respectively. In Tranmere, this correlated with the largest significant decrease in canopy cover on private land across all suburbs together with an increase in bare ground and a decrease in non-sporting grass cover. What's more, the percentage of canopy cover lost in Tranmere translated to a larger area of canopy cover lost (129,901 m^2) than impervious cover gained. Similarly, the increased impervious cover in Magill correlated with a loss of canopy cover equivalent to almost 80% of the impervious cover gained (166,260m^2).

Whilst increased impervious cover on public also resulted in canopy cover loss in most suburbs, the conversions were not as extreme as those on private land. For Campbelltown and Newton, no canopy cover was lost on public land, with canopy cover remaining unchanged in Campbelltown, and actually increasing by 10,601 m^2 in Newton. The gain in canopy cover on public land in Newton was half as much as the gain in impervious cover, but the gain in canopy on public land was countermanded by the 63, 608m^2 loss on private land.

The implications in urban areas of losing green infrastructure (particularly trees and associated canopy cover) to impervious cover is well documented and observed, and may include:

- increased urban heat island effects (i.e. increased ambient temperatures), which will have substantial negative implications for human health and well-being, particularly for vulnerable members of the community;
- decreased resilience to climate change impacts, such as increased temperatures (which will exacerbate the urban heat island effect), wind and rainfall intensity associated with storms, and sea level rise;
- compromised physical and mental health and wellbeing for people living and working in the City, resulting from a loss of "nature" interactions, decreased community

connectivity, and a loss of ecosystem services provided by trees (e.g. oxygen production, carbon storage and sequestration, and air pollution removal);

- increased amount and velocity, and decreased quality, of stormwater run-off, which will have negative ramifications for aquatic and marine environments;
- decreased local economic prosperity and real estate values due to a loss of trees, with trees having been shown to produce more "attractive" places to live and work and treed areas commanding higher property values and longer retail visitations than non-treed counterparts; and
- decreased biodiversity benefits, such as wildlife foraging and shelter opportunities, and landscape connectivity (which will become particularly important for conserving wildlife species in the plains regions by facilitating range shifts in response to climate change).

5.3 Implications of tree declines

The trends of land cover change observed in this assessment are echoed in urban areas around the world. The ongoing significant replacement of green infrastructure (particularly tree canopy cover) with built impervious surfaces present a significant challenge for Council in meeting liveability, prosperity, and long-term resilience targets, particularly given projected rates and extents of on-going urban in-fill on private land.

The implications of on-going declining tree cover will be wide and varied, with substantial negative impacts on various aspects within the City, including:

- lower air quality (e.g. dust and pollutants), which will impact human health and well-being, particularly vulnerable members of the community (e.g. very young or elderly, and those with compromised respiratory systems);
- hotter average day and night temperatures, contributing further to the urban heat island effect, which will itself be exacerbated by climate change-induced temperature rises. Higher temperatures will impact negatively on: the health and well-being of community members; the wear and maintenance of built assets (e.g. roads); water availability; building energy efficiency; and, the survival and maintenance costs associated with existing green infrastructure elements;
- decreased shading, which will lead to people being less inclined to spend leisure time outdoors in parks and gardens and so negatively influence community connectedness and health and well-being. Where shading is lost near buildings, increased energy costs associated with cooling the building may occur;
- increased winds, with this exacerbating decreased air quality and community health, as well as decreasing the liveability and attractiveness of the City;
- increase localised flooding and destabilised waterway/coastal banks and margins, which will directly impact infrastructure and communities and decrease water quality;
- decreased biodiversity which will compromise the functioning of whole ecosystems, and potentially have flow-on effects to other systems reliant on natural ecosystem functioning (e.g. nearby horticultural systems may be impacted if natural pest predators and pollinators no longer occur in the region); and
- decreased amenity, which will decrease property values and the desire for people to live, work and visit the City, with flow-on effects to local economic prosperity and crime rates.

5.4 Future opportunities

Mitigating future tree loss and moving towards overall canopy cover gain across the City will require dedicated and complimentary greening actions on public and private land. The information derived from this assessment will likely have immediate applications for informing management decisions and target-setting, such as how best to achieve the State Plan's directive for a 20% increase in green infrastructure by 2045. A number of additional opportunities exist to further inform decisions and prioritise actions, such as:

- linking outputs with the region's thermal mapping outputs to identify areas with hotspot and plantable opportunity spatial congruence, indicating areas that may particularly benefit from increased tree plantings;
- identifying and spatially mapping key demographic indicators that may benefit from increased tree plantings, such as: socio-economic classes, age classes, and health classes;
    - such information can be also be linked with thermal mapping to pinpoint not only locations that could benefit from tree plantings, but also key communities within those locations that well most benefit;
- valuing the urban forest as an urban asset;
    - using i-Tree Eco, the value of some ecosystem services provided by urban trees can be calculated which can then be used to view trees as urban assets and justify the business-case for trees;
    - this information can also be used converted to use in community engagement activities that promote a positive attitude and community stewardship towards trees (e.g. Seed's Tree Engagement Experience, including Tree Tags);
- understanding the drivers of change and what should be avoided and encouraged to achieve greening targets can help to inform the suitability of future private developments and public redevelopments and master plans; and
- informing revisions of existing documents and policies, such as Council Tree policy and Environmental Management Plan.

6 Attachments

Attachment A	Comparison of approaches for assessing land cover change
Attachment B	Notes on statistical analysis.
Attachment C.	Number of points and equivalent percent cover for each land cover category in each tenure type and time period relative to the Council area.
Attachment D.	Number of points and equivalent percent cover for each land cover category in each tenure type and time period relative to suburb.

Attachment A. Comparison of approaches for assessing land cover change

There are a range of options available for mapping, measuring and monitoring land-cover, including vegetation cover. In addition to the i-Tree Canopy approach applied in this project, other approaches are generally remote sensing-based using either aerial or satellite imagery (e.g. NDVI, multi- or hyper-spectral imaging, automated algorithms). The different approaches vary in their: scale of resolution, data input requirements, data output load, user skills and equipment required, flexibility in application, and cost and resource intensiveness.

While various approaches exist for mapping land-cover, the i-Tree Canopy approach applied for this project is considered a good choice because analysis is statistically sound and can be repeated and interpreted by Council staff with limited advanced GIS expertise.

The "best" approach will vary among projects and may even involve an integration of different approaches. The choice of approach should be based on a project's specific objective/s, desired functionality of outputs, and available budgets and resources. Underlying this choice, should be the goal to collect enough data to meet the project's objectives, and avoid collecting more data than is required, which can prove to be inefficient and potentially ineffective or cumbersome.

The following provides an outline of the i-Tree Canopy approach, highlighting pros and cons as applicable to this project and a comparison with alternative remote sensing-based approaches.

i-Tree Canopy versus other land cover analysis approaches

i-Tree Canopy is part of the i-Tree software suite[3], and is applied widely across the world as a method to measure, monitor, and value urban forests. It is a free, online-based, user-friendly interface that allows random points to be allocated within a defined survey area and classified into different landcover or land-use categories (cover classes). Cover classes are user-defined *a priori*, with at least one category required to represent "tree canopy". The selection and definition of cover classes is an important step for ensuring relevant and useful outputs that are able to also be repeated in the future.

The software links with the Google Earth imagery to allow the categorisation of points to be determined by the user. A "change survey" function allows already classified points to be reclassified based on comparisons with historical aerial photos, thereby enabling direct comparisons and analysis of land cover and land use changes over time.

Benefits and drawbacks for this project of using i-Tree Canopy to assess landcover, and a comparison with remote-sensing approaches, are as follows:

Software

- i-Tree Canopy software is web-based, freely available and user-friendly;
    - comparatively, remote-sensing approaches require desktop-based software and often produce a high data output, which can be costly to acquire and may require substantial computing power to run and store;

[3] developed in the USA by the USDA Forest Service and other collaborators. www.itreetools.org

- use of the i-Tree Canopy software to classify points requires an initial familiarisation of the software (which is highly user-friendly), but does not require specialist skills or equipment;
    - this means that Council can build capacity "in-house" to enable monitoring of landcover/use and canopy cover in the future.

Categorisation process

- user-defined categories allow land cover as well as land use to be mapped and are entirely user-defined to suit Council's needs and interests. Whilst manual interpretation may take longer than an automated remote-sensing approach, there are substantial benefits for local-scale assessments, such as this project, from manual user-interpretation of imagery;
    - for example, the manual categorisation using i-Tree Canopy allows the user to differentiate between different land cover types types (e.g. tree, grass, agricultural crops), whereas a remote-sensing NDVI approach can identify vegetation cover, but not specifically differentiate between types. A more advance remote-sensing approach suc a LiDAR or other complex spatial algorithms can help to differentiate vegetation types based on heights, but this approach requires specific equipment, skills, and high computing power for data analysis; and
    - the manual categorisation using i-Tree Canopy also allows the user to define land-use types, which is not possible with other remote-sensing approaches. This is particularly useful in helping to identify plantable opportunities. For example, grass cover can be identified as plantable (e.g. sidewalk verges, parks/gardens) or non-plantable (e.g. sporting fields, airports); similarly, bare ground could be identified as plantable or non-plantable (e.g. construction site). Different categories of "impervious" (e.g. roads, footpaths, buildings) and "water" (e.g. ocean, canal, wetland, pool) can be assessed which can improve understanding of land cover trends, particularly when comparing changes over time.

Statistical rigour

- i-Tree Canopy is based on random sampling statistics and statistical rigour is user-defined, with more points sampled giving improved accuracy. To achieve a statistically significant increase in accuracy may require many additional points being assessed. However, conducting a power analysis *a priori*, as required in this project, can identify trade-offs in resourcing required to sample more points and the level of statistical power achieved.
    - a remote-sensing approach would achieve a high statistical power of broad landcover category cover types as the entire area is sampled and classified. However, such approaches can experience accuracy issues as they tend to require substantial ground-truthing.
    - further, although i-Tree Canopy estimates land cover and land use based on a random sample of user-defined points, this can still produce outputs that are more than adequate for informing decisions and actions in a statistically rigorous manner and can prevent collecting more data than is required to fulfill the project's objectives.

Input data

- both i-Tree Canopy and remote-sensing based approaches use satellite or aerial input imagery and so are subject to potential issues of resolution and image quality.
    - initial assessments (and random allocation of points) in i-Tree Canopy are linked to Google Earth imagery. As Google Earth compiles mosaics of best resolution/clarity aerial images, care needs to be taken to ensure the date of the imagery being assessed is understood. The flexibility of i-Tree Canopy is such that once random points are generated, these can be compared and assessed against any other available aerial or satellite imagery;
    - although remote-sensing approaches do not use Google Earth, like i-Tree Canopy they will be limited to the quality, resolution and date of satellite or aerial imagery available;
    - an advantage of i-Tree Canopy is that in some instances, the manual user interpretation of imagery can counter poor quality imagery that may pose problems for remote-sensing approaches;
- land cover analyses are often inhibited by poor quality or skewed imagery, which may impact aerial and satellite imagery;
    - an advantage of the manual user-interpretation of imagery used in i-Tree Canopy is that a user can realistically infer land cover and land use when imagery is not of the highest quality or is dramatically skewed (as can happen with aerial imagery);
    - similarly, user-interpretation can also identify land covers temporarily altered by seasonal or climatic impacts. For example, grassed areas may appear lush and green in winter, but brown and dried in summer, or may vary in condition depending on long-term flood/drought periods. Similarly, an agricultural cropping area may appear vegetated in one year, but unvegetated in another year (following harvest and ploughing). Despite such apparent changes in land cover, the areas may still realistically be the same land use type. An i-Tree Canopy user would be able to readily consider this in their analysis;
    - comparatively a remote-sensing approach may misinterpret coarse skewed imagery and is often limited by spectral signature of water content and so would likely classify a grassed area differently when it is brown and dried compared to when it is lush and green. This may lead to incorrect landcover calculations, and overinflated estimates of land cover change over time.
- change over time analyses in i-Tree Canopy can identify both land cover and land use change;
    - for example, it's possible to identify that even though the amount of impervious surfaces may not have changed between time periods, there may have been a significant increase in building cover;
    - comparatively, remote-sensing approaches will only be able to detect landcover changes and only then if the change is between vegetated and non-vegetated landcover types.

Landcover outputs

- outputs for an i-Tree Canopy assessment are readily compatible with other popularly used spatial and statistical analysis software programs, such as: a GIS, Google Earth, and Excel;
  - this means that the outputs from an i-Tree Canopy project can be readily exported and further interrogated, for example, in a GIS to identify relationships between canopy cover (or other land uses) and Council's strategic frameworks metrics (e.g. greenspace networks, settlement patterns, strategic infrastructure sites and growth corridors), as well as other risk metrics (e.g. thermal hotspots, social vulnerability, climate change vulnerability);
  - comparatively, outputs from remote-sensing approaches tend to be more technical and detailed and have limited compatibility with other spatial and statistical analyses without specialist knowledge about how to manipulate and interpret the data;
- for fine-scale projects such as this, where outputs will be used to inform on-ground local decisions and actions, analysis outputs need to be as relevant, readily understood, and applicable as possible.
  - the flexibility in user-defined settings for an i-Tree Canopy project allow for such local scale relevance and application. The process and outputs are also transparent and readily understood by a range of factions, such as Council Officers, planting and development contractors, and the public. This can facilitate the justification of decisions and actions and communication and engagement with the community.
  - comparatively, remote-sensing approaches can produce highly attractive maps for communication purposes, and are useful for assessments at large-scales, though the process is less readily understood by a wide range of factions without knowledge of remote-sensing and GIS approaches. This may lead to less confidence or increased skepticism about the outputs.

Tree ecosystem services outputs

- in addition to land cover and land use outputs, i-Tree Canopy will also provide a broad quantification of a subset of tree ecosystem services, specifically the amount and market value of: carbon dioxide stored annually and sequestered (not an annual rate), pollution removed annually (CO, NO2, O3, SO2, and particulate matter less than 10 microns). This information can start to justify the business-case for trees. Such a function is not provided by any other landcover assessment tool available.
  - it should be noted that, unlike i-Tree Eco[4], the calculations provided in i-Tree Canopy are a broad, averaged estimate based on the number of points classified as user-defined "tree" categories. The valuations are also based on American metrics (e.g. tree species, weather and pollution, market values),

[4] Another freely available tool in the i-Tree suite. This tool provides detailed information about forest structure and function, including species- and tree-specific quantifications and valuations of carbon dioxide stored and sequestered, pollution removed, and rainfall intercepted. Unlike i-Tree Canopy, Eco has been specifically adapted for Australian conditions (i.e. tree species, weather and pollution metrics included).

    though this is not expected to vary from Australian conditions by significant orders of magnitude, and can still be used as a useful benchmark, and for assessing relative change in ecosystem services over time.

    - although based on American metrics, if market values of carbon dioxide and pollution are known for the study area, these can be incorporated in the software settings to produce market values of relevance to your area (though note quantification amounts will still be based on American tree species, pollution and weather metrics).

Support systems

- as a well-used tool across Australia and globally, i-Tree Canopy has a community of users which Council may interact with and learn from. All i-Tree software is also continually evolving and updated to ensure leading scientific knowledge is incorporated. There is also a central, integrated technical support service provided by the US developers should issues or questions arise.
    - Comparatively, remote-sensing approaches, particularly novel developments, tend to be more specialised in their applications and any advice in the future may require the specific contractor to be contacted.

Attachment B. Notes on statistical analysis

A p-value, or probability value, is one output from a t-test (i.e. any statistical hypothesis test) which indicates whether the differences between data being compared are occurring due to chance (i.e. not significantly different) or are a real phenomenon (i.e. is significantly different). The critical alpha value sets the standard to which the p-value is compared and is usually set to 0.05. Therefore, a p-value less than or equal to 0.05 indicates the observed difference between the data is so unusual that it would only have happened by chance, at most, 5% of the time and so the difference is considered statistically significant. If a p-value is greater than 0.05, this indicates that the observed difference between data could have happened by chance more than 5% of the time and so the difference is considered statistically insignificant.

Comparing p-values can indicate relative significance between multiple significance tests. For example, a p-value of 0.001 indicates a more statistically significant difference than a p-value of 0.01. However, other factors are also generally considered in statistics which influence how significance tests are interpreted, such as autocorrelation and effect size.

Autocorrelation refers to the influence that different values have on each other. For example, in this project, points would be considered to be spatially auto-correlated if their proximity to each other influenced the type of land cover category of each point. Detailed statistical analyses were beyond the scope of this project though and so for the purposes of the broad level indicative statistical analyses conducted here, we assumed no spatial or temporal autocorrelation between points. Meaning that it was assumed that the data points are independent and land-use category of one point does not influence the land-use category of nearby points in the same time period or the same point across time periods.

Effect size can help to interpret substantive significance, rather than purely statistical significance. The statistical analyses in this report were intended only to provide an indication of whether land cover change was likely to be statistically significance or not. Accordingly, for the purposes of these analyses, we did not report on effect sizes.

Attachment C. Number of points and equivalent percent cover (%) for each land cover category in each tenure type and time period relative to the points sampled across Campbelltown City Council area (CoCamp).

LAND COVER CATEGORY		NUMBER OF POINTS ACROSS CoCAMP						PERCENT COVER ACROSS CoCAMP (%)					
		2006			2016			2006			2016		
		Total	Private	Public	Total	Private	Public	Total	Private	Public	Total	Private	Public
Impervious	Building impervious	543	531	12	594	581	13	25.86	25.29	0.57	28.29	27.67	0.62
	Impervious other	315	214	101	357	242	115	15.00	10.19	4.81	17.00	11.52	5.48
	Impervious road	201	4	197	238	21	217	9.57	0.19	9.38	11.33	1.00	10.33
Tree	Tree other	394	244	150	259	138	121	18.76	11.62	7.14	12.33	6.57	5.76
	Tree impervious	135	58	77	135	63	72	6.43	2.76	3.67	6.43	3.00	3.43
Plantable space	Bare ground	191	121	70	281	186	95	9.10	5.76	3.33	13.38	8.86	4.52
	Grass other	265	200	65	179	138	41	12.62	9.52	3.10	8.52	6.57	1.95
Other	Grass sporting	51	29	22	50	32	18	2.43	1.38	1.05	2.38	1.52	0.86
	Wetland vegetation	1	0	1	0	0	0	0.05	0.00	0.05	0.00	0.00	0.00
	Water	4	2	2	7	2	5	0.19	0.10	0.10	0.33	0.10	0.24

Attachment D. Number of points and equivalent percent cover (%) for each land cover category in each tenure type in 2016 and 2006 relative to the points sampled in each suburb. BldImp = building impervious; ImpOth = impervious other; ImpRd = impervious road; TrOth = tree other; TrImp = tree impervious; BG = bare ground; GrOth = grass other; GrSpt = grass sporting; WV = wetland vegetation; W = water.

2016		NUMBER OF POINTS PER SUBURB										PERCENT COVER PER SUBURB (%)									
		Impervious			Canopy		Plantable		Other			Impervious			Canopy		Plantable		Other		
Suburb	Tenure	BldImp	ImpOth	ImpRd	TrOth	TrImp	BG	GrOth	GrSpt	WV	W	BldImp	ImpOth	ImpRd	TrOth	TrImp	BG	GrOth	GrSpt	WV	W
Athelstone	Private	64	33	1	12	11	23	16	5	0	0	18.29	9.43	0.29	3.43	3.14	6.57	4.57	1.43	0.00	0.00
	Public	0	13	29	60	16	50	14	2	0	1	0.00	3.71	8.29	17.14	4.57	14.29	4.00	0.57	0.00	0.29
Campbelltown	Private	67	24	2	10	5	20	21	2	0	0	26.8	9.60	0.80	4.00	2.00	8.00	8.40	0.80	0.00	0.00
	Public	6	15	33	18	10	11	4	1	0	1	2.40	6.00	13.20	7.20	4.00	4.40	1.60	0.40	0.00	0.40
Hectorville	Private	90	27	0	16	6	36	14	3	0	0	36.00	10.80	0.00	6.40	2.40	14.40	5.60	1.20	0.00	0.00
	Public	2	14	21	5	7	7	2	0	0	0	0.80	5.60	8.40	2.00	2.80	2.80	0.80	0.00	0.00	0.00
Magill	Private	79	40	2	22	3	21	15	6	0	1	31.60	16.00	0.80	8.80	1.20	8.40	6.40	2.40	0.00	0.40
	Public	2	18	22	0	9	4	3	2	0	0	0.80	7.20	8.80	0.00	3.60	1.60	1.20	0.80	0.00	0.00
Newton	Private	81	29	10	9	9	24	10	1	0	0	32.40	11.60	4.00	3.60	3.60	9.60	4.00	0.40	0.00	0.00
	Public	3	15	31	2	9	5	1	11	0	0	1.20	6.00	12.40	0.80	3.60	2.00	0.40	4.40	0.00	0.00
Paradise	Private	70	31	5	10	11	15	14	9	0	0	28.00	12.40	2.00	4.00	4.40	6.00	5.60	3.60	0.00	0.00
	Public	0	17	25	19	8	6	5	2	0	3	0.00	6.80	10.00	7.60	3.20	2.40	2.00	0.80	0.00	1.20
Rostrevor	Private	68	24	0	33	14	28	23	5	0	0	27.20	9.60	0.00	13.20	5.60	11.20	9.20	2.00	0.00	0.00
	Public	0	9	26	6	4	3	7	0	0	0	0.00	3.60	10.40	2.40	1.60	1.20	2.80	0.00	0.00	0.00
Tranmere	Private	32	34	1	26	4	19	24	1	0	1	24.80	13.60	0.40	10.40	1.60	7.60	9.60	0.40	0.00	0.40
	Public	0	14	30	11	9	9	5	0	0	0	0.00	5.60	12.00	4.40	3.60	3.60	2.00	0.00	0.00	0.00

2006		NUMBER OF POINTS PER SUBURB										PERCENT COVER PER SUBURB (%)									
		Impervious			Canopy		Plantable		Other			Impervious			Canopy		Plantable		Other		
Suburb	Tenure	BldImp	ImpOth	ImpRd	TrOth	TrImp	BG	GrOth	GrSpt	WV	W	BldImp	ImpOth	ImpRd	TrOth	TrImp	BG	GrOth	GrSpt	WV	W
Athelstone	Private	60	21	0	18	14	18	27	7	0	0	17.14	6.00	0.00	5.14	4.00	5.14	7.14	2.00	0.00	0.00
	Public	0	13	29	75	13	27	25	2	1	0	0.00	3.71	8.29	21.43	3.71	7.71	7.14	0.57	0.00	0.00
Campbelltown	Private	53	26	1	22	8	6	33	2	0	0	21.20	10.40	0.40	8.80	3.20	2.40	13.20	0.80	0.00	0.00
	Public	7	11	28	16	12	10	10	5	0	0	2.80	4.40	11.20	6.40	4.80	4.00	4.00	2.00	0.00	0.00
Hectorville	Private	88	26	0	29	5	15	26	3	0	0	35.20	10.40	0.00	11.60	2.00	6.00	10.40	1.20	0.00	0.00
	Public	1	14	19	7	7	5	3	0	0	0	0.40	6.40	7.60	2.40	2.80	2.00	1.20	0.00	0.00	0.00
Magill	Private	71	32	0	32	7	17	25	5	0	1	28.40	12.80	0.00	12.80	2.80	6.80	10.00	2.00	0.00	0.40
	Public	2	14	22	3	9	3	5	2	0	0	0.80	5.60	8.80	1.20	3.60	1.20	2.00	0.80	0.00	0.00
Newton	Private	75	35	1	16	8	16	21	1	0	0	30.00	14.00	0.40	6.40	3.20	6.40	8.40	0.40	0.00	0.00
	Public	2	17	28	2	8	5	4	11	0	0	0.80	6.80	11.20	0.80	3.20	2.00	1.60	4.40	0.00	0.00
Paradise	Private	68	28	2	27	3	13	17	7	0	0	27.20	11.20	0.80	10.80	1.20	5.20	6.80	2.80	0.00	0.00
	Public	0	12	23	23	9	8	6	2	0	2	0.00	4.80	9.20	9.2	3.60	3.20	2.40	0.80	0.00	0.80
Rostrevor	Private	60	22	0	57	8	25	20	3	0	0	24.00	8.80	0.00	22.80	3.20	10.00	8.00	1.20	0.00	0.00
	Public	0	5	23	8	8	5	6	0	0	0	0.00	2.00	9.20	3.20	3.20	2.00	2.40	0.00	0.00	0.00
Tranmere	Private	56	24	0	43	5	11	31	1	0	1	22.40	9.60	0.00	17.20	2.00	4.40	12.40	0.40	0.00	0.40
	Public	0	13	25	16	11	7	6	0	0	0	0.00	5.20	10.00	6.40	4.40	2.80	2.40	0.00	0.00	0.00

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