SPECIFIC AND ACHIEVABLE CANOPY TARGETS: HOW TO MODEL YOUR CAPACITY FOR TREE CANOPY

Phillip Julian and Karen Sweeney
City of Sydney Council

Abstract

Targets are commonly used by urban foresters to advertise an appetite for increased tree canopy. To be credible they must be achievable and specific to the environment they relate to. Not all cities are the same. The capacity of a local government area to provide tree canopy is influenced by the land uses contained within it, and the relative proportions of those land uses.

This paper explores data typically available to urban foresters and presents the site-based analysis and modelling methods used by the City of Sydney to calculate the potential capacity of specific land uses to accommodate tree canopy. It will also demonstrate how this analysis and modelling can be used to set canopy targets specific to land use types, and how the results can be used to direct operational programs towards achieving such targets.

Introduction

Urban local government areas differ in their capacity to accommodate tree canopy and greening. The relative proportions of streets, parks, and other built or open spaces is a major influence on this capacity. Leff (2016) suggests that each community must adopt its own goals, depending on a number of considerations that are unique to its particular circumstances, including land cover and land use patterns. The City of Sydney (the City) has endeavoured to develop targets for greening and canopy that are ambitious, yet also achievable and relative to the current and future opportunities provided by the specific composition of land uses within our local government area. Consideration was also given to research suggesting minimum amounts of canopy cover is required for community health or cooling outcomes.

Land use mapping

In the process of setting targets for greening and canopy, all land within the City of Sydney local government boundary was considered and assessed, including all public and private land regardless of ownership or accessibility. The capacity and opportunity for greening and canopy was quantified and assessed at the scale of individual land parcels using techniques specific to their land use type. Analysis at such a fine scale allows for the data to be aggregated in many different ways, but for the purpose of setting greening and canopy targets it was summarised under three broad land-use themes; being Streets, Parks, and Properties. Overall targets for greening and canopy for the entire city were produced as a sum of these parts.

Figure 1: Example of street, park, and property land parcels, each with a unique site code identifier, overlaid on aerial image and aerial acquisition of vegetation height strata.

Our stratified approach to the development of targets provides a rich dataset that may be used to guide site-specific actions towards their achievement. This approach also promotes accountability within each of the three land-use themes, encouraging land managers to strive to meet the targets specific to the land or site that are managing.

To allow the targets to be directly compared and assessed against current or future aerial measurement of vegetation areas, the analysis of land parcels included only those that are visible from the air. Road tunnels and street segments beneath bridges or viaducts were not assessed. Similarly, parcels of property that exist above or below the surface (e.g. private basements beneath roads etc.) were also excluded from the analysis.

All spatial analysis was done using the ArcMap GIS application, with Microsoft Excel used for modelling of canopy capacity and targets.

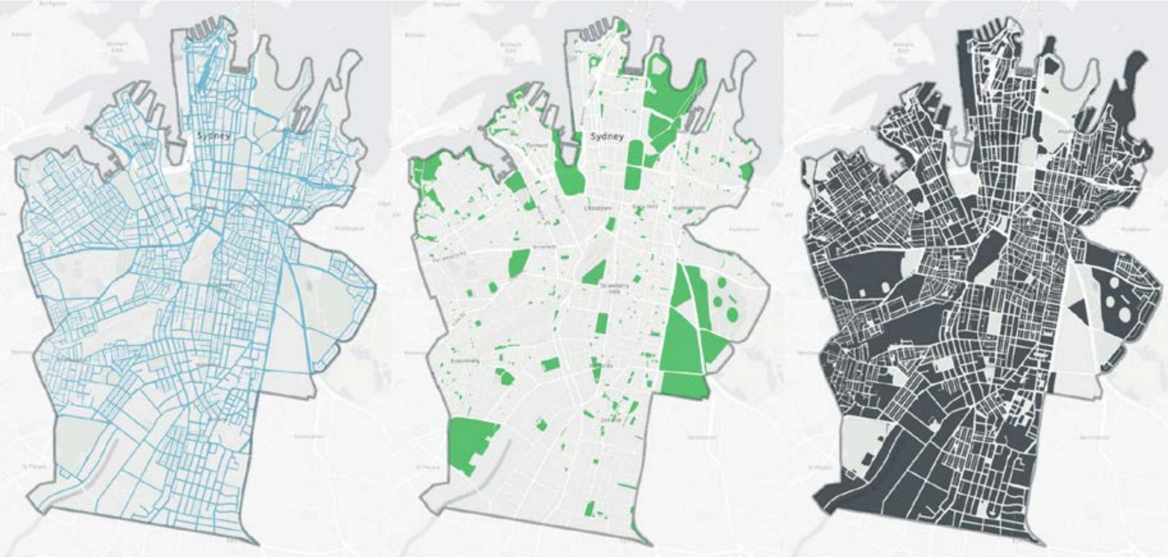

Figure 2: Maps of the City of Sydney streets (left), parks (middle), and property (right). A sum of these three land use areas is equal to the total City land area.

Streets

The city's road network is a sum of 4915 individual road segments, covering a total of 608.8 hectares (or 23%) of the city's land area.

Most street segments follow a conventional layout, with road pavement areas allowing movement of heavy traffic and roadside verge or nature strip areas between the road pavement and other land parcels being the space for typical street tree planting. Attributes and measurements of these street segments were used as inputs to formulas to calculate the capacity of each street segment to host tree canopy. The aim was to quantify the potential canopy area that may be achieved within the boundary of each street segment under real world conditions, and model the potential for additional canopy based on specific scenarios.

Data used

The following street segment attributes and measurements were compiled or calculated from existing City datasets:

- Segment code, name, location, suburb
- Street segment type (Street Section or Street Intersection)
- Street classification (State, Regional, Local, Laneway, Motorway)
- Street segment area (m2)
- Street segment length (m)
- Street segment width (m, derived from area and length)
- Road pavement width (m)
- Street verge width (m, derived from road segment width and road pavement width)
- Percentage of existing trees within each street segment impacted by overhead power lines

The optimal mature size of tree suitable for planting in each street segment was determined based on the available street verge width in accordance with the City's Street Tree Master Plan guidelines.

Table 1: Associations used in the street capacity model to relate street verge width, mature tree size, and canopy diameter at maturity.

Street Verge Width	Mature Tree Size	Mature Tree Canopy Diameter
Less than 1.3m	Unable to Plant	-
1.3m - 1.8m	Small	5m
1.8m – 3m	Medium	8m
Greater than 3m	Large	12m

The number of trees able to be planted within each street segment was calculated using the following formula:

$$Tree\ Quantity = 2(P - V)\left[\left(\frac{L - 10}{S}\right) + 1\right]$$

Where:

$P =$ planting optimisation rate (expressed as a decimal)
$V =$ planting site vacancy rate (expressed as a decimal)
$L =$ street segment length (m)
$S =$ tree spacing (m)

The formula assumes typical street segments have two single rows of trees and a 10m tree setback on approach to intersections. Tree spacing is proportional to the size of tree suitable for the street segment, and was equal to mature tree canopy diameter. The Planting Optimisation Rate is an indication of the reduced proportion of trees able to exist due to conflicts within the streetscape (e.g. driveways, poles, shop awnings etc.). The general rate applied in the city was 0.8 (or 80%), however a lower rate (0.7) was applied in the central business district (CBD) due to a greater prevalence of awnings and below ground utility conflicts. The vacancy rate is the proportion of planting sites that may be expected to be vacant at any point in time. The rate used by the City, based on historical data, was 0.015 (or 1.5%). Street intersection segments were treated in a similar way but assumed one row of trees only and a reduced optimisation rate of 0.5. All street segments defined as motorways were assigned a tree quantity of zero to reflect the inability to plant trees within roads of this type in the city.

Age diversity

Not all trees in the City's streets are mature. Therefore, a diversity of tree ages was factored into the analysis before the quantity of trees was used to calculate the canopy area. A percentage age class distribution was used to represent the expected distribution of age classes for the entire population of street trees. For the city this was determined to be 60% mature (including over-mature), 30% semi-mature, and 10% juvenile, and was based on the current age distribution of the City's street tree assets and expected future removal and planting rates.

Table 2: Age class distribution and relationship to canopy spread.

Age Class / Maturity Stage	City of Sydney Optimum Age Distribution	Size (% of mature canopy spread)
Juvenile	10%	25%
Semi-mature	30%	75%
Mature and Over-mature	60%	100%

The canopy diameter for semi-mature and juvenile trees were defined as 75% and 25% of the mature canopy diameter respectively. These relative proportions and size parameters were applied to the modelled quantity of trees in each street segment to calculate a realistic and sustainable total canopy area produced by trees within each street segment.

Table 3: Tree size and relationship to age class and canopy diameter.

Tree Size	Canopy spread / diameter (m)		
	Juvenile	Semi-mature	Mature and Over-mature
Small	1.25	3.75	5
Medium	2	6	8
Large	3	9	12

Infrastructure impacts

Data on the proportion of existing street trees within each street segment impacted by low voltage multi-span overhead power lines was used as a factor in the analysis to reflect the reduced potential of trees beneath such infrastructure. Within relevant street segments, the proportion of impacted large, medium, and small sized trees were assumed to achieve 60%, 50%, and 80% of their respective potential canopy area. These assumptions were based on medium sized trees being most impacted by multi-span low voltage overhead wires, and large sized trees have potential to grow up and around them. Trees impacted by a single insulated and bundled low voltage wire were assumed to achieve 95% of their potential canopy area. This analysis enabled the modelling of reduced impact scenarios and their effect on canopy cover, such as exposed low voltage power lines being converted to insulated bundled cables or the complete removal of overhead wires.

Canopy area calculations

The total canopy capacity for each street segment was calculated as the sum of each tree canopy area, factoring in the above considerations, using simple formula for the area of a circle. Since canopy cover is measured and aggregated according to boundaries between land use types, it was necessary to calculate the areas of canopy overhanging other land parcels adjacent to the road segment and subtract these from the total canopy capacity area (see Figure 3). This was done by applying a trigonometric formula for the area of a circle segment, where the known parameters are the circle segment height and circle radius. The circle segment height was derived from the width of the road verge and the typical tree setback from the road kerb for each tree size.

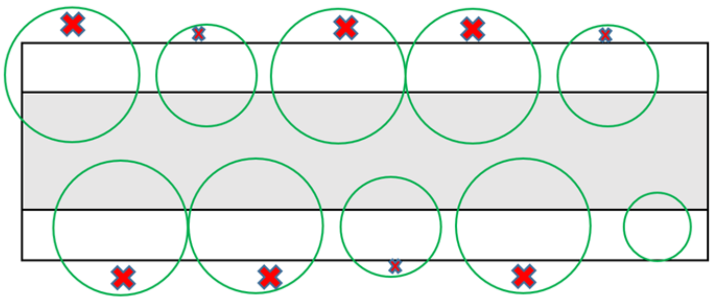

Figure 3: Diagram representing the street canopy model within street segment, showing setback on approach to intersections, an age diverse group of trees, and canopy areas overhanging the street boundary to be subtracted from the total canopy area calculation.

In-road planting scenarios

The planting of trees within the road pavement area is an opportunity to increase tree canopy within the street network above that provided by typical planting within the verge. Three different in-road tree planting scenarios were modelled and added to the base canopy capacity calculation for relevant sites, as listed below.

1. Tree planting within parking lanes. Within local road segments wider than 12m, every third tree located within the verge is replaced with a large sized tree planted within the parking lane.
2. Tree planting within laneways. Within local road segments or laneways wider than 6m, having narrow verges unable to accommodate conventional tree planting, a single row of trees is planted within the parking lane at the side of the road. If the road pavement width was wider than 10m the tree size was large. If less than 10m it was medium.
3. Tree planting within medians. Within local roads wider than 15m, an additional row of large sized trees is planted within a median island.

If more than one modelled scenario applied to any single street segment, the scenario that produced the highest amount of canopy was used.

Summary of street analysis and targets

The canopy capacity areas overhanging each street segment were summed to provide an overall canopy capacity for the entire city street network. This total canopy area was divided by the total area of the street network to give a percentage canopy target for the city's streets. Since the overall target is an aggregate of individual site analyses, the overall target is a summary and cannot be applied to any specific individual site. Each individual street segment has a site-specific canopy target equal to its calculated capacity.

Targets for green cover were recommended for each street type classification and aggregated to an overall target for the street network. They were based on the existing green cover and a consideration of the potential increase in green cover realistically able to be achieved within each street type in addition to the increase in tree canopy cover.

Table 4: Summary of street canopy cover and target analysis.

Street types	Number of land parcels	Land area (ha)	Land area as a proportion of total LGA	2019 Canopy Area (ha)	2019 Canopy Cover (% of land area)	Modelled canopy area (ha)	2050 target canopy cover	Required gain in canopy to meet target (ha)
State Road	579	111.28	4%	19.65	18%	26.92	24%	7.27
Regional Road	356	65.19	2%	15.63	24%	19.71	30%	4.08
Local Road	2909	392.36	15%	114.84	29%	149.56	38%	34.73
Laneway	859	38.31	1%	6.69	17%	9.58	25%	2.88
Other	212	1.66	0%	0.00	0%	0.00	0%	0.00
Street Total	4915	608.80	23%	156.81	26%	205.77	34%	48.96

Parks

Parks are parcels of land dedicated for public open space and recreation. The City of Sydney local government area has 421 parks within its boundaries, covering a total of 401.7 hectares (or 15%) of the total land area. They are owned and managed by a number of government agencies, including the City, the Royal Botanic Gardens and Domain Trust, Centennial Parklands, and Property NSW. They must provide for a range of competing uses and may serve a variety of functions, including active and passive recreation, heritage conservation, wildlife habitat, and other environmental services. The expected uses and functions of a park influence the amount of greening or tree canopy cover that is appropriate for the space, and therefore parks with similar uses and functions are assumed to have similar potential for canopy and green cover. An analysis of the parks was undertaken, with the aim being to determine the most appropriate amount of tree canopy and green cover for each park type.

Park classifications and analysis

All parks were grouped into one of the following park types; iconic, neighbourhood, pocket, civic, sports field, or golf course. These park types were existing functional categories used by the City for park asset management. Within each category, parks were ranked by their existing canopy cover percentages (2019 aerial canopy measurement). The median and percentiles above and below the median (15%, 25%, 75%, and 85%) were plotted over the ranked distribution of park canopy cover. This analysis was then used to identify and select five examples within each of the park types, each having different levels of canopy cover. Consideration was given to the age of the parks and maturity of trees when selecting each of the examples.

Qualitative survey

A survey was developed asking respondents to score each of the examples on a scale on 1 (least appropriate) to 5 (most appropriate) in terms of the amount of canopy cover being appropriate for the type of park. Aerial images were used to present the examples within the survey. Park areas classified as sports fields and the golf course were not included in the survey. Sports fields were assumed to have zero capacity for tree canopy cover and there is only one golf course within the city.

Professional staff employed by the City, who are familiar with park management issues were invited to participate in the survey. They included professionals in park and tree management, landscape architecture, and city design. Staff less involved with parks management also participated, including strategic planning and engineering. 46 responses to the survey were received (Figure 4). The survey results (Figure 5) were used to consider and identify the most appropriate target for canopy cover for each park type.

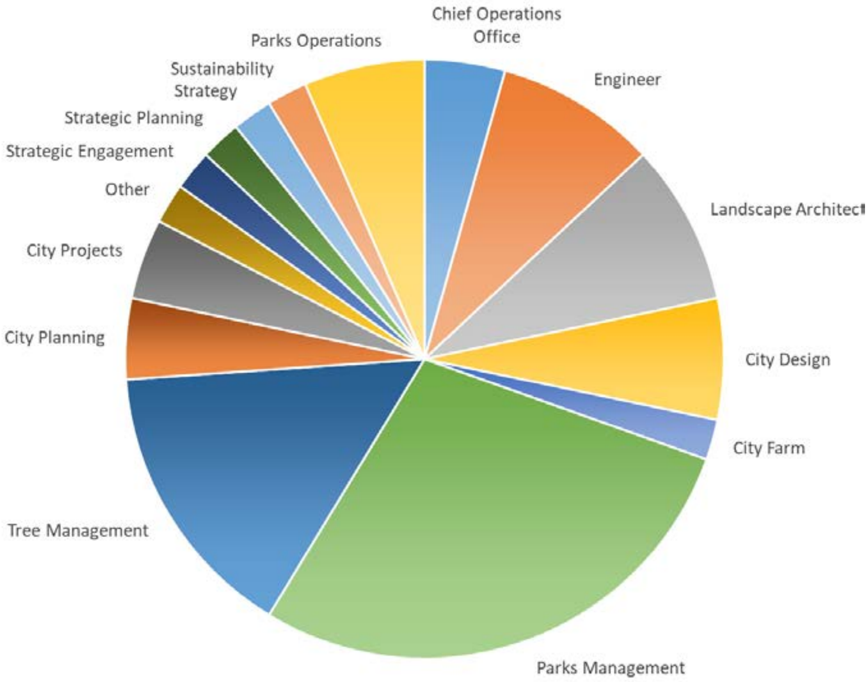

Figure 4: Participants in the park canopy cover survey and their professional role at the City.

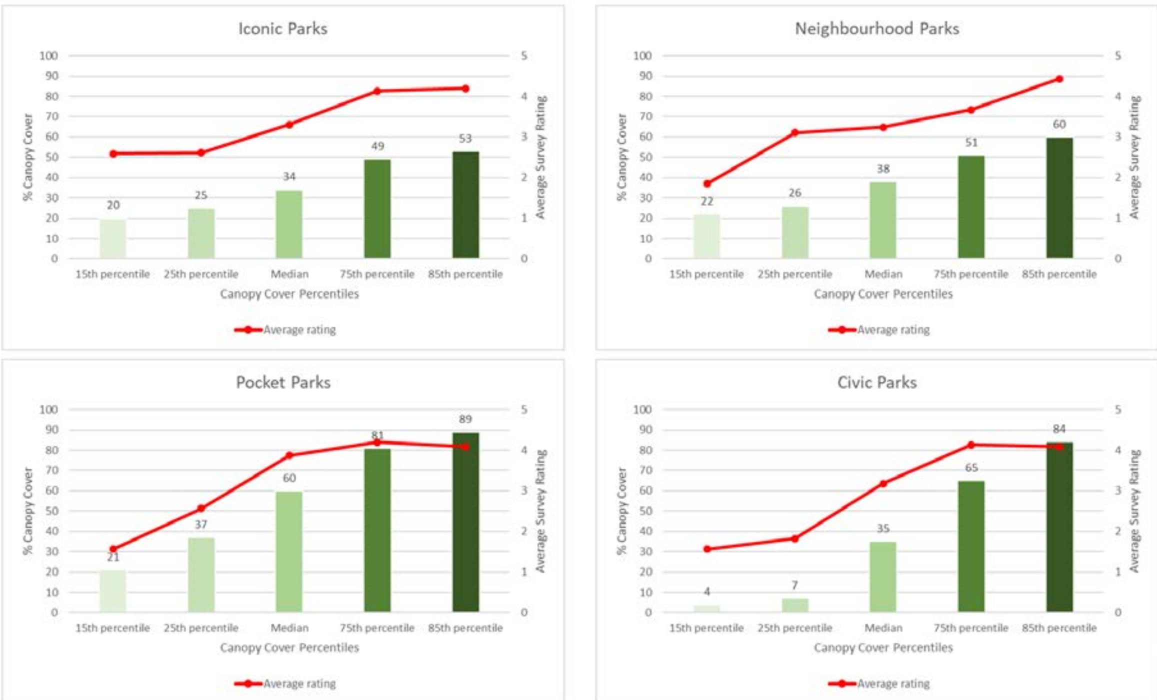

Figure 5: Survey results for each park type, with average survey rating plotted with % canopy cover for each of the five representative examples.

Summary of park analysis and targets

The target canopy cover percentages considered most appropriate for each park type were applied to each individual park, with target canopy areas calculated and summed to determine an overall target amount of canopy area and percentage canopy cover for the entire park land area of the city.

Table 5: Summary of park canopy cover and target analysis

Park Types	Number of land parcels	Land Area (ha)	Land area as a proportion of total LGA	2019 Canopy Area (ha)	2019 Canopy Cover (% of land area)	Target canopy area (ha)	2050 Target Canopy Cover	Required gain in canopy to meet target (ha)
Iconic	29	248.96	9.4%	79.86	32%	124.48	50%	44.62
Neighbourhood	46	33.75	1.3%	12.41	37%	18.56	55%	6.15
Pocket	296	37.19	1.4%	17.31	47%	26.04	70%	8.72
Civic	32	2.90	0.1%	0.93	32%	1.45	50%	0.52
Sports field	17	34.58	1.3%	0.29	1%	0.00	0%	0.00
Golf Course	1	44.32	1.7%	8.42	19%	13.30	30%	4.87
Park Total	421	401.70	15%	119.30	30%	183.82	46%	64.52

Properties

For the purposes of this analysis, a property was considered to be any land parcel not classified as a street or a park. It included 26,527 individual parcels of land covering 1,651 hectares (or 62%) of the city land area. A wide variety of uses, ownership arrangements, and controls apply to this large group of land parcels. They range from small single lot private residences through to large commercial CBD properties and large tracts of government owned land used for transport infrastructure or education.

Estimating private open space

Analysis was undertaken to estimate the amount of open space potentially available for tree planting within these land parcels. Data gathered from the City's Floor Space and Employment survey was used to calculate an approximate building footprint area per land parcel, with the remaining unbuilt portion of each land parcel then used to assess the potential for tree canopy.

The area of private open space required to accommodate trees was determined to be 20-25m^2 for a small sized tree, 25-60m^2 for a medium sized tree, and >60m^2 for a large sized tree. Areas of private open space less than 20m^2 were considered as inadequate spaces for any tree. If a land parcel had greater than 200m^2 of open space, multiple large trees were assigned to the parcel with each requiring at least 200m^2 of space.

A consideration of age diversity was factored into the analysis (using the same method as for the street tree analysis) to estimate the potential canopy area for each private land parcel.

The potential canopy areas for each land parcel, along with the measured amount of existing tree canopy and greening per parcel, were aggregated by City of Sydney Local Environment Plan land zonings to assess and consider potential targets for tree canopy cover and green cover for each zoning and the private land use overall.

Assumptions and limitations

The above analysis for private land is based on a number of assumptions that make it less reliable than the capacity analysis used for the street land area. The analysis inaccurately assumes that any open space not occupied by a building is available for tree planting, and that tree canopy is unable to overhang buildings. There is also no accounting for canopy provided by overhanging trees located in parks or streets, and it is based on existing land development only, with no consideration for how properties may change or be developed in future.

Summary of property analysis and targets

For the reasons outlined above, the analysis was used as a guide to indicate existing potential only, and to compare and contrast the existing canopy cover and potential for canopy between different zonings and specific areas such as heritage conservation areas, urban renewal areas, and the CBD. A summary of results, presented as grouped by aggregated zonings for the property land use, is presented in Table 6.

The future development and potential for canopy, along with the City's ambition for greener development of private open spaces were important considerations when setting overall targets for properties.

Table 6: Summary of property canopy cover and target analysis

Property zoning	Number of land parcels	Land Area (ha)	Land area as a proportion of total LGA	2019 Canopy Area (ha)	2019 Canopy Cover (% of land area)	Target canopy area (ha)	2050 Target Canopy Cover	Required gain in canopy to meet target (ha)
General Residential (R1)	16,847	414.07	16%	84.31	20%	103.52	25%	19.20
Low Density Residential (R2)	775	50.97	2%	6.35	12%	20.39	40%	14.04
Mixed use, business, enterprise (B4-B7)	5,229	487.69	18%	36.58	8%	73.15	15%	36.57
Neighbourhood, local centre (B1 & B2)	1,219	56.26	2%	4.90	9%	8.44	15%	3.54
Metro CBD, commercial core (B3 & B8)	1,125	163.69	6%	7.67	5%	8.18	5%	0.52
Special Activities, Health, Education (SP1 & SP2)	274	163.22	6%	31.47	19%	40.80	25%	9.33
General Industrial (IN1)	96	71.66	3%	2.92	4%	7.17	10%	4.24
Public Recreation (RE1)	294	22.11	1%	5.28	24%	6.63	30%	1.35
All Other Subtotal	668	222.11	8%	23.52	11%	55.53	25%	32.01
Property total	26,527	1,651.76	62%	203.00	12%	323.81	20%	120.81

Leveraging data to towards achieving targets

Analysis at the scale of individual land parcels has allowed for a detailed comparison of existing canopy and targets for future canopy cover based on site specific assessments of capacity. The analysis can highlight sites that are over or under achieving, and provides insight to drive site-specific projects and programs aimed towards the achievement of targets (see Figure 6). It will also help to highlight specific land where the removal of canopy will compromise the ability to achieve targets. Combining the site-specific analysis with the City's asset management data will provide further opportunity to better manage the City's tree assets within streets and parks. Future analysis will be undertaken to determine the best method to express the target for properties, and the controls required to promote its future achievement.

Figure 6: Example of map highlighting parks that have existing canopy cover above (>100%) and below (< 100%) of the target canopy cover specific to their park type.

Acknowledgements

The City of Sydney is proud to have developed these ideas and examples of data analysis. The authors thank Carl d'Entremont and Matthew Sund of the City of Sydney Spatial Information Team for their assistance in compiling the spatial data.

References

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